Northwest **Power** and
Conservation Council

September 7, 2022

MEMORANDUM

TO: **Council Members**

FROM: **Jennifer Light, Power Division Director**

SUBJECT: **HVAC Technology Performance in Extreme Weather Conditions**

BACKGROUND:

Presenter: Ben Larson, Larson Energy Research

Summary: The RTF recently contracted with Larson Energy Research and Sharply Focused ("Contractor Team") to conduct an analysis on the performance of weather-sensitive technologies (such as heating and cooling equipment) under extreme weather conditions. The purpose of this effort is to help understand the potential grid implications during these extreme conditions and identify opportunities for improving equipment performance.

For this work, the Contractor Team identified extreme hot and cold weather events from the climate record. Those events were integrated into weather files, traditionally representing "typical" weather, and used in building simulation models that allow us to understand the performance of buildings and heating, ventilation, and air conditioning (HVAC) equipment throughout the year. The Contractor Team looked separately at the impacts on this equipment for both the extreme hot and extreme cold events.

Ben Larson will cover the key findings from this analysis including:

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- Energy use and peak power are significantly greater during extreme weather events
- In extreme cold events, heat pumps can provide benefits for much of the region, but those benefits will be less in the coldest areas (note: even in these areas they can provide annual energy savings)
- In extreme hot events, the typically sized unit is not likely capable of keeping up with the cooling needs
- Insulation can reduce the impact in both extreme hot and extreme cold events

Relevance: The 2021 Power Plan highlights the need for improved understanding of extreme weather events and their impact on the power system. Although more research is needed, this project provides some initial insights on the magnitude and frequency of extreme weather. It also provides important insights on the impacts from HVAC technologies on the grid. These insights will improve our modeling of extreme events for future planning and should also inform potential opportunities for demand-side programs to minimize building-level impacts from extreme events.

More Info: The full report is available here: https://nwcouncil.box.com/v/082022-xtremeweatherevntsmemo

Exploring Extreme Weather Impacts

Larson Energy Research

Presented by

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13 September 2022

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"Those two years seem extreme now, but years that look normal now would have been extreme 50 years ago….

That's how climate change works.

Today's outliers become tomorrow's averages."

William Colgan
Glaciologist at the Geological Survey of Denmark and Greenland
August 2022
https://apnews.com/article/science-oceans-glaciers-greenland-climate-and-environment-9cd7662658ebbeaba05682352de8aa87

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Project Objectives

- Define “extreme weather”
- Establish approach to model extreme weather events
  - Collect necessary data
- Calculate effects of extreme weather on efficiency measures, peak power, and energy use

Topics

- Extreme Weather Events
  - How we defined them
  - Severity and frequency
- Impacts on Heating
- Impacts on Cooling

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Spoilers

- We selected extreme events from the last 30 years' of weather records to use as data source
- Events much more severe than anything in typical weather (TMY) data
- Heating/cooling energy use and peak power significantly higher during extremes
- Heat pumps can still reduce energy and power, but effect is very climate dependent
- Extreme heat waves overpower cooling capacities
- Look out for thermostat setback recovery

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Extreme Weather Events

Identification

For both cold snaps and heat waves, we searched the 30-year weather record for:

- **Hour** with lowest/highest temperature
- **1-day** period with lowest/highest average temperature
- **3-day** period with lowest/highest average temperature
- **5-day** period with lowest/highest average temperature

NPCC covers a large region containing different climates. We selected sites that represent all three heating zones and all three cooling zones:

Heating Zones	Cooling Zones
HZ1: Seattle	**CZ1: Seattle**
HZ2: Elko	**CZ2: Elko**
HZ3: Miles City	**CZ3: Boise**

Context: Building Construction Practice

- Buildings not built to handle 100% of all events every year
  - Cost is too great to design for every extreme event
  - Although contractors & engineers are fond of safety factors
- "99.6% Design Temperature" means, in an average year, 35 hours will be colder and 35 hours will be hotter

Heating Design	
Location	**Temperature (F)**
HZ1 - Seattle	25.4
HZ2 - Elko	-3.2
HZ3 - Miles City	-16.2

