Don’t Freeze! The Heating Electrification Train is Barreling Towards Us?

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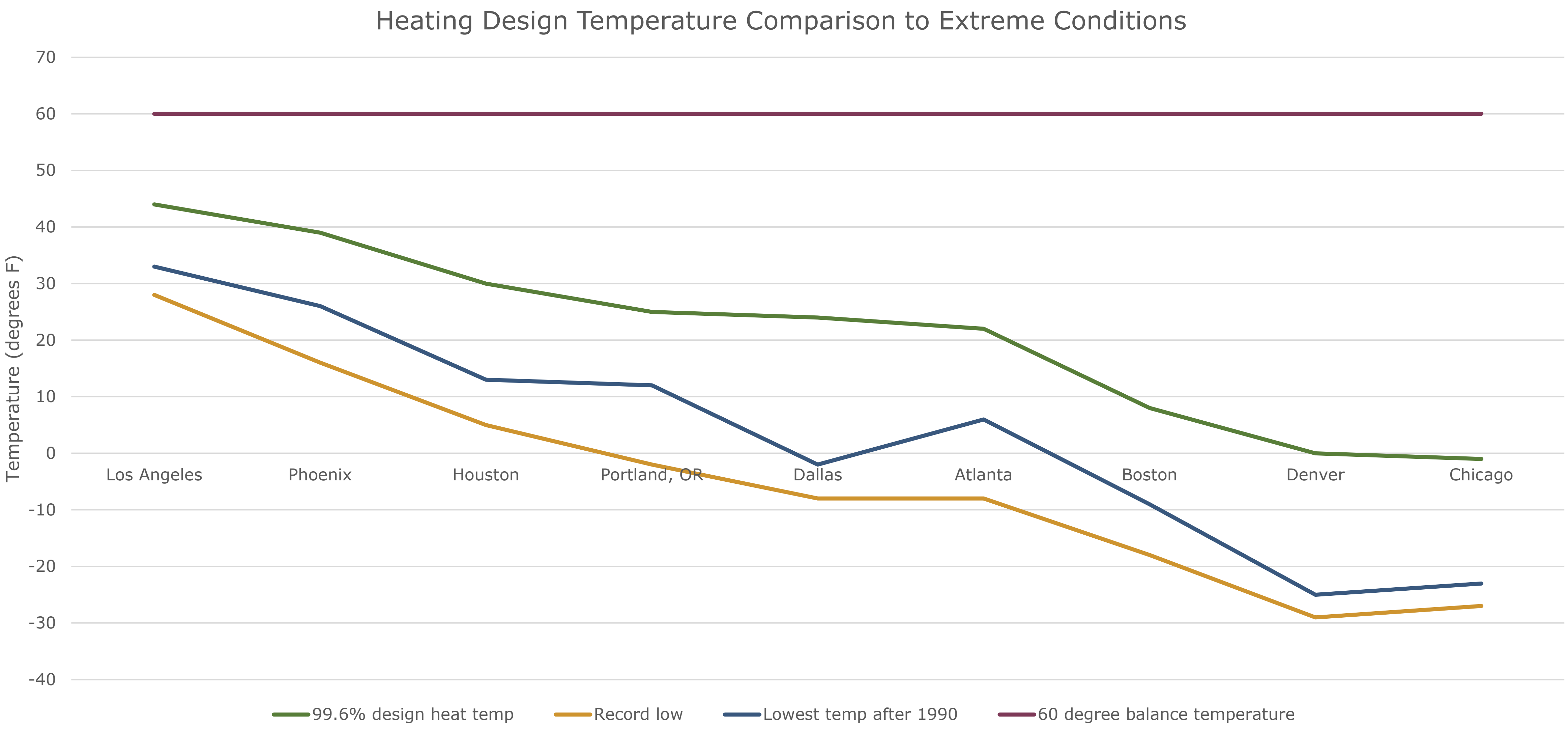
Heat pumps are almost as awesome as trains – I love 'em!

Ignoring the hardest electrification technical challenges is like ignoring the river crossings on a rail line.

