Design Approach and Performance Analysis of a Small Integrated Heat Pump (IHP) for Net Zero Energy Homes (ZEH)

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DOE/BT Strategic Goal – Net ZEH Technology Market Ready by 2020

Net Zero Energy Home (ZEH) Definition:

A home with greatly reduced energy use (60% to 70% less) through envelope and equipment efficiency improvements, with the balance of energy needs supplied by renewable technologies.

HVAC & Water Heating Program Supporting Goal:

Develop equipment that can reduce HVAC/WH energy use by 50% (from DOE Building America benchmark) in net ZEHs while providing indoor humidity control with no increase (or preferably a decrease) in net monthly costs for mortgage and utilities.

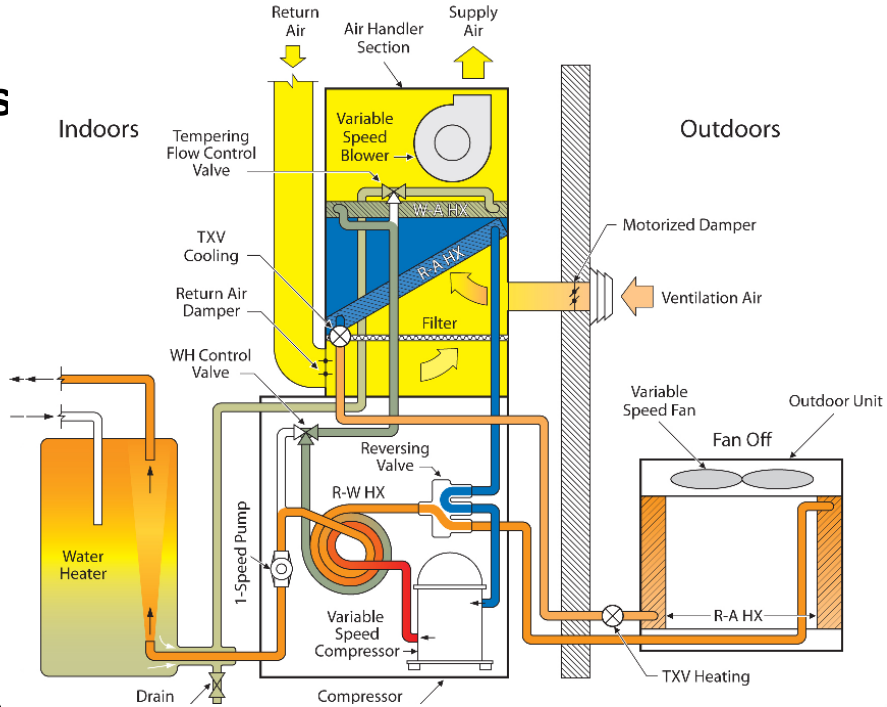
Scoping studies at ORNL identified integrated heat pump (IHP) as highest ranking concept

Focus of this presentation

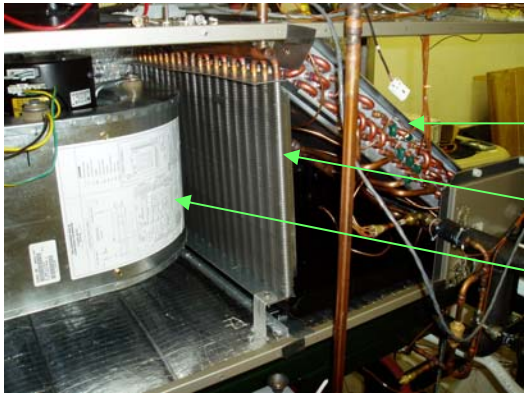
- Review design concept and analysis approach
- Compare components and performance of AS-IHP to previous U.S. IHP design
  - In four basic operation modes
- Summarize predicted energy savings relative to current minimum efficiency baseline
  - for both air- and ground-source IHP configurations
  - in five U.S. climates
  - for 1800 ft^2 (167 $m^{2)}$ ZEH

AS-IHP Concept

- **Full integration to space condition, heat water, dehumidify, and ventilate as needed using a single VS compressor**
- **Concept shown at right →**
  - multiple possible modes
  - **Space H or C / w ventilation**
  - **Dedicated water heating or heat recovery**
  - **Dedicated dehumidification w or w/o WH**
  - **Ventilation air only w or w/o conditioning**
- **Lab prototype constructed and tested**



