SAND2022-9082C

Probabilistic Modeling for Extreme Events and Concurrent Outages

Energy Resilience for Mission Assurance

Daniel L. Villa[1], P.E., Juan Pablo Carvallo[2] PhD, and Sang Hoon Lee[2] PhD

[1]Sandia National Laboratories
[2]Lawrence Berkeley National Laboratory

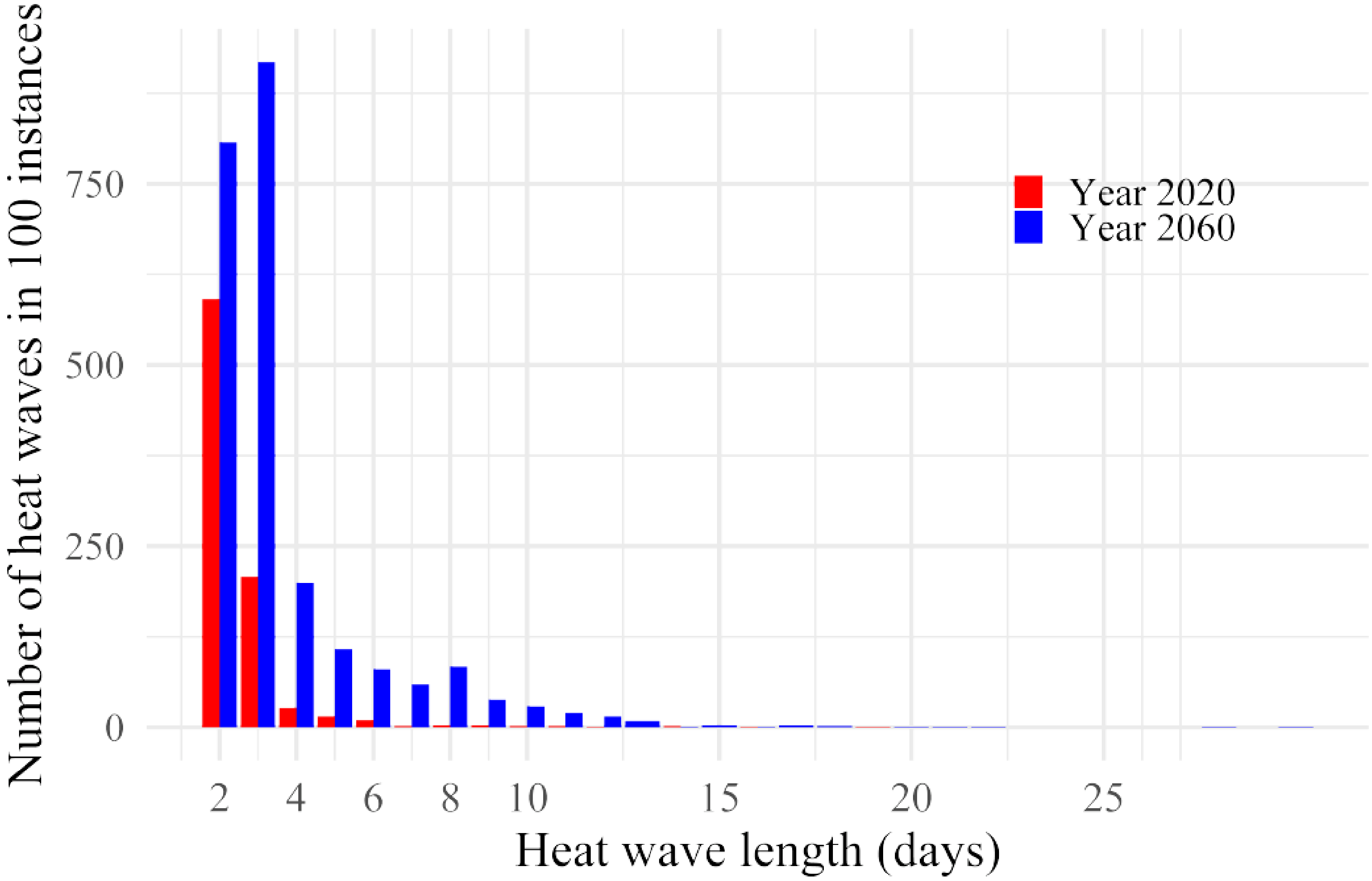
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Acknowledgements

- For funding via the Energy Resilience for Mission Assurance Project initiated through the Grid Modernization Laboratory Consortium (GMLC) funded by the Department of Energy (DOE) Office of Electricity Delivery and Energy Reliability and the Office of Energy Efficiency and Renewable Energy
- For funding from the Future Weather Project funded by DOE's Building Technology Office
- For my family's support, especially my wife Marina

Outline

- Why extreme events?
- Why a probabilistic approach?
  - Multi-scenario extreme weather simulator (MEWS)
- Outages due to extreme events
- Buildings During Outages
- Conclusion



Why extreme events?

“Simulating reality”

Why extreme events?