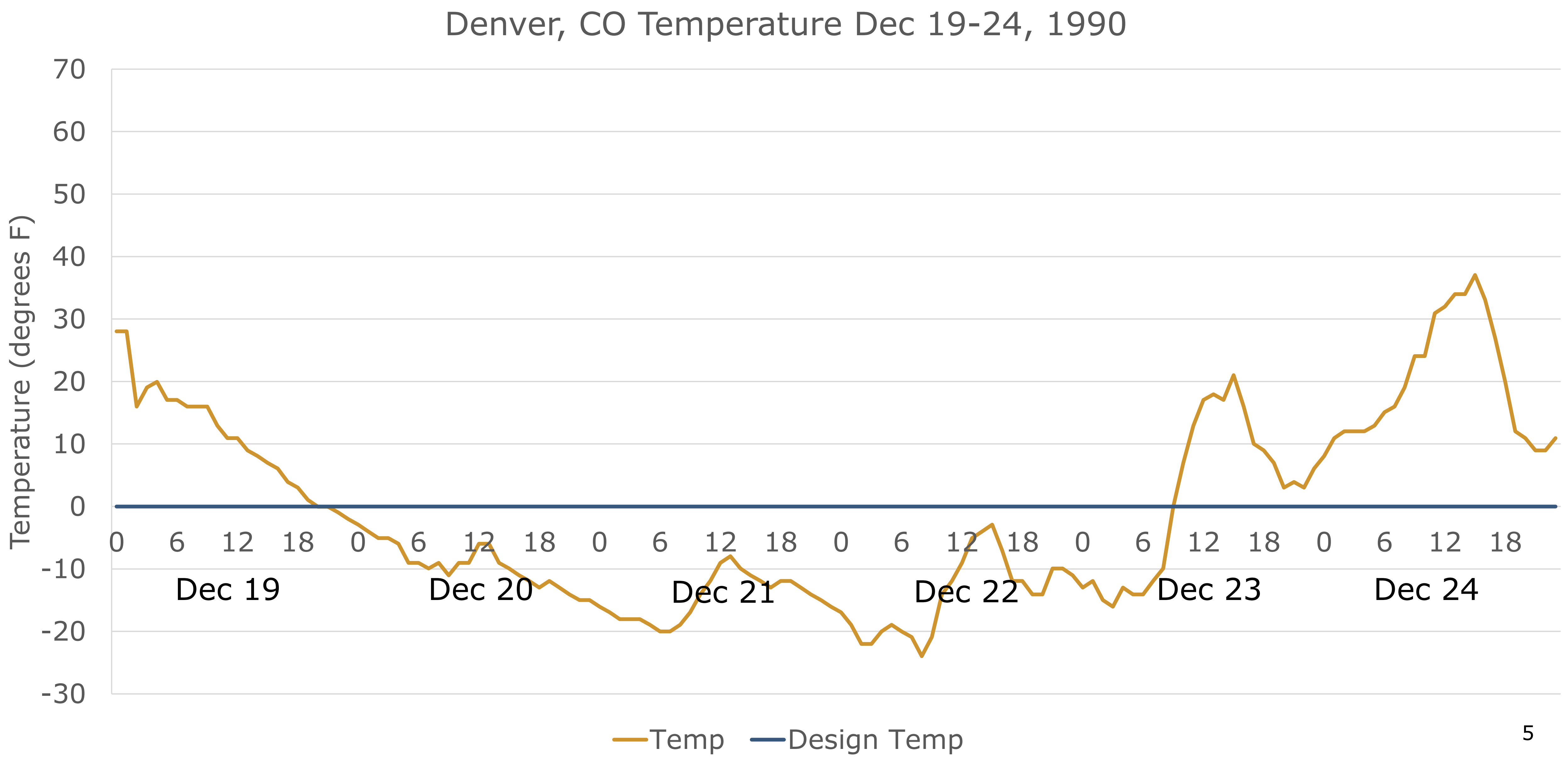
Winter peaks are the most difficult river crossings in our electrification build-out

What temperatures are we designing systems for?

APEX ANALYTICS



What does a river of cold look like? In Denver?