Cooling Design	
Location	**Temperature (F)**
CZ1 - Seattle	85.3
CZ2 - Elko	94.9
CZ3 - Boise	98.6

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Cold Snaps

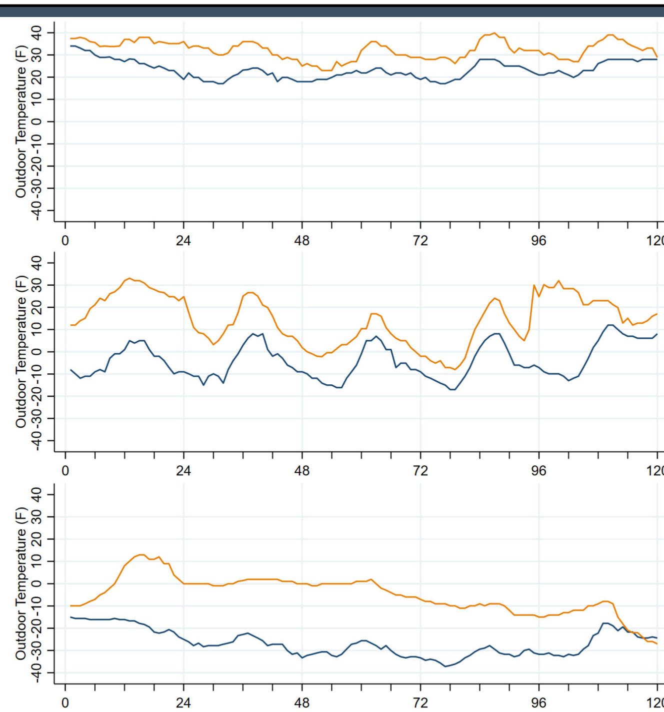
Graphs compare temperatures over 5-day extreme cold events (in blue) to a typical 5-day cold snap (yellow) found in average year (TMY) data.

(x-axis is hours)

HZ1 – Seattle

HZ2 – Elko

HZ3 – Miles City



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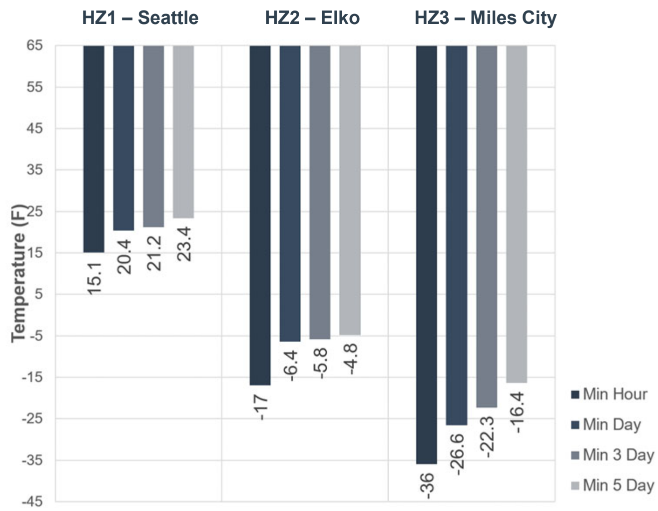

Average temperatures of each extreme cold event for each zone.

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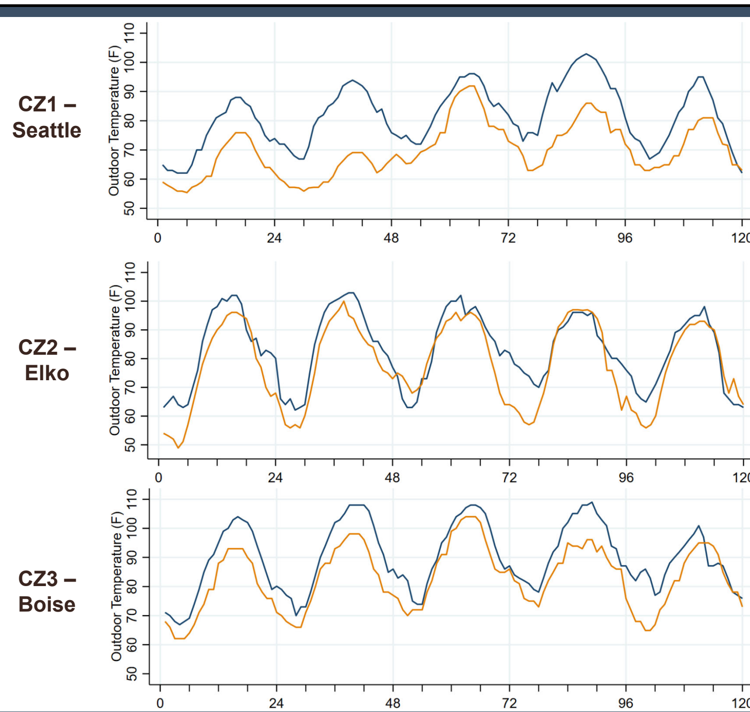
Heat Waves