Global Climate Change

1. **Global Climate Change**

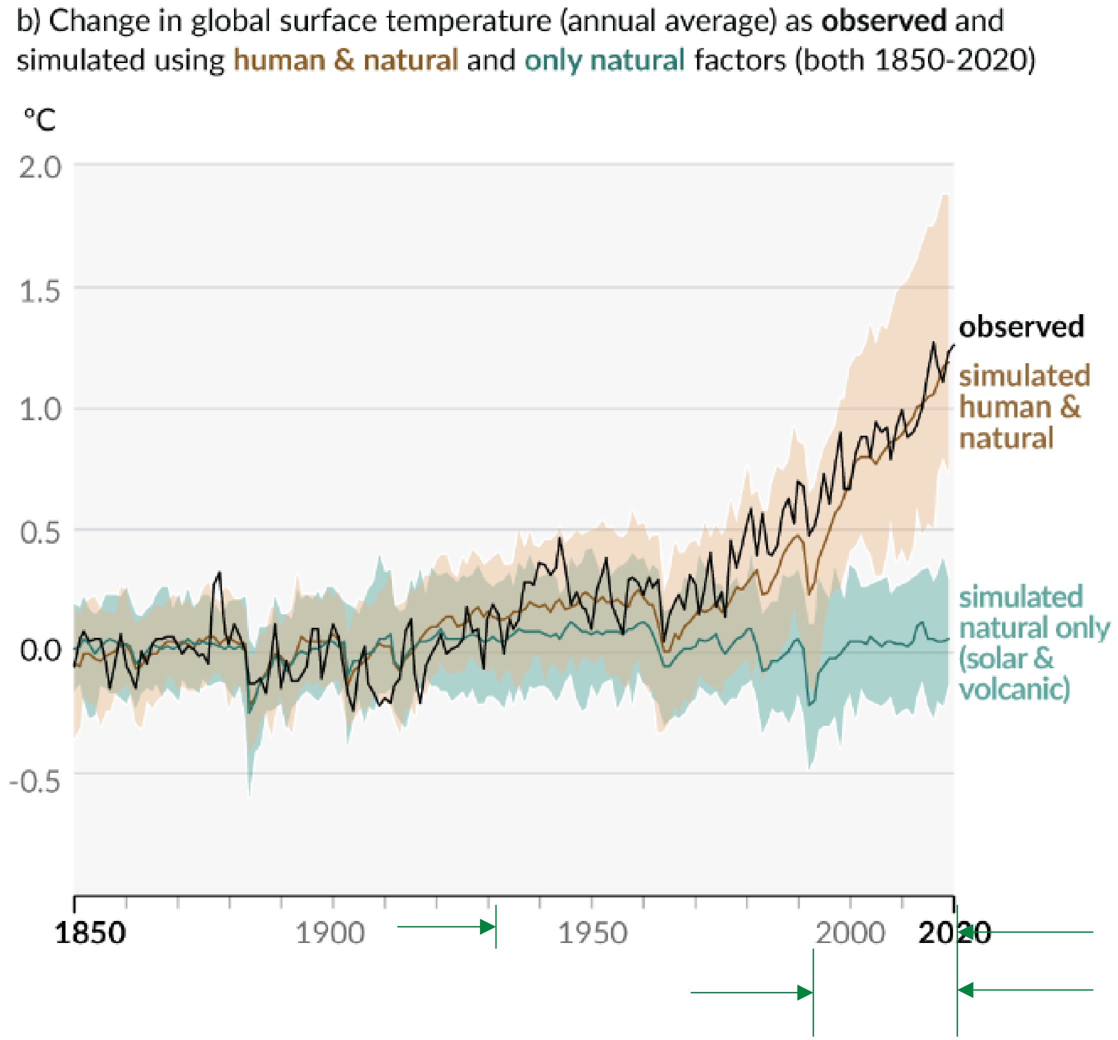


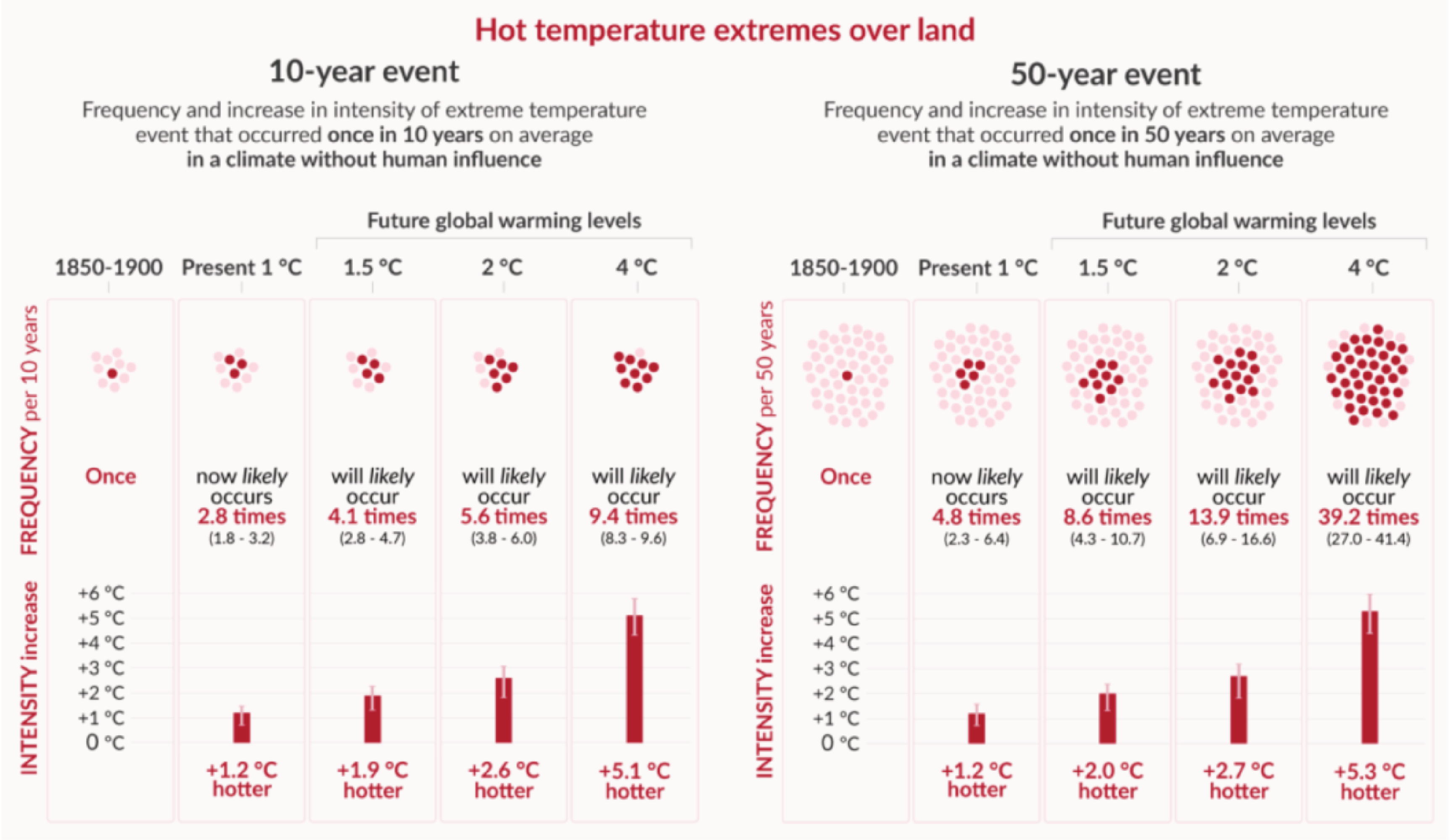
Figure SPM.1 Intergovernmental Panel on Climate Change (IPCC) Working Group I – The Physical Science Basis Sixth Assessment Report (AR6) (approved for release for education on climate change issues to society)

Approximate building & Grid equipment timescales

See ASHRAE fundamentals chapter 36 on climate change

Why extreme events?

Increased frequency, and intensity of extreme weather

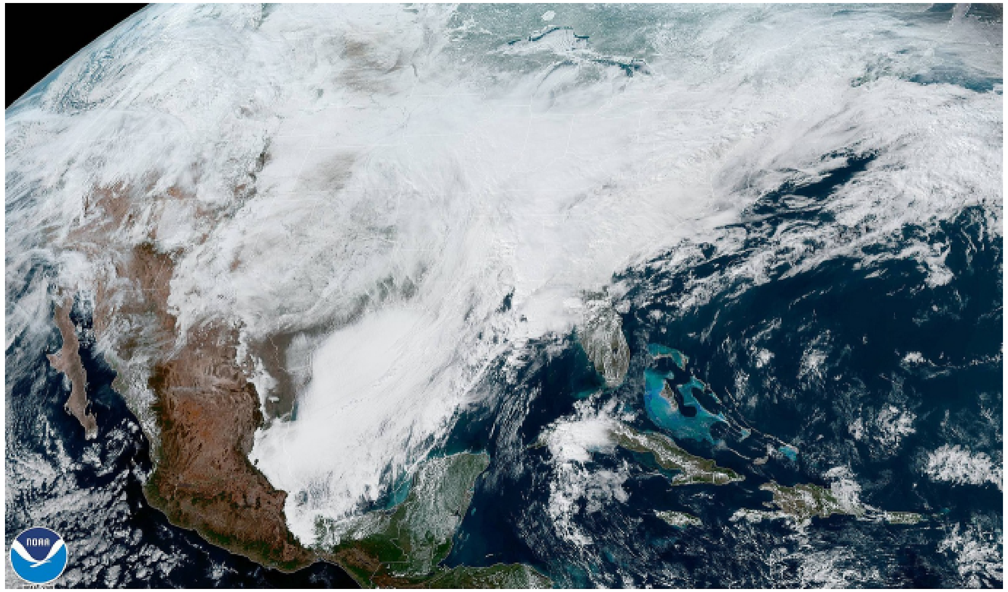


Why extreme events?