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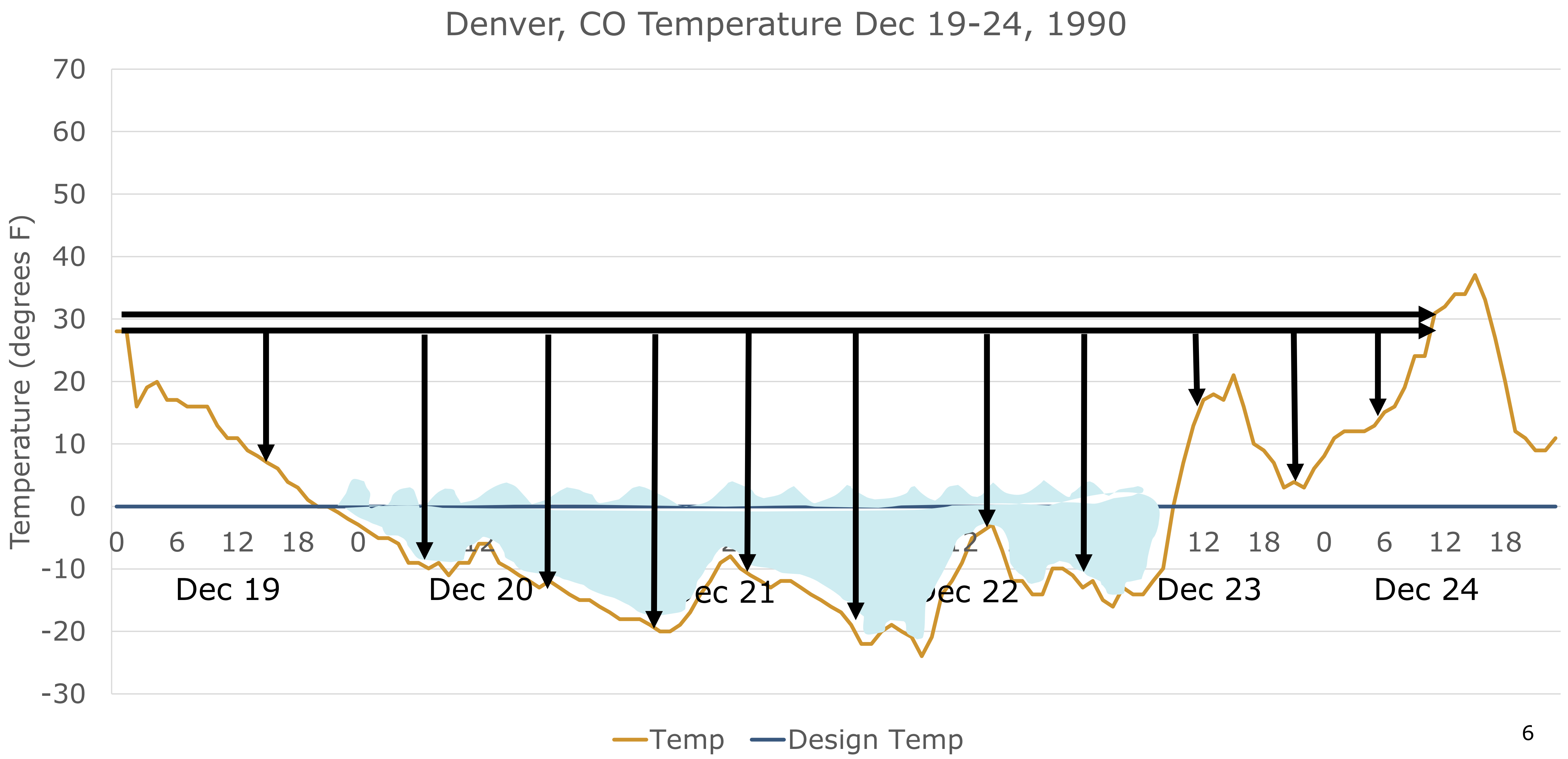