Graphs compare temperatures over 5-day extreme heat events (in blue) to a typical 5-day heat wave (yellow) found in average year (TMY) data.

The 2021 Heat Dome produced greater extremes than what we used (2021 weather data was not yet available at the time).

(x-axis is hours)



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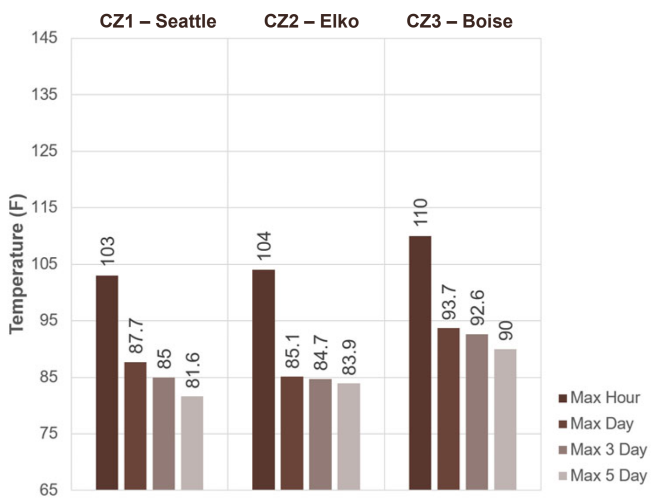

Average temperatures of each extreme heat event for each zone.

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Frequency

Loosely, the events we found are **10-Year Events**

30-year weather records contained 2-4 similar events of each type we selected.

We used the most extreme of those, and we estimate similar events happen about once every ten years.

Events in typical/average/TMY data are more like 1-year events.

Frequency may **increase**

Most climate change models predict an increase in extreme weather, in both frequency and severity.

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Modeled Heating Impacts

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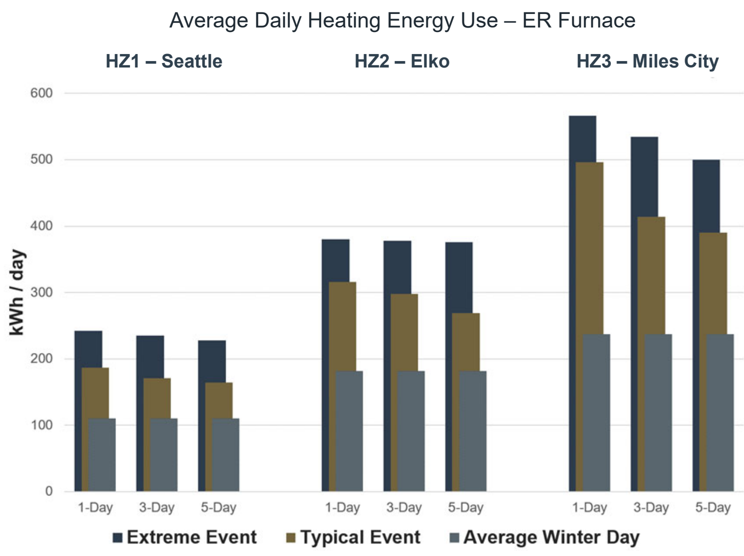
Energy Use – Electric Resistance (ER) Furnace



An electric resistance furnace uses 15-40% more energy during an extreme event compared to a typical cold snap.