Increased demand for resilience to future design basis threats (DBR)

Resilience analysis requires simulation of a system’s failure and recovery due to **DBR’s**

Extreme Weather DBR’s



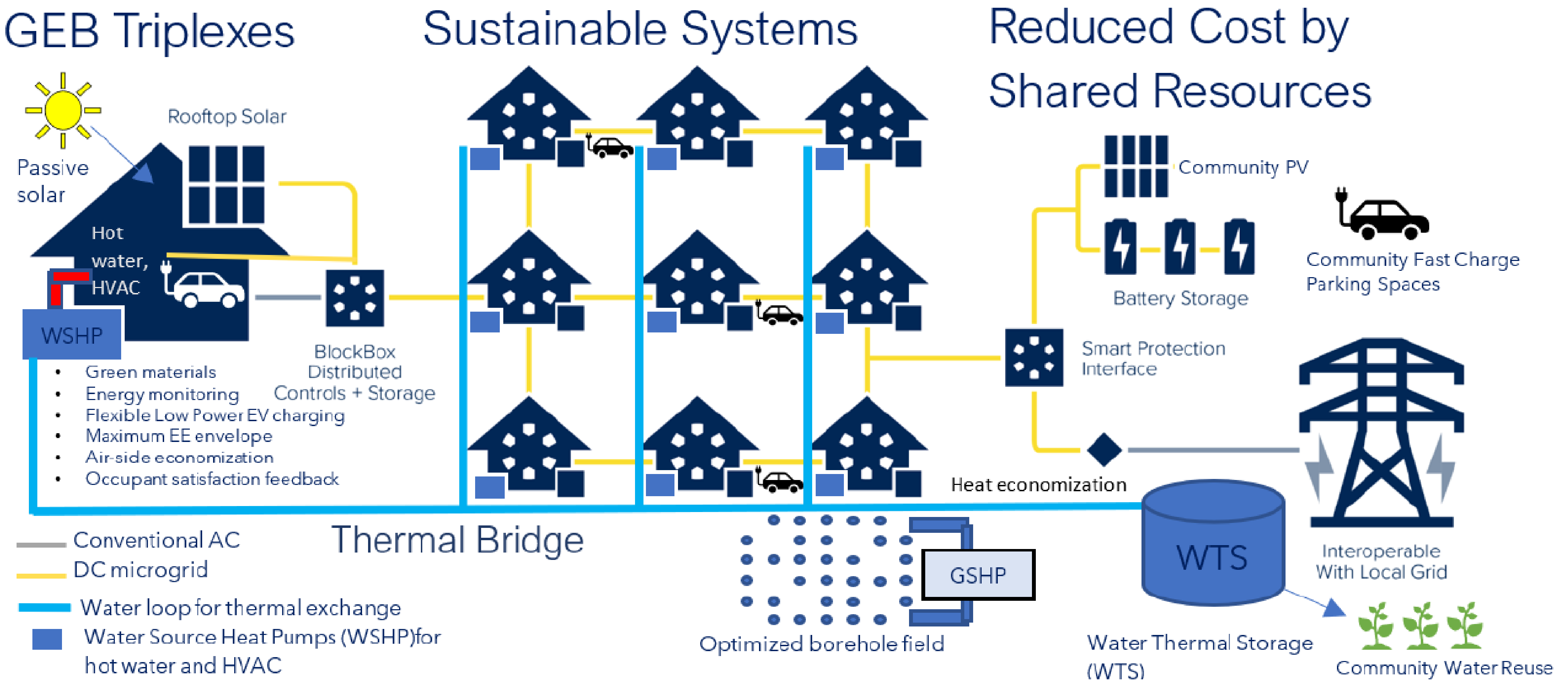
Creative commons Wikimedia – Winter Storm URI over the U.S. February 15th, 2021

Other DBR’s (e.g. Earthquake)

Collapsed apartment buildings in the Niigata area of Japan. *DOC/NOAA/NESDIS/NCEI (1964) Public Domain*

Extreme event risk

↑ Connectivity ↑ Extreme events = ↑ ↑ Risk



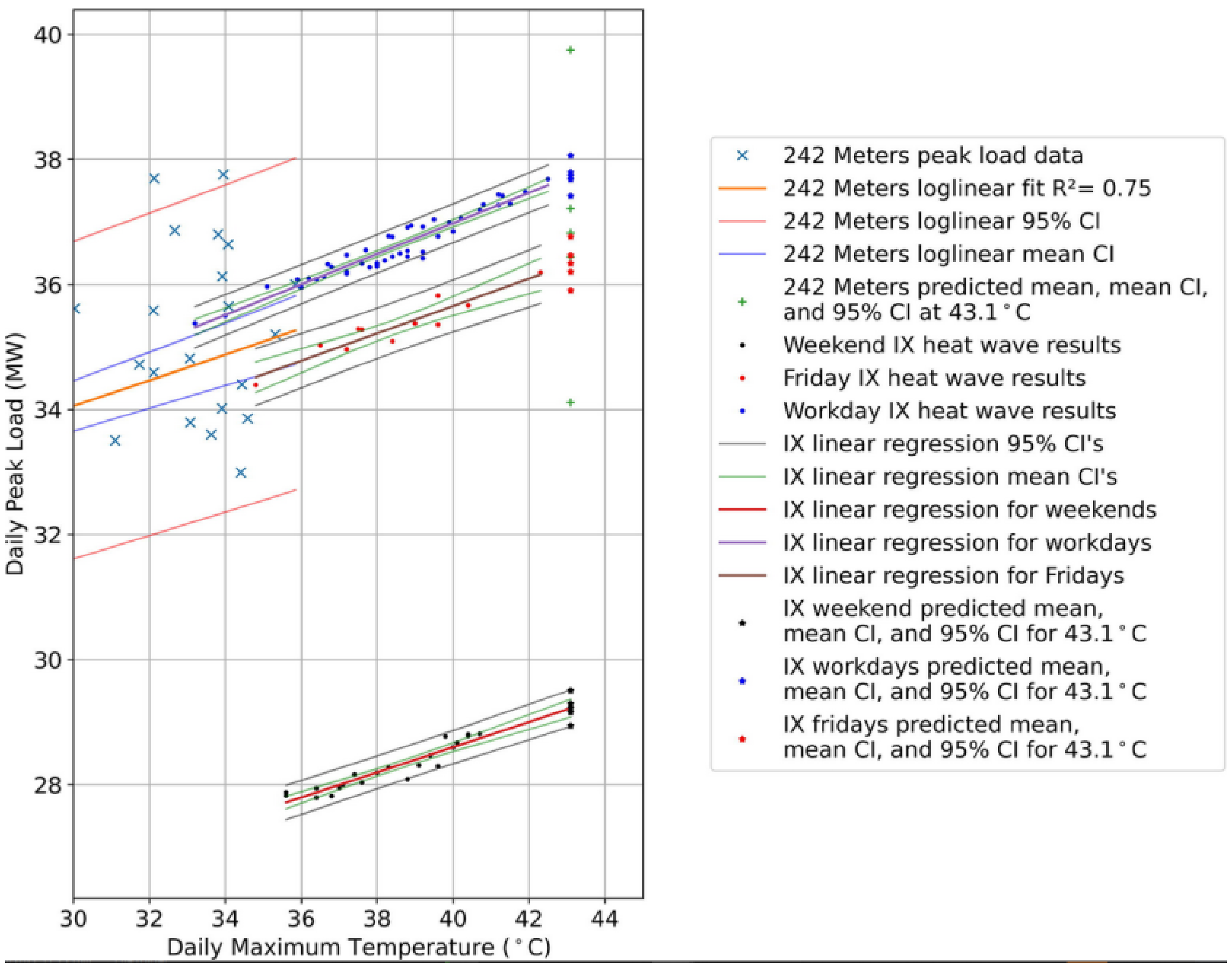
Why a probabilistic approach?