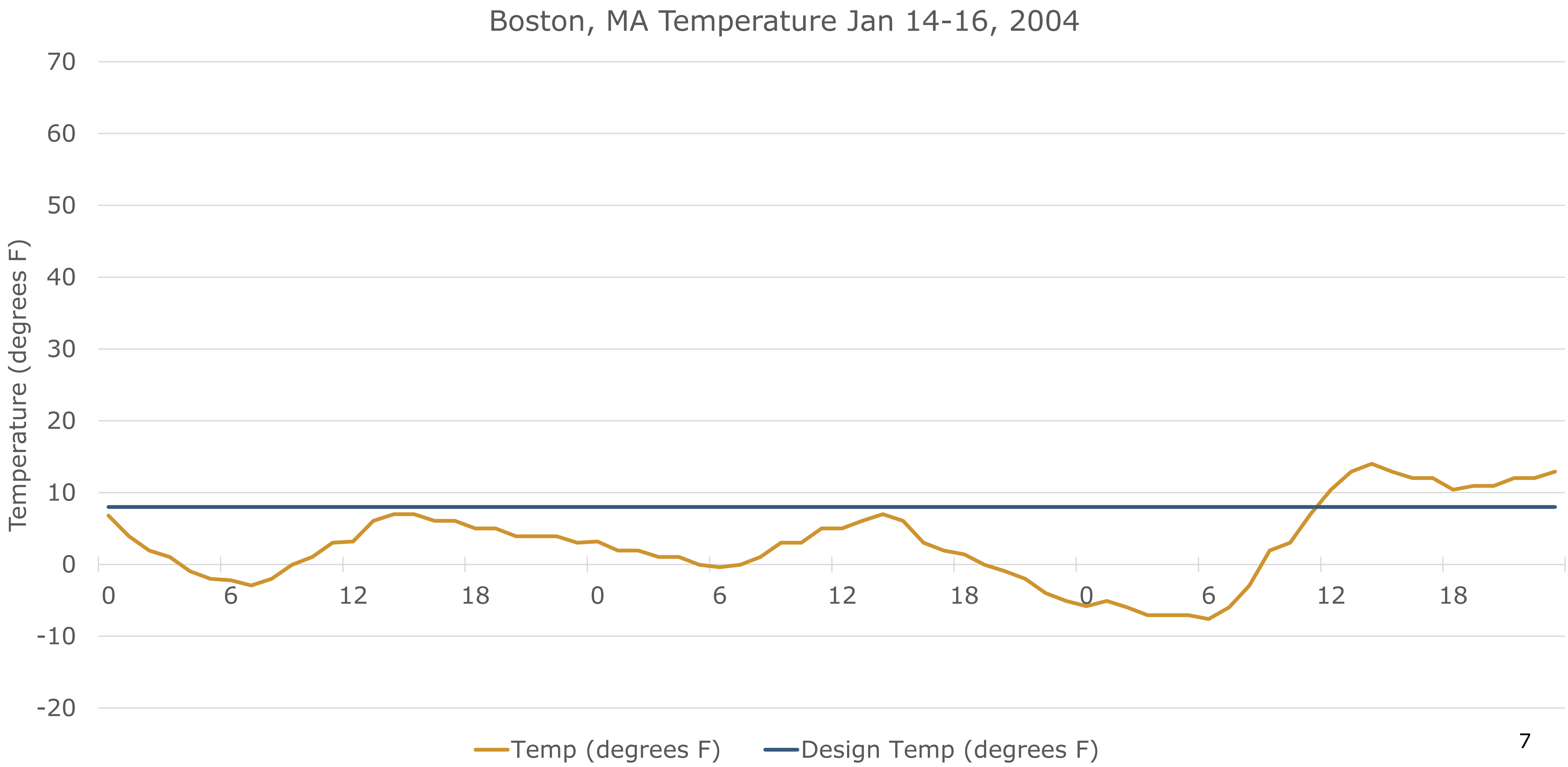
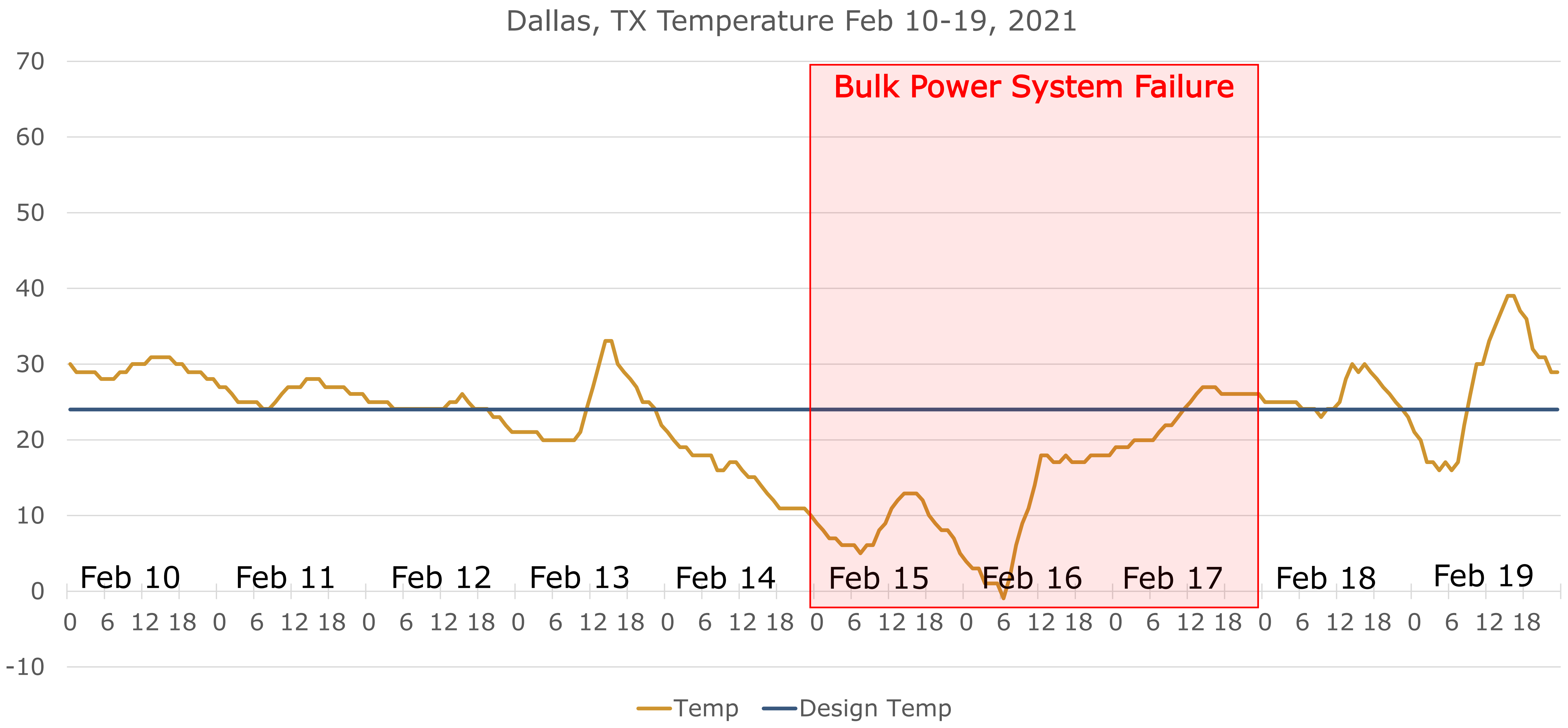