Possible AS-IHP packaging approach



Lab prototype air handler

ref/air HX

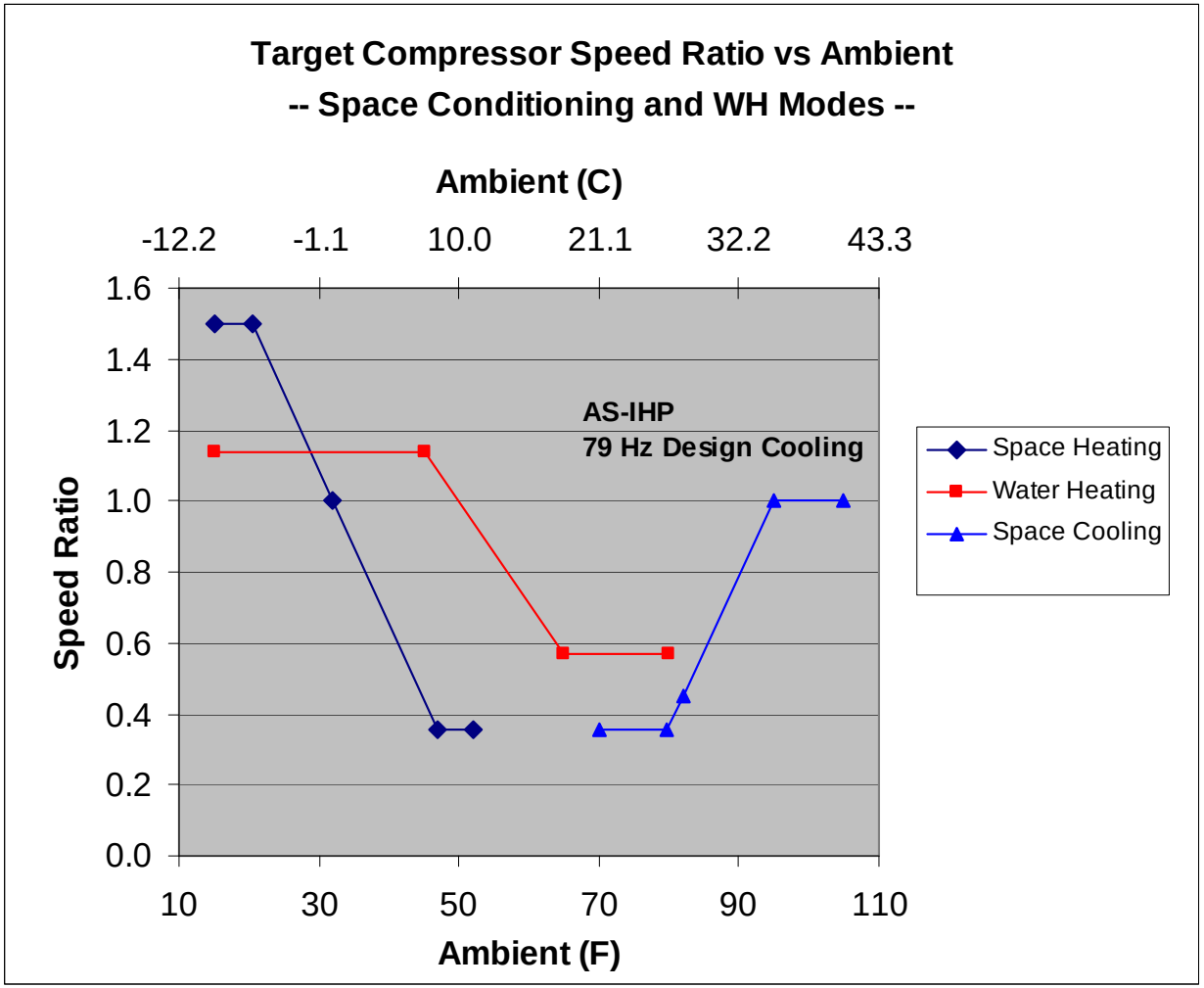
water/air HX

blower

IHP – System Simulation/Design Approach

- Lab test data used to calibrate hardware-based variable-speed equipment model
  - DOE/ORNL Heat Pump Design Model (HPDM)
    - Including new fluted tube-in-tube model for w-to-r HX
- Calibrated HPDM used for design optimization and control assessments
  - Established target compressor and fan speed ranges for major operation modes as functions of ambient
    - initially for lab prototype system components (R-22 based)
    - later re-optimized design and speed/control relationships for VS R-410A system
    - control approach is to vary fan speeds and condenser subcooling as a function of compressor speed
    - details provided in referenced ORNL reports