“Simulating reality”

Extreme events

Scenario approach

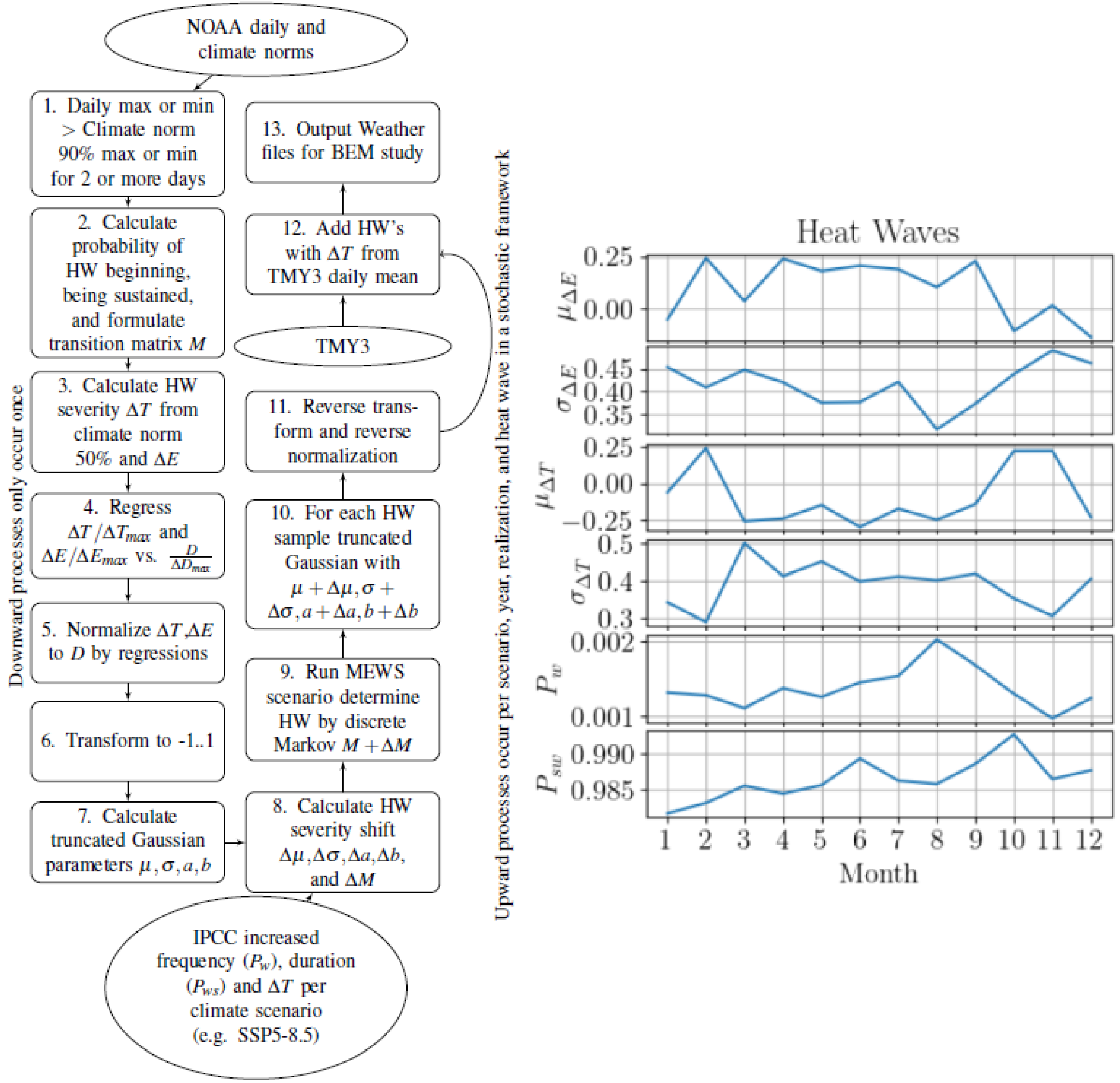
- Create a set of heat wave scenarios
  - Safety factors
  - Success criteria
- Apply these scenarios to engineering analysis of grid and buildings
  - Evaluate design criteria
  - Uncertainty due to operations and equipment
  - No weather based uncertainty
- Hopefully worst case!



Extreme events

Stochastic approach

- Propagate statistical properties of extreme weather events
- Difficulties
  - Insufficient historical data
    - Poor statistics of distribution tails
  - Duration of data needed can be non-stationary
  - Complexity
- Validation
  - Verify historic accuracy
  - Verify ensemble model based accuracy
- Advantages
  - Natural blending of normal conditions versus extreme event conditions



Comparison
Probabilistic vs. Scenario

Hybrid Scenario/Probabilistic approaches can also work.

Scenario		Probabilistic	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Simple	Indirect comparison of normal vs. resilience	Direct comparison of normal vs. resilience	Complex
Can be conservative	Can be unconservative	Quantifies chance of worst case, samples possibilities	Often requires unavailable data
Shorter run time		Consistent with probability based resilience metrics	Longer run time
Facilitates higher fidelity models		Fair playing field for other random, correlated processes	Simplified models needed

Why a probabilistic approach?

Fair comparison of normal vs. resilience conditions

We cannot "future proof" all tech! Who is going to pay the bill?

"Tornado proof"