What does a river of cold look like? In Boston?



What does a river of cold look like? In Dallas?



Extreme conditions matter – when designing a system, what does your system failure look like?

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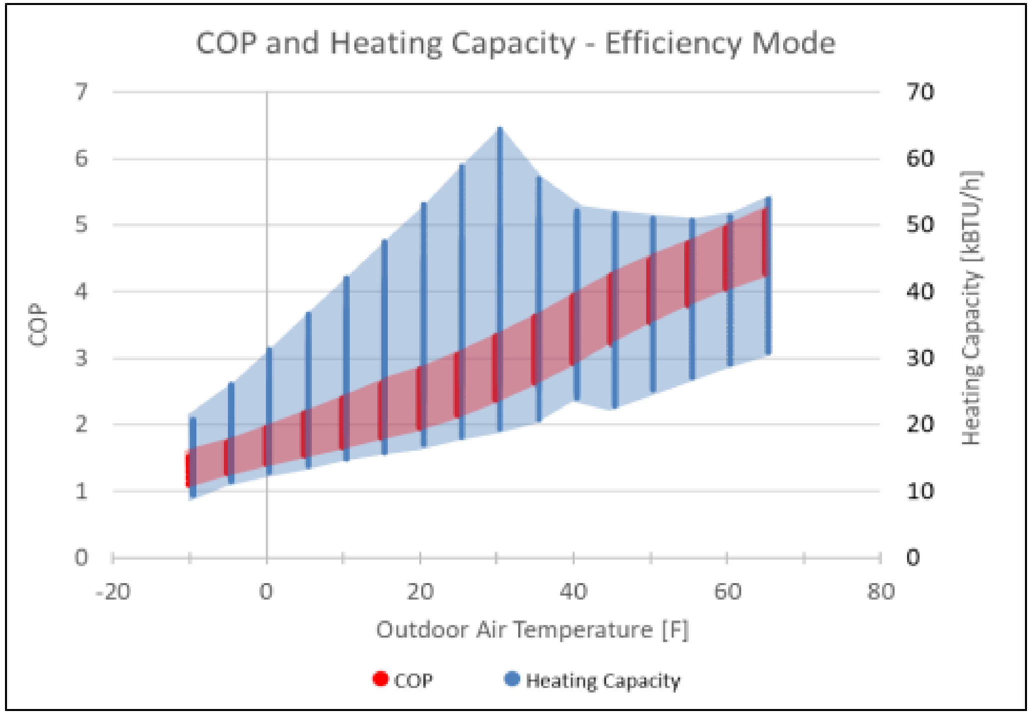
- In Texas, 200 people died as a result of Winter Storm Uri, mostly from lack of heat.
- More than half of homes in Texas's region are heated with electricity, with a combination of heat pumps and electric forced air furnaces.
- As we electrify heating, the human costs of grid failures go up, necessitating a higher level of grid reliability

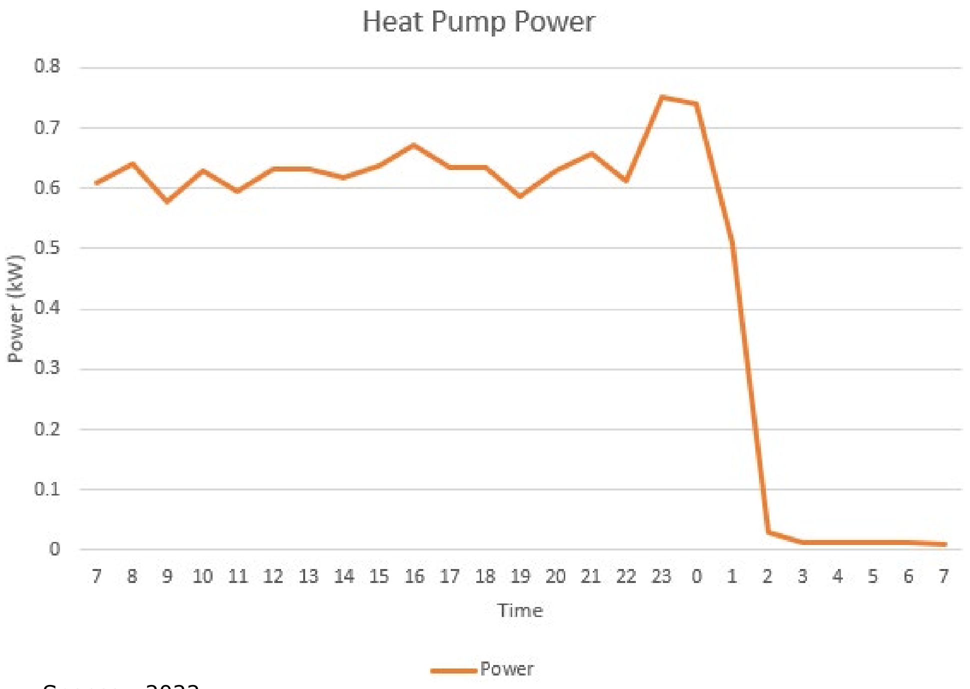
How do we keep people warm during extreme cold weather? How do we get them across the river of cold?