Compared to the heating-season average, energy use is 116% higher during extreme events, on average.

A 5-day extreme cold event can account for 6-7% of the total annual heating energy use.
(An average 5-day stretch is 3%)

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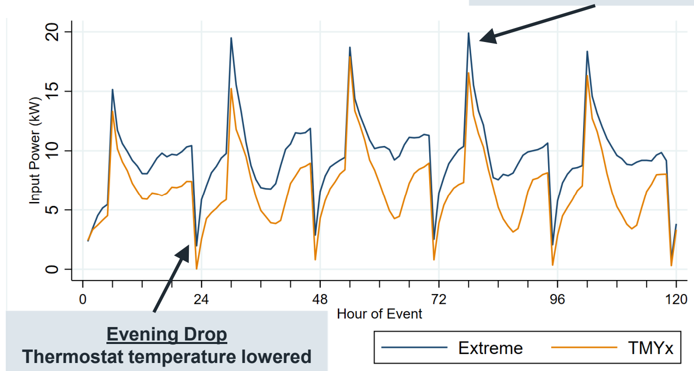
Peak Power – ER Furnace

Coincidence of morning recovery and low temperature drives peak power

Power During Peak Hour		
	Typical Cold Event	Extreme Cold Event
HZ1 – Seattle	**17.9** kW	**19.9** kW
HZ2 – Elko	**24.6** kW	**26.9** kW
HZ3 – Miles City	**27.3** kW	**32.8** kW

Power During 5-day Cold Event
ER Furnace, HZ1 – Seattle



Morning Peak
Coldest period of day coincides with thermostat temperature increase

Evening Drop
Thermostat temperature lowered overnight, demand reduced as furnace "coasts" to lower temp

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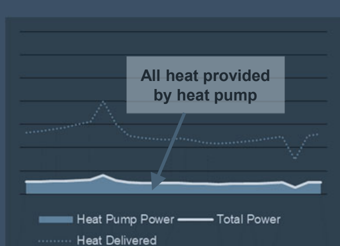
Sidebar: Heat Pump Refresher

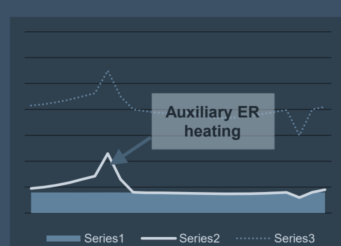
Heat pump systems have auxiliary electric resistance heating elements for times when compressor alone cannot meet demand.

The portion of heat provided by the compressor is delivered at significantly higher efficiency than any part provided through ER.

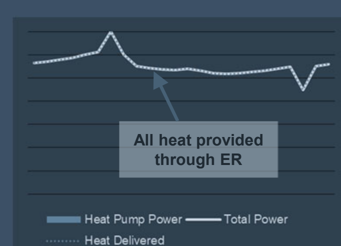
In normal weather, heat pump compressor provides most or all necessary heat – highest efficiency



If temperature drops and demand exceeds compressor capacity, ER will make up the difference, reducing efficiency



In extreme cold conditions, compressor cannot run and system effectively becomes an ER furnace



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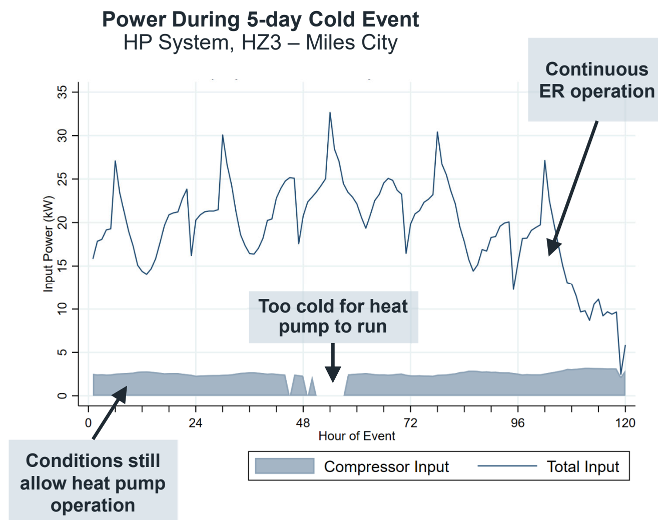
Peak Power – Heat Pump

Heat pumps reduce peak power compared to ER, but that reduction decreases with colder temperatures – in the most extreme case, they provided no benefit in this regard.