AS-IHP, Target Compressor Speed Ranges

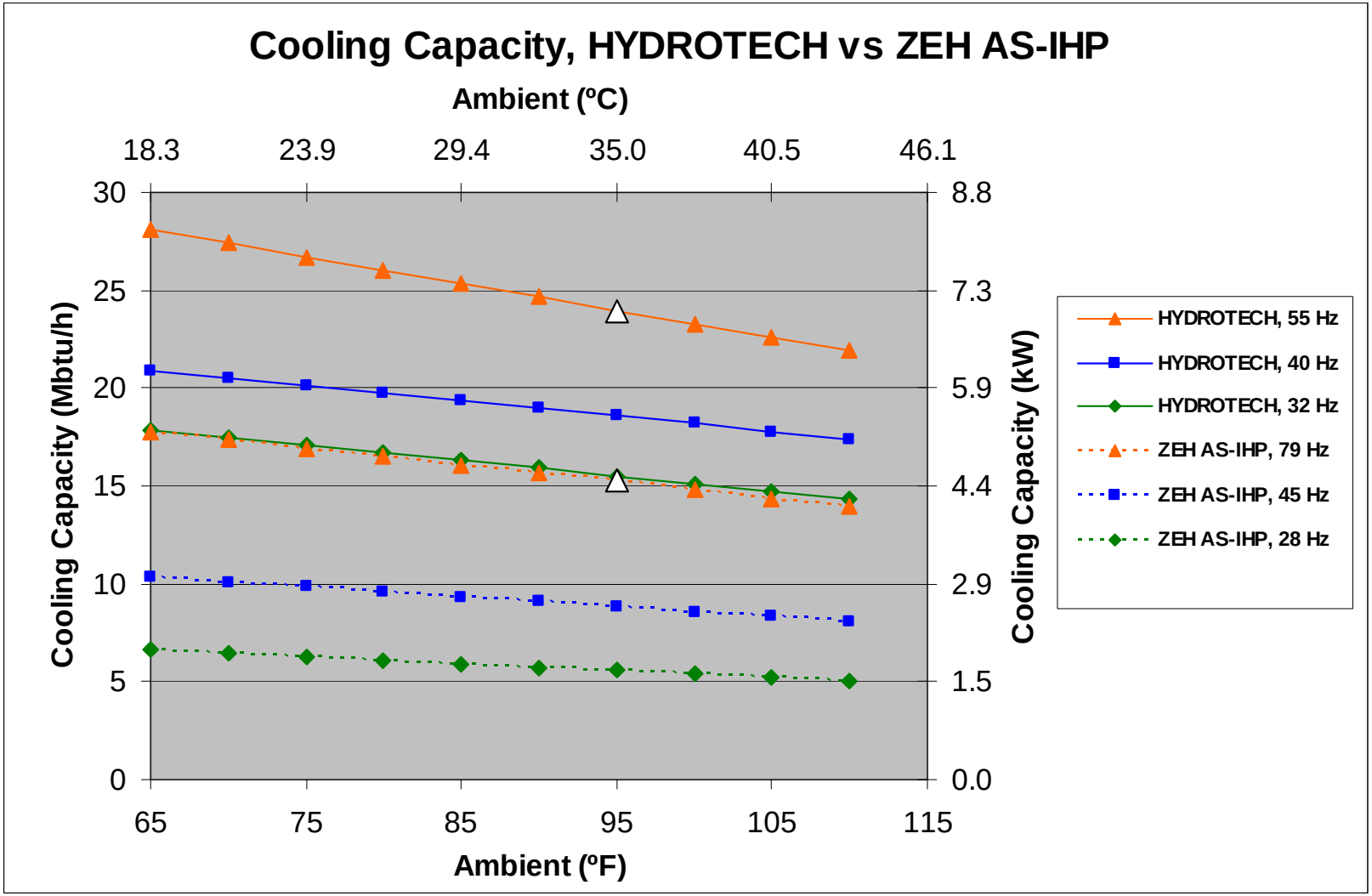


Comparison to Previous U.S. IHP Product

- **Carrier/EPRI HYDROTECH 2000**
  - Circa 1990
  - VS reciprocating compressor and indoor blower (BPM motors)
  - 2-ton (7kW) cooling design
    - 32 to 73 rps max compressor speed
  - R-22 refrigerant
  - Dedicated water heating and partial heat recovery modes