APEX ANALYTICS

- Right now, we mostly use gas furnaces or electric resistance heat
- Heat pumps don't work as well (or don't work at all) – capacity and efficiency both drop
- Meeting peak loads with electric resistance backup heat in moderate to cold climates adds 10 kW or more.



Shoukas et al, 2022



Spencer, 2022

How do we keep people warm during extreme cold weather? How do we get them across the river of cold?

APEX ANALYTICS

Electric Options (require capacity)

- Oversized/cold-climate heat pumps (in some places)
- Electric resistance heat
- Ground Source Heat Pumps

Non-Electric Options

- Keep the furnace Extreme efficiency/deep energy retrofits
- Pellet Stoves

Options to meet that capacity need

- Combustion turbines (and wait for renewable gas or carbon sequestration)
- Batteries (fail)
- Seasonal storage (Hydro?)
- More energy efficiency/new demand response products/technologies

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Electric options require grid solutions.

Compare each of these to a baseline, low cost system of plain heat pump + gas furnace.

We need more research ASAP on many of these.

Extreme Cold Electric Option 1: Backup Electric Resistance Heat

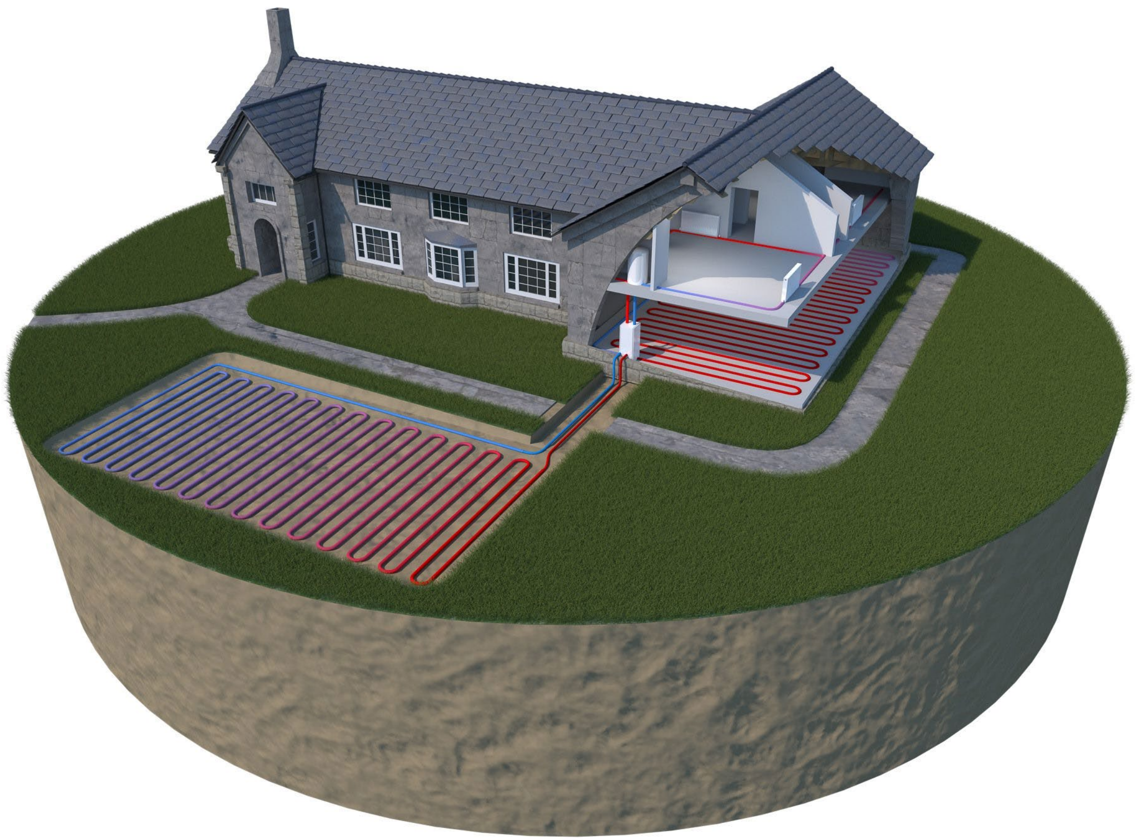
- **Carbon emissions:** Zero when using zero carbon electricity, high when using gas-fired electricity
- **Incremental Cost:** Very low, even negative compared to a furnace + AC
- **Grid Impacts:** Large, on the order of 10 kW/home (less in very mild climates, more in very cold climates)
- **Applicability:** All climates and locations
- **Customer ease:** Super easy.
- **Research needs:** Better quantification of actual electric heat usage during extreme cold.