In all sites, total annual energy use still significantly lower than ER.

Heat Pump Power During Peak Hour					
	Typical Cold Event	Extreme Cold Event			
		Total	Heat Pump	Aux ER	
HZ1 – Seattle	**12.6** kW	**14.8** kW	3.1 kW	11.7 kW
HZ2 – Elko	**19.4** kW	**25.4** kW	2.5 kW	22.9 kW
HZ3 – Miles City	**25.5** kW	**32.7** kW	0.0 kW	32.7 kW



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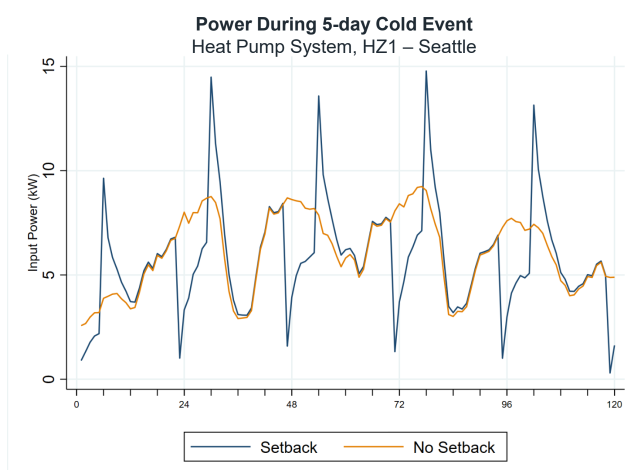
Thermostat Setback and Load Shape

Eliminating overnight thermostat setback drastically reduces peak power.

…but increases overall energy use.

Control over thermostat schedule and demand response programs can offer significant value to the grid.

Power During Peak Hour		
	No Setback	Setback
HZ1 – Seattle	**9.2** kW	**14.8** kW
HZ2 – Elko	**20.1** kW	**25.4** kW
HZ3 – Miles City	**27.0** kW	**32.7** kW



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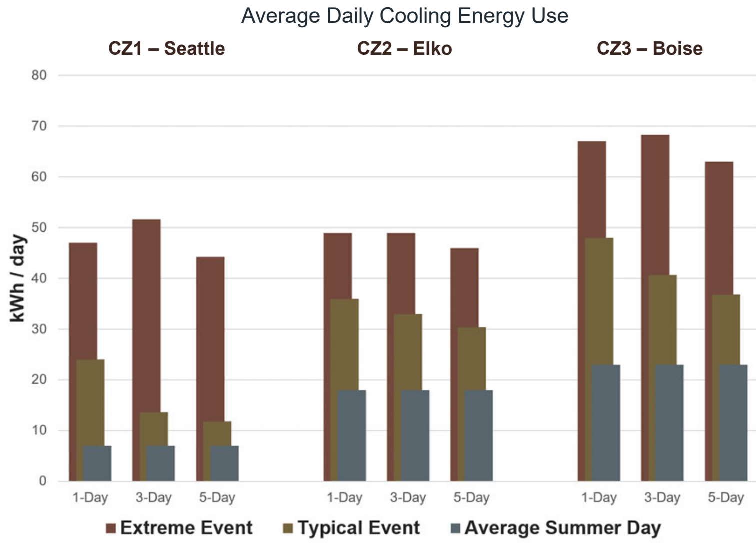
Insulation Benefits

- Increasing ceiling insulation reduces both energy used during cold snap and the peak power consumption
- R-19 to R-38 is a modest upgrade to overall house heat loss. Whole-house retrofit approaches will yield substantially more benefits.

	HZ1 Seattle	**HZ2 Elko**	**HZ3 Miles City**
Energy Use Reduction	3.6%	2.7%	1.6%
Peak Hour Power Reduction	1.7%	1.3%	1.0%

Modeled Cooling Impacts

Energy Use – Cooling



Extreme events use 37-275% more energy than a typical heat wave.
CZ1 increase is so great largely because a typical Seattle heat wave is fairly mild.