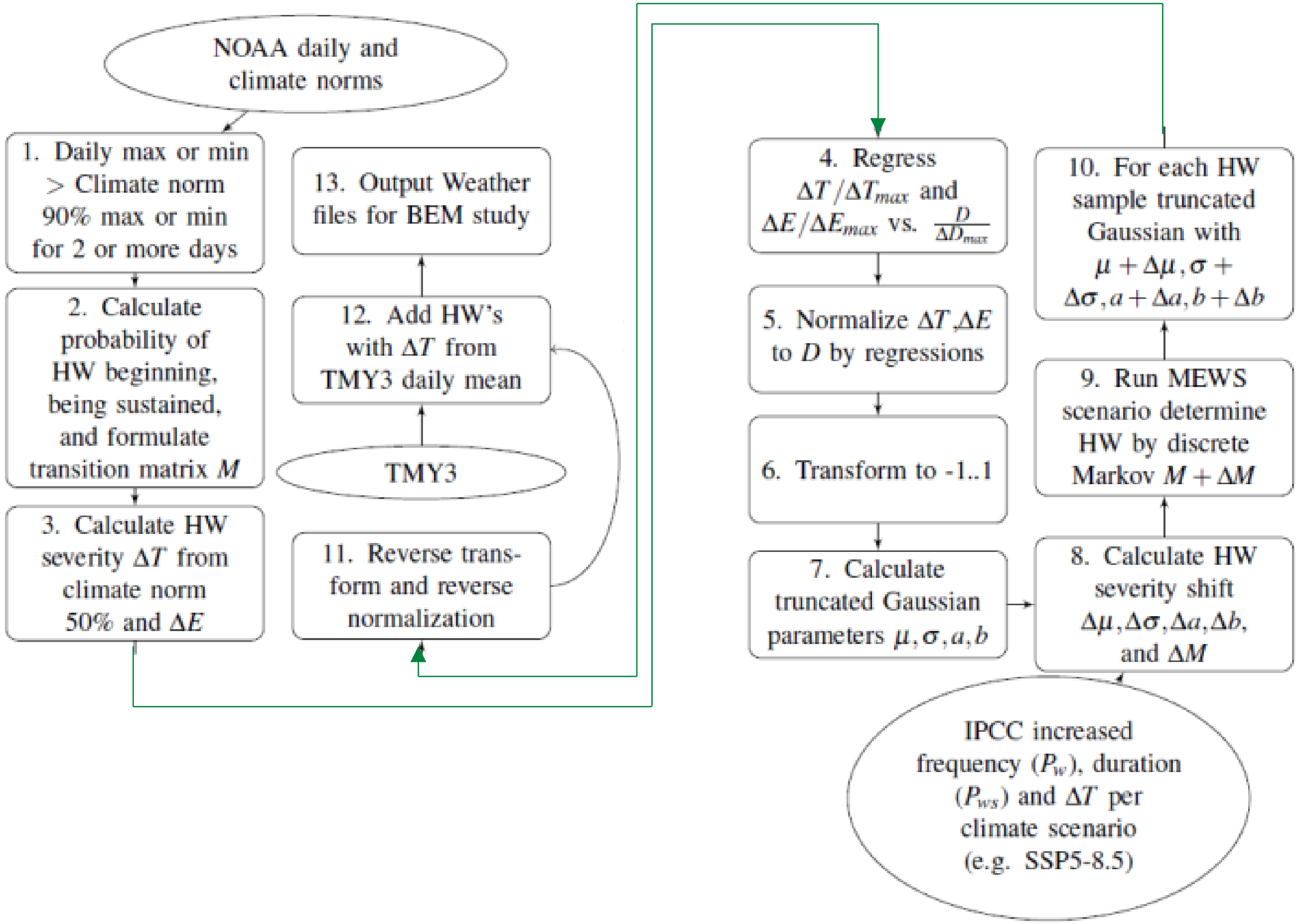
The TIV (Tornado Intercept Vehicle) built from a Ford F-450 (2006) Creative commons Wikimedia Creative Commons Attribution 2.0 Generic license.

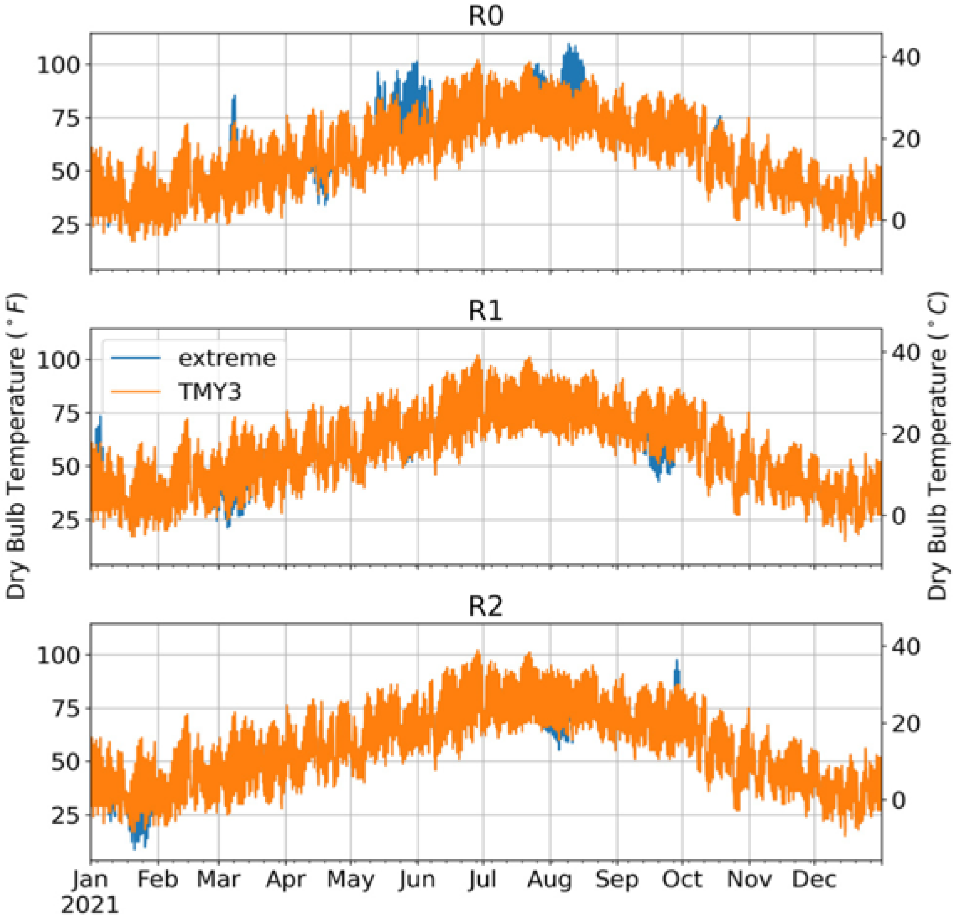
"Flood proof"

https://commons.wikimedia.org/wiki/File:Car_Boat_%3F_(3830832878).jpg
License: Creative Commons Attribution 2.0 Generic