Extreme Cold Electric Option 2: Oversized/Extra Cold Climate Air-Source Heat Pumps

- **Carbon emissions:** Zero when using zero carbon electricity, moderate when using gas-fired electricity
- **Incremental Cost:** High, on the order of $10,000 or more
- **Grid Impacts:** Medium-High, on the order of 6-7 kW/home (less in very mild climates, more in cold climates)
- **Applicability:** Should work well when record low temps are above ~ 0 degrees F (e.g. Portland/Seattle/Houston/Florida)
- **Customer ease:** May experience cool supply air at extreme temps
- **Research needs:** Better measurement of in situ performance during extreme cold.

Extreme Cold Electric Option 3: Ground Source Heat Pumps

- Carbon emissions: Zero when using zero carbon electricity, low when using gas-fired electricity
- Incremental Cost: High, $10,000 or more
- Grid Impacts: Low, on the order of 3-4 kW/home (less in very mild climates, more in very cold climates)
- Applicability: Almost all climates, dependent on soil conditions
- Customer ease: Easy to run, difficult to fix/maintain
- Research needs: Performance data on more systems in more places for more years



Will a decarbonized grid actually be carbon-free at extreme temps?

- Recent NREL study (Denholm et al, 2022) shows that the 2035 grid is likely to still use fossil fuel for the last ~5% of loads.

My conclusion: In most places, marginal resource for last 5-10% of heating will be natural gas until we get a technological breakthrough.

At extreme temps, we should expect the grid to use fossil fuel to deal with multi-day capacity problems.