A 5-day extreme heat event can account for 12-30% of the total annual cooling energy use.
(An average 5-day stretch is 4-5%)

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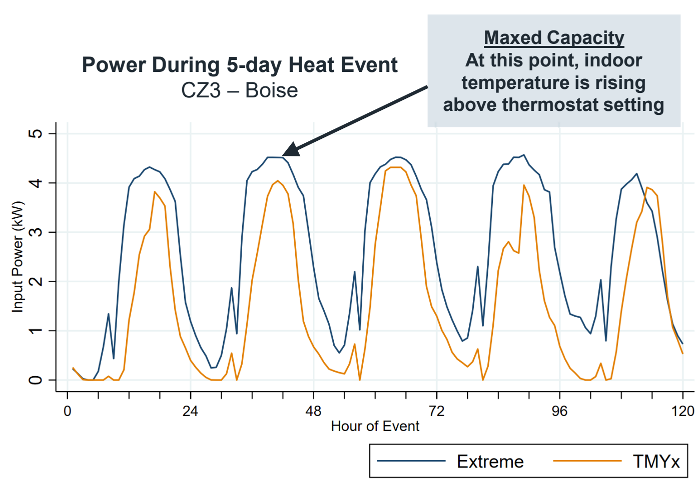
Peak Power – Cooling

In hottest events, energy use is limited by air conditioner capacity. Demand is not met.

Power During Peak Hour		
	Typical Heat Event	**Extreme** Heat Event
CZ1 – Seattle	**3.8** kW	**4.3** kW
CZ2 – Elko	**3.9** kW	**4.2** kW
CZ3 – Boise	**4.3** kW	**4.6** kW



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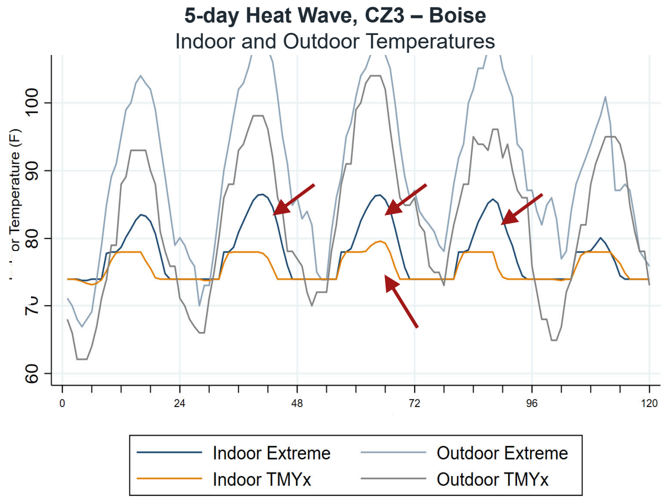
Unmet Demand – Cooling



Typical Boise heat wave already stresses 4-ton AC – thermostat temperature slightly exceeded for a few hours on third day.

Extreme heat wave is beyond system capability. Indoor temperature exceeds thermostat setting by over 7 degrees (85+° indoor temperatures) most days.

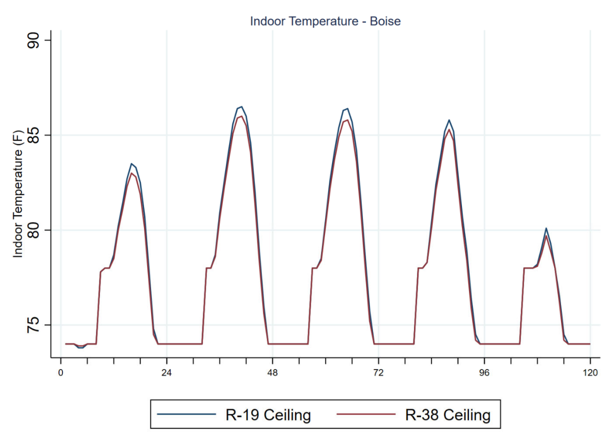
Meeting thermostat setpoint would require an 8-ton system. This would also drastically increase peak power:

Peak Power (kW)			
Capacity	**CZ1 Seattle**	**CZ2 Elko**	**CZ3 Boise**
4 tons	4.3	4.2	4.6
8 tons	7.3	6.1	8.9

Benefits of Insulation

- Increasing ceiling insulation from R-19 to R-38 reduces energy use about 1% during extreme heat events
- Insulation upgrade does not reduce peak power, as system is still maxed out during hottest periods
- While the energy and power reductions are minimal, the insulation does provide a comfort benefit: the air inside the house is cooler

	CZ1 Seattle	CZ2 Elko	CZ3 Boise
Energy Use Reduction	1.7%	1.5%	0.9%
Peak Power Reduction	~~~	~~~	~~~



Conclusions

Method to create extreme weather files successfully demonstrated.

Extreme events much colder & hotter and last longer than the coldest & hottest events in typical year.

The extreme events considered for this project occurred roughly 1 in 10 years.

Future research:

- Assess temperature distribution and locate typical year data on it, plus other events
- Research thermostat schedules (e.g. End Use Load Research Study) to understand realistic grid-wide behavior impacts

Both total energy use and peak power significantly greater during extremes.

Thermostat schedules are a large contributor to peak load.

Heat pumps still reduce energy and power, but the degree of savings is very weather dependent.

Insulation upgrades demonstrate clear benefit to both energy and power.

- Upgrades also show comfort benefits

Cooling capacity likely maxed out during heat waves.

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Additional Slides

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Terminology Reference Card

Acronyms

Climo – Climatological record from 1991-2020 assembled from ISD and NSRDB sources in Part 1 of this project.

ISD – Integrated Surface Database. A product of National Oceanographic and Atmospheric Administration (NOAA). Database of weather station observations.

NSRDB – National Solar Radiation Database

TMY – Typical Meteorological Year. Used in this presentation to generically mean typical weather files suitable for use in building energy simulation (regardless of vintage)

TMYx or **TMY2004-2018** – TMY datasets from Climate.OneBuilding.Org using data from the years 2004-2018 to create TMY datasets

Nomenclature

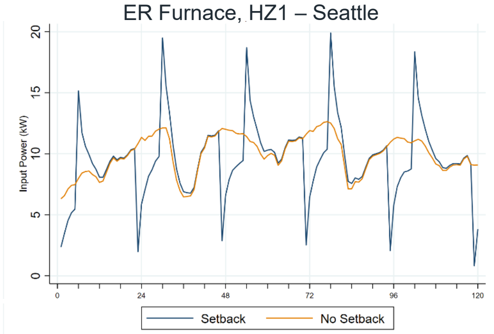
Typical Coldest / Hottest – The coldest or hottest temperature for a given time period found in the TMY data

Extreme Cold / Hot – The coldest or hottest temperatures for a given time period found in the 1991-2020 climatological record.

Thermostat Setback and Load Shape

Eliminating overnight thermostat setback drastically reduces peak power.

Effect is greatest with a heat pump in a climate that allows continuous compressor operation.



Peak Power and Energy Use, 5-Day Extreme Cold Events						
		ER Furnace		Heat Pump		
		Peak Power (kW)	Total Energy (kWh)	Peak Power (kW)	Total Energy (kWh)	
HZ1 – Seattle	With Setback	19.9	1,139	14.8	688	
	No Setback	12.6 *-37%*	1,195 *+5%*	9.2 *-38%*	730 *+6%*	
HZ2 – Elko	With Setback	26.9	1,879	25.4	1,655	
	No Setback	21.5 *-38%*	1,952 *+4%*	20.1 *-21%*	1,708 *+3%*	
HZ3 – Miles City	With Setback	32.8	2,498	32.7	2,343	
	No Setback	27.1 *-17%*	2,554 *+2%*	27.0 *-17%*	2,396 *+2%*	

Eliminating overnight thermostat setback increases total energy use.

Temperature Distribution

Open questions for future research:

- Where do the TMY hottest and coldest fall on the temperature distribution?
- Where do the extreme hot and cold fall on the distribution?