Extreme Events

Multi-scenario Extreme Weather Simulator





Power outages relation to weather

Challenges

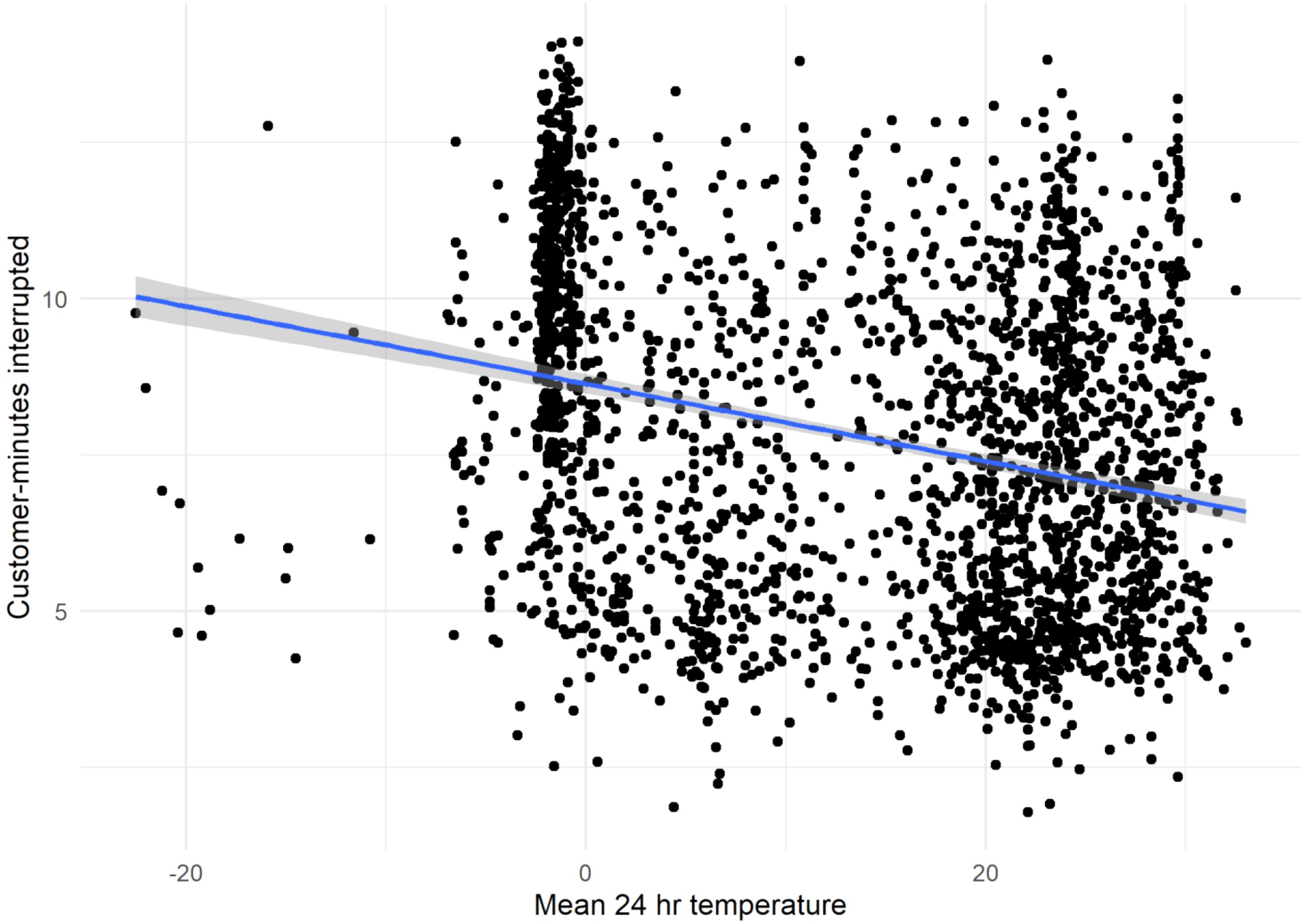
Identification of outage-weather relationship

Use a database of half million interruptions correlated with weather data by zip code

Look for correlations

Mean 24 hr temperature seems to be negatively correlated with customer-minutes interrupted (CMI)

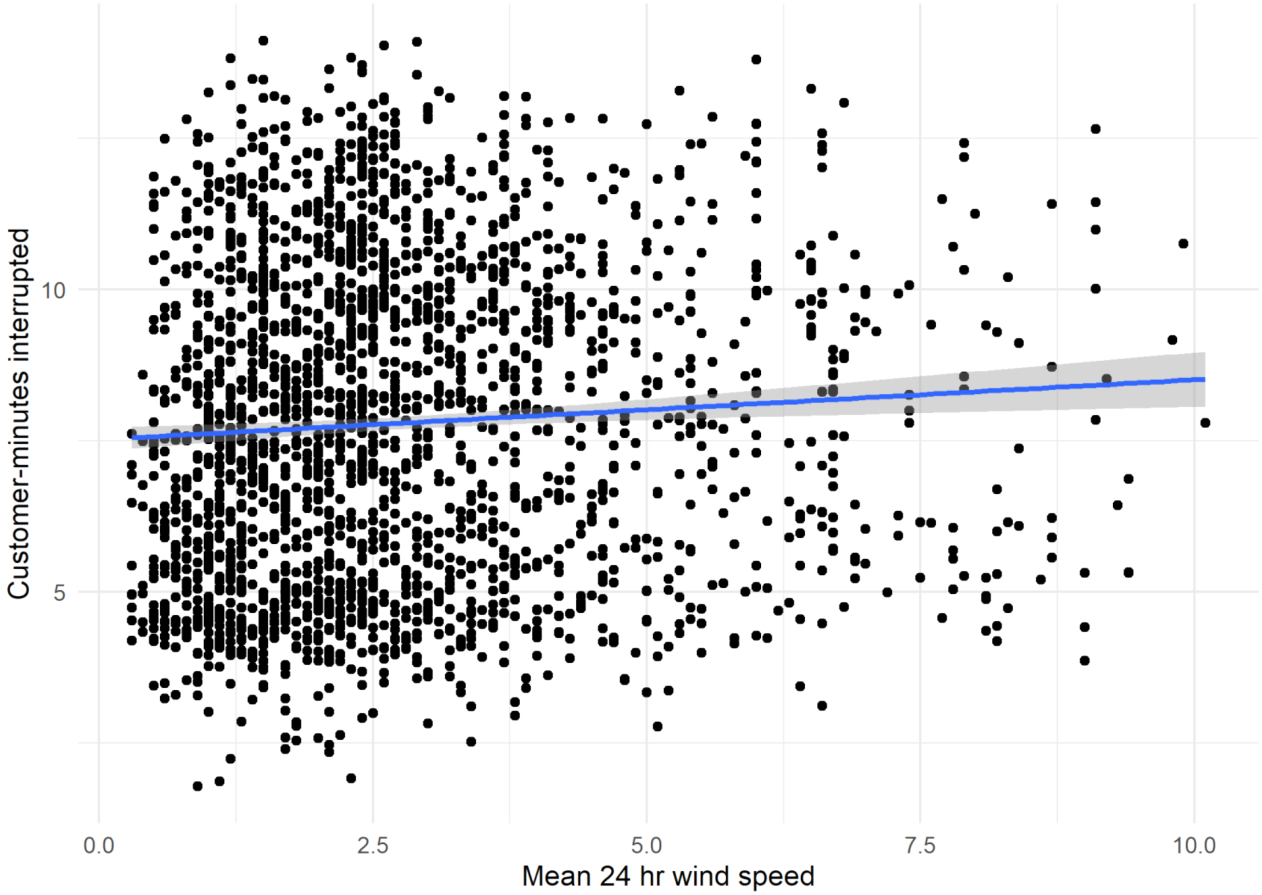
- Higher temperature leads to lower CMI



Challenges

Identification of outage-weather relationship

- However, other meteorological variables don't behave nearly as well
- Mean wind speed over 24 hours has poor correlation with CMI
- Certain variables may affect *onset* of interruption (failure rate) while others may affect *duration* (restoration rate)



Outstanding Issues

Identification of outage-weather relationship

Unaddressed research questions:

- Do outages respond to absolute meteorological variable's levels or deviation from normals?
- What techniques can quantify the impact of cumulative weather impacts on power outages that lag by days, weeks, or even months?
- How to express the likelihood of interruption in a probability of occurrence, rather than just correlations?
  - We have tried several probit/logit and zero-inflated Poisson models at the hourly level
  - Results are not very convincing