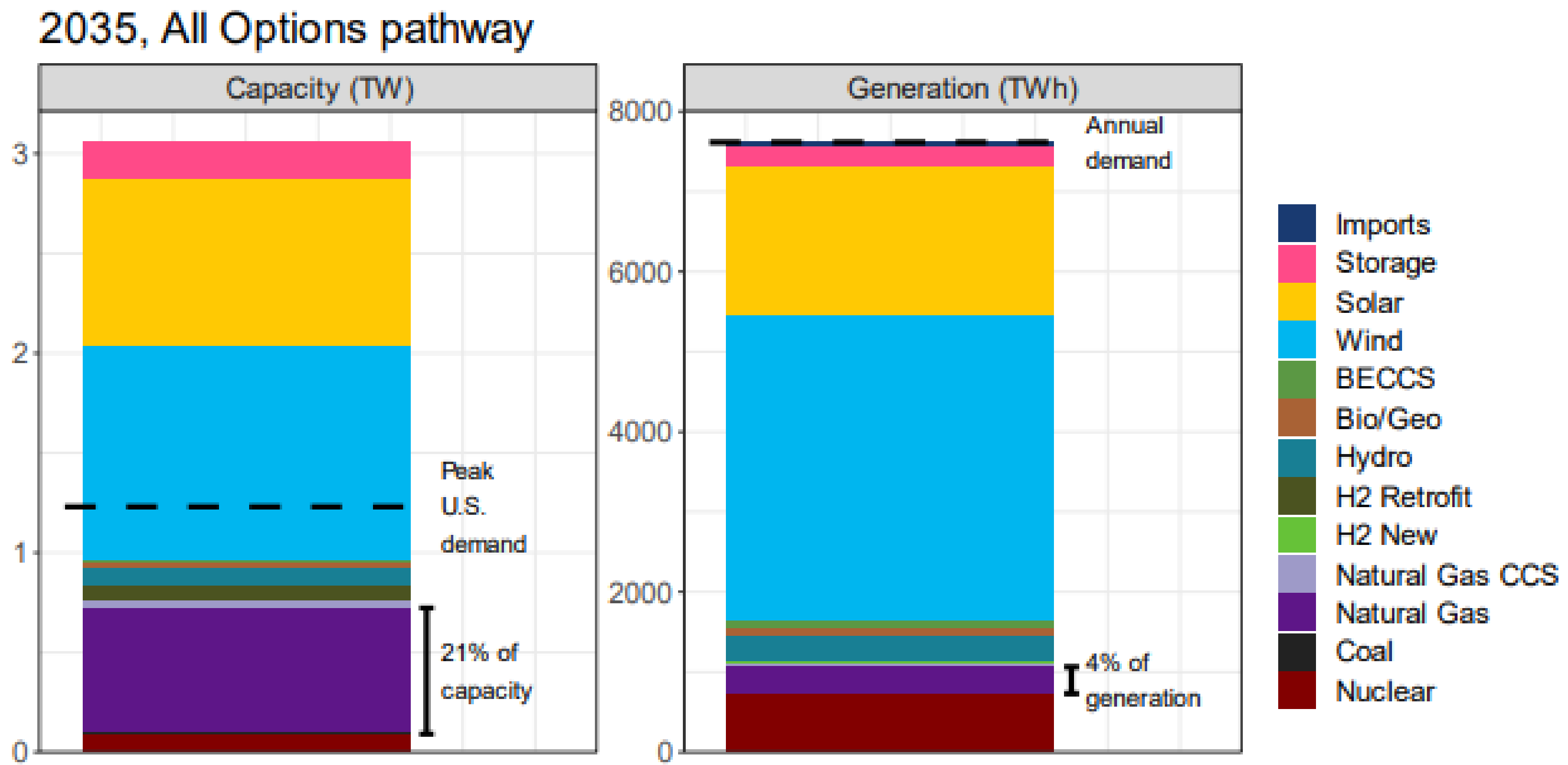


Figure 19. Energy and capacity in the 2035 All Options scenario (ADE demand case) show the significant dependence on remaining fossil-fueled capacity to provide peaking capacity and ensure resource adequacy during the clean energy transition.

Does electrification of the last 5% actually save GHG at extreme cold temps?

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Backup Heating Technology/ Backup Generation Case	Generation efficiency	Wire losses	Thermal Equipment Efficiency	Total efficiency	Total GHG emissions rate (pounds CO2e per MMBtu delivered heat)
Existing Furnace/ None	100%	0%	80%	80%	146
Electric Resistance / Combustion Turbine	40%	10%	100%	36%	324
Oversized Cold Climate Heat Pump / Combustion Turbine	40%	10%	~150%	54%	216
Electric Resistance / Magic Zero Emissions Combustion Turbine	40%	10%	100%	36%	0

Heat Pump COP of 2.0 or higher required for carbon savings when the marginal resource is fossil-fueled.

Grid and distributed solutions to extreme cold problem need further research.

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- **Seasonal hydropower.** Add extra turbine capacity to existing dams.
  - Pros: It works and it's not as expensive as some other options.
  - Cons: Still need lots of transmission capacity (which is not as expensive as generation)
- **New long-duration demand response.** Set buildings up to "hibernate" during extreme cold. Don't operate non-essential buildings during extreme events.
  - Pros: Inexpensive.
  - Cons: Requires buildings to be closed for multiple days.
- **Carbon sequestration.** Pull carbon from atmosphere or generation exhaust.
  - Pros: Works regardless of technology.
  - Cons: Expensive, not ready yet.
- **Renewable natural gas.** Use hydrogen production (that you can turn off during peak events). Or use
  - Pros: Can use some of existing infrastructure.
  - Cons: Expensive. Hard to store. Fuel conversion efficiency is terrible.

Extreme Cold Non-Electric Option 1: Existing Backup Gas Furnace

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- **Carbon emissions:** always have moderate emissions
- **Incremental Cost:** Low. Keep existing backup gas furance
- **Grid Impacts:** Near-zero. Electricity for blower.
- **Applicability:** All climates and locations
- **Customer ease:** Super easy. May experience cold supply temps from some heat pumps at moderately cold temperatures.
- **Research needs:** Better quantification of actual electric heat usage during extreme cold.

Extreme Cold Non-Electric Option 2: Deep Energy Retrofits and Extremely Efficient New Construction

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- **Carbon emissions:** If everybody does this, seasonal mismatch due to heating is reduced and grid gets greener, though heating load factor is terrible.
- **Incremental Cost:** Very high. 10s of thousands of dollars for existing homes. Much lower for new homes.
- **Grid Impacts:** Low. Electricity for blower.
- **Applicability:** All climates and locations
- **Customer ease:** Super easy. Always works, even when the power is out.
- **Research needs:** Lower cost retrofit methods.

Extreme Cold Non-Electric Option 3: Pellet stoves

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- **Carbon emissions:** always have low, but non-zero emissions.
- **Incremental Cost:** Low. About $3000-$5000 for a pellet stove, comparable to a new gas furnace.
- **Grid Impacts:** Near-zero. Electricity for blower.
- **Applicability:** All climates and locations
- **Customer ease:** Requires customers to load fuel hoppers and clean out ash. Does not distribute heat to entire home. May not be too difficult for 1 week/year.
- **Research needs:** Improved technology that make it easier for customer to run.

Conclusions/Recommendations

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- Electric Resistance Backup is Terrible – don't do it.
- Gas Furnace backups are cheap and OK for now.
- Cold climate heat pumps alone should be sufficient in more mild climates with well-built homes.
- Ground source heat pumps, deep energy retrofits, pellet stoves, and building hibernation all deserve more research.

Any Questions?

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