- **Proposed IHP design**
  - VS rotary compressor and both fans (BPM motors)
    - mass-produced multi-split compressor (28 to 118 rps max speed)
  - Smaller 1.25-ton (4.4 kW) cooling design
  - R-410A refrigerant
  - Dedicated water heating and full heat recovery modes

Space Cooling, Capacity Comparisons



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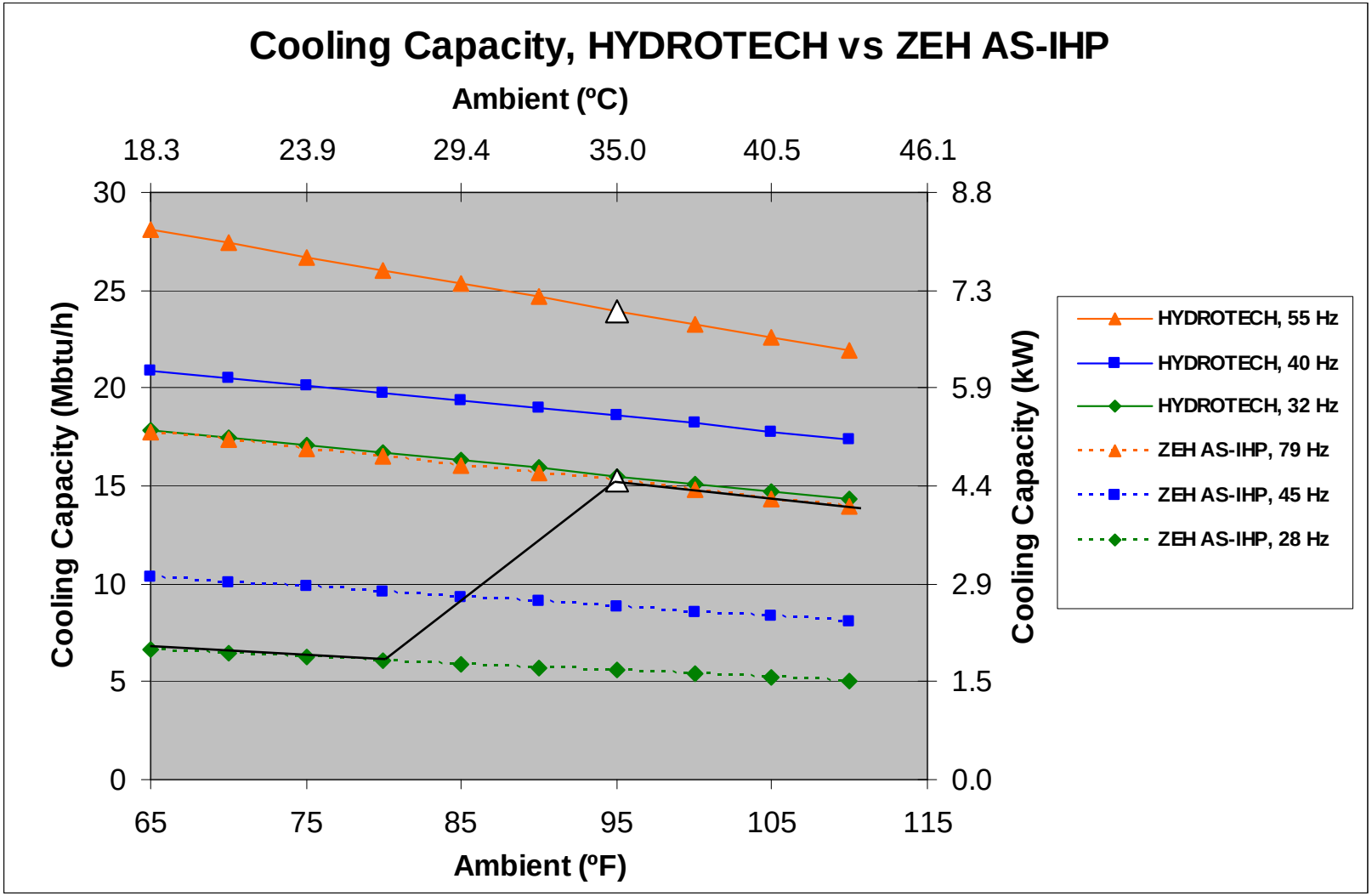
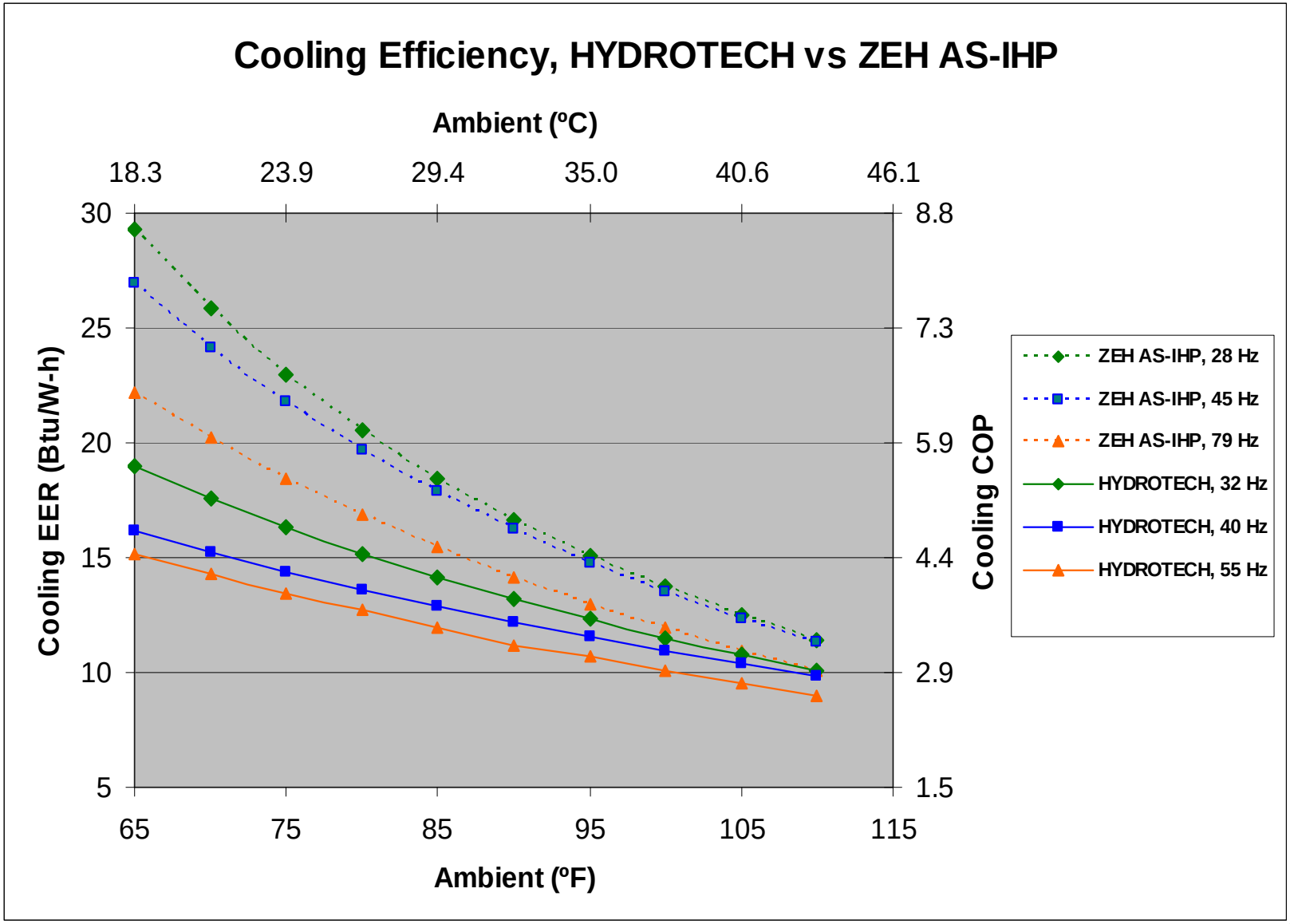