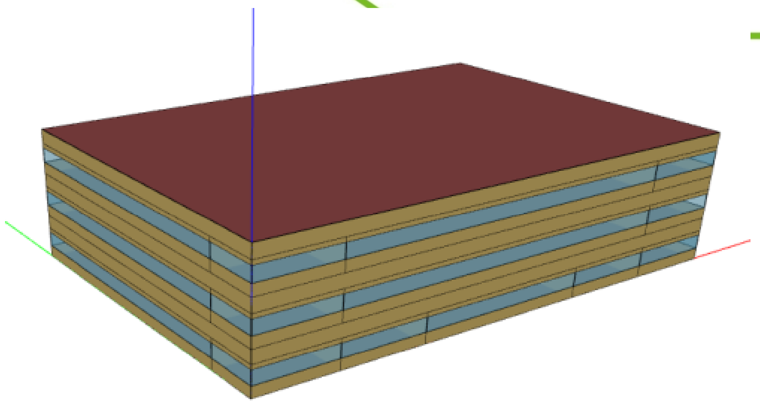
Modeling Outages in Buildings

Building Outage Performance

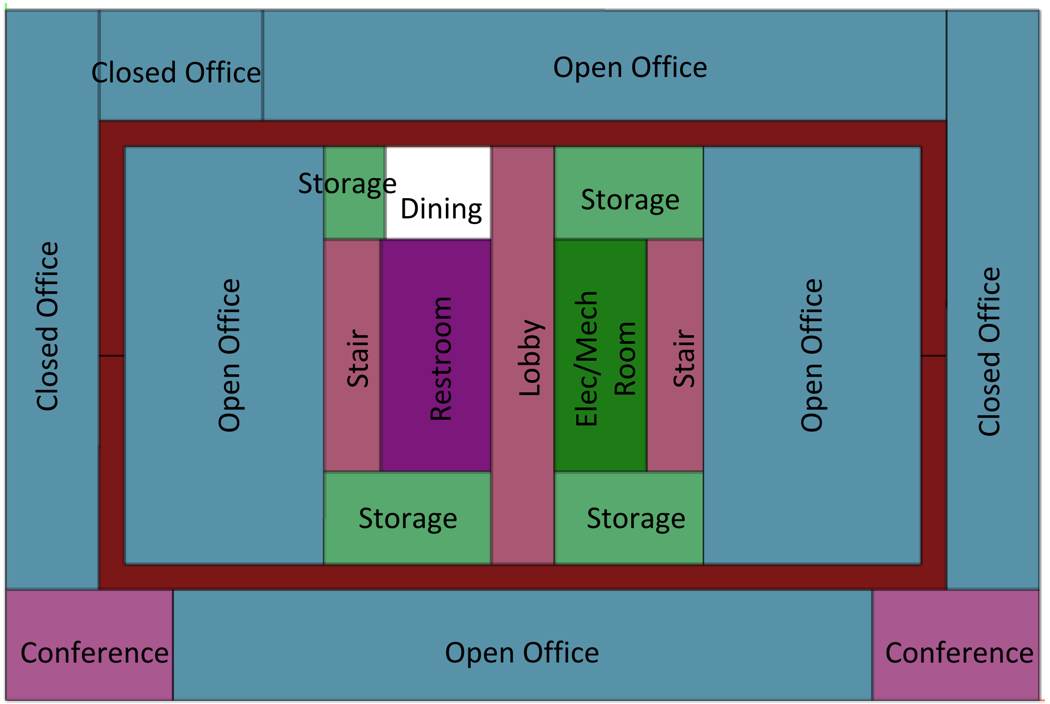
We used a medium office building

US DOE prototype EnergyPlus model

- Total building area: 4,982 m^2
- ASHRAE 90.1 2007 vintage
- 3 floors
- 65 thermal zones for open/enclosed office, conference, lobby, and storage spaces
- HVAC system:
  - Roof top unit (RTU) cooling system serving each floor air handling unit (AHU)
  - Gas furnace serving each floor AHU
  - VAV box with electric reheat system