Space Cooling, Efficiency Comparisons



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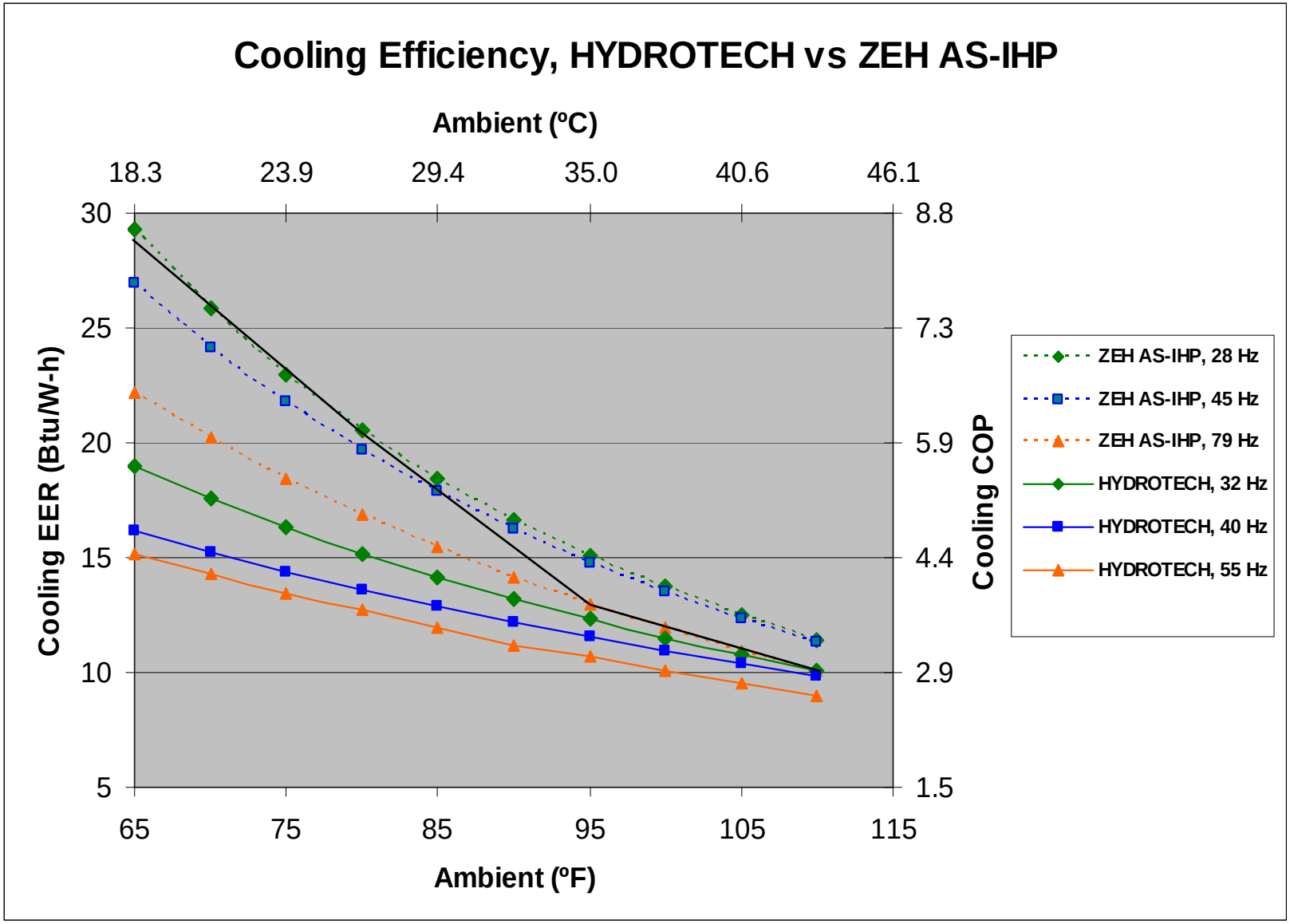

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