3D View

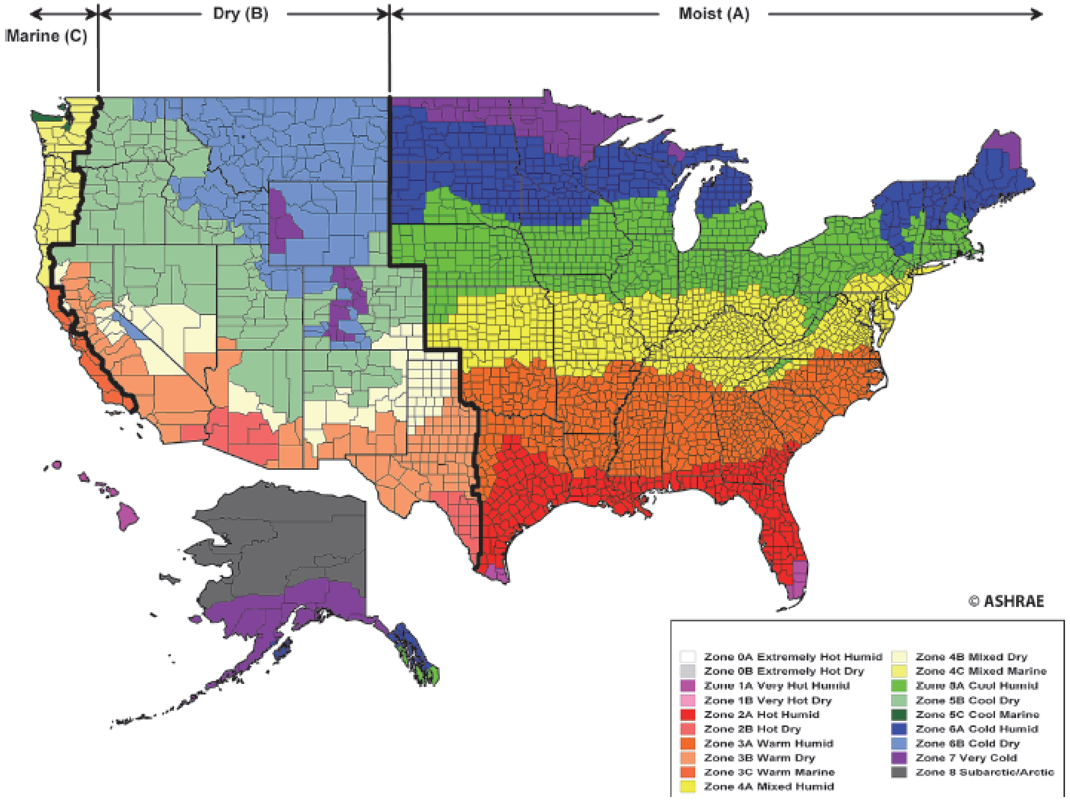


Floor plan showing space type

Site

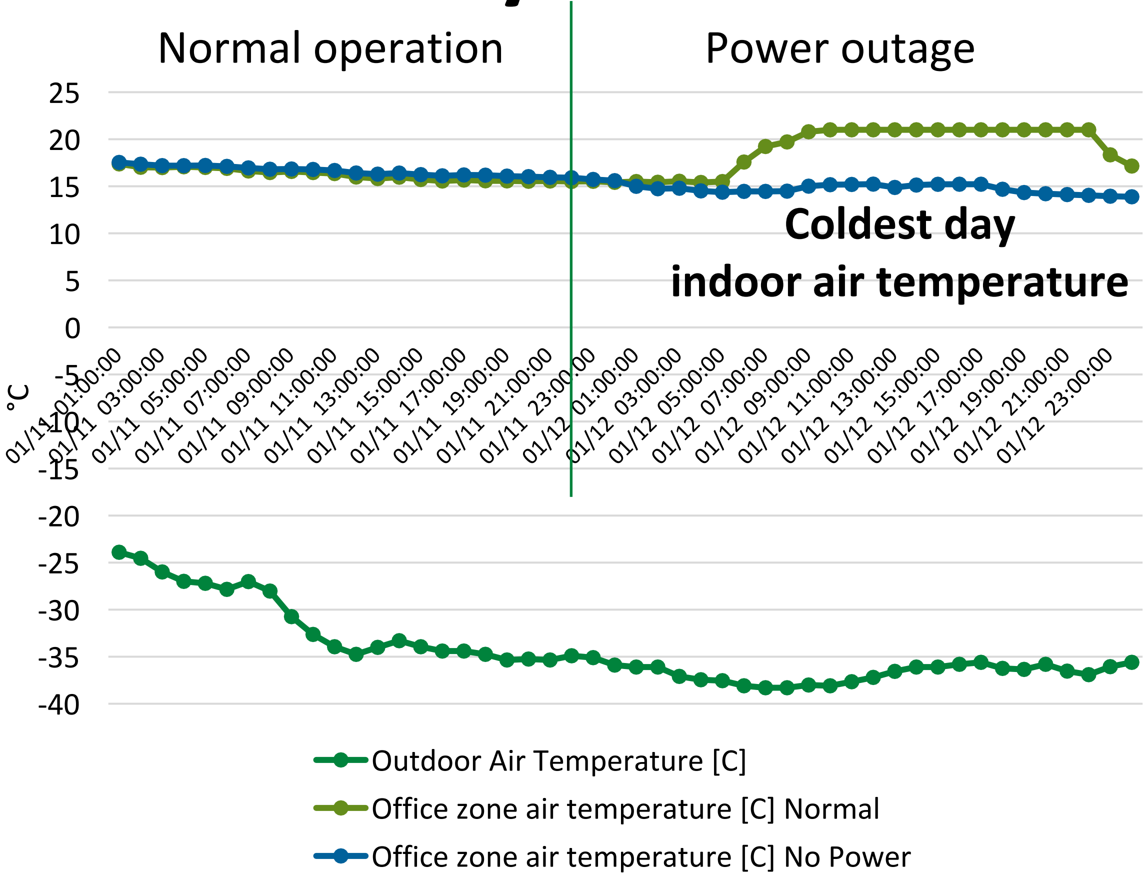
We used Fairbanks, Alaska in climate zone 8

- ERMA case study military camp in Alaska
  - Climate zone: 8
- Weather file: 8A_Fairbanks_702610_TMY3.epw
- Heating dominant climate
  - HDD (10°C baseline) : 4751 annual
  - CDD (18°C baseline): 27 annual
- Coldest temperature and time:
  - -38.3 °C on January 12th 6 am
- Hottest temperature and time:
  - 30 °C on July 29th 5 pm



Results

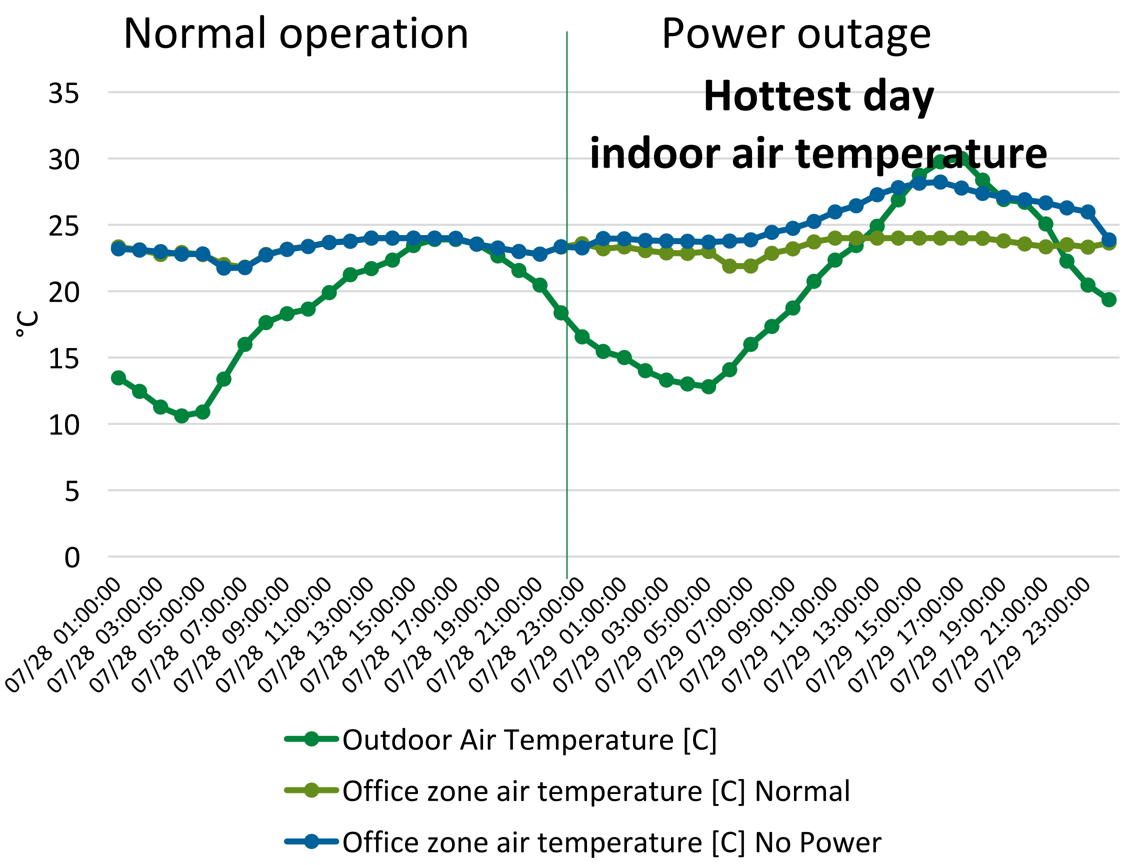
Indoor air temperature under power outage on the coldest day was evaluated



- Normal operation with power till 1/11 midnight
- No power on the coldest day on 1/12
- We simulated the indoor air temperature of the bottom floor North open office during the power outage event
- In normal operation condition (orange) shows temperature is set to 21°C
- Power outage scenario shows low indoor air temperature gray)
- Coldest temperature: 13.9 °C at midnight
- Although outdoor air temperature drops to -38.3 °C, ASHRAE 90.1 2007 building code insulation, infiltration, and building mass of show a slow temperature drop during the cold snap event.

Results

Simulated power outage on the hottest day: 7/29



- Normal operation with power till 7/28 midnight
- No power on the hottest day on 7/29
- We simulated the indoor air temperature of the top floor South open office during the power outage event
- In normal operation condition (orange) shows temperature is set to 24°C
- Power outage scenario shows high indoor air temperature (gray)
- Highest zone air temp: 28.2 °C at 4 pm
- The highest outdoor air temperature is 30 °C, ASHRAE 90.1 2007 code medium office can maintain indoor temperature less than the highest outdoor air temperature

Limitations

- Only 1 coldest and 1 hottest weather-related events were simulated. MEWS weather data with stochastic heatwave and cold snap events can be explored.
- Alaska for a case study is not super hot for a heatwave event.
- Indoor air temperature is the only metric studied. Other resilience metrics can be explored
- More dynamic mission scenarios can be explored.
- Use of the medium office prototype model was used. More realistic buildings can be explored.

Conclusions

Conclusion

Much more work to be done

- Probabilistic approaches to extreme weather are essential
  - Fair playing field
  - Avoiding overly conservative approaches
- Complexity
- Lack of Data
- Concurrent outages relation to extreme events needs expansion

Questions?

Daniel Villa
dlvilla@sandia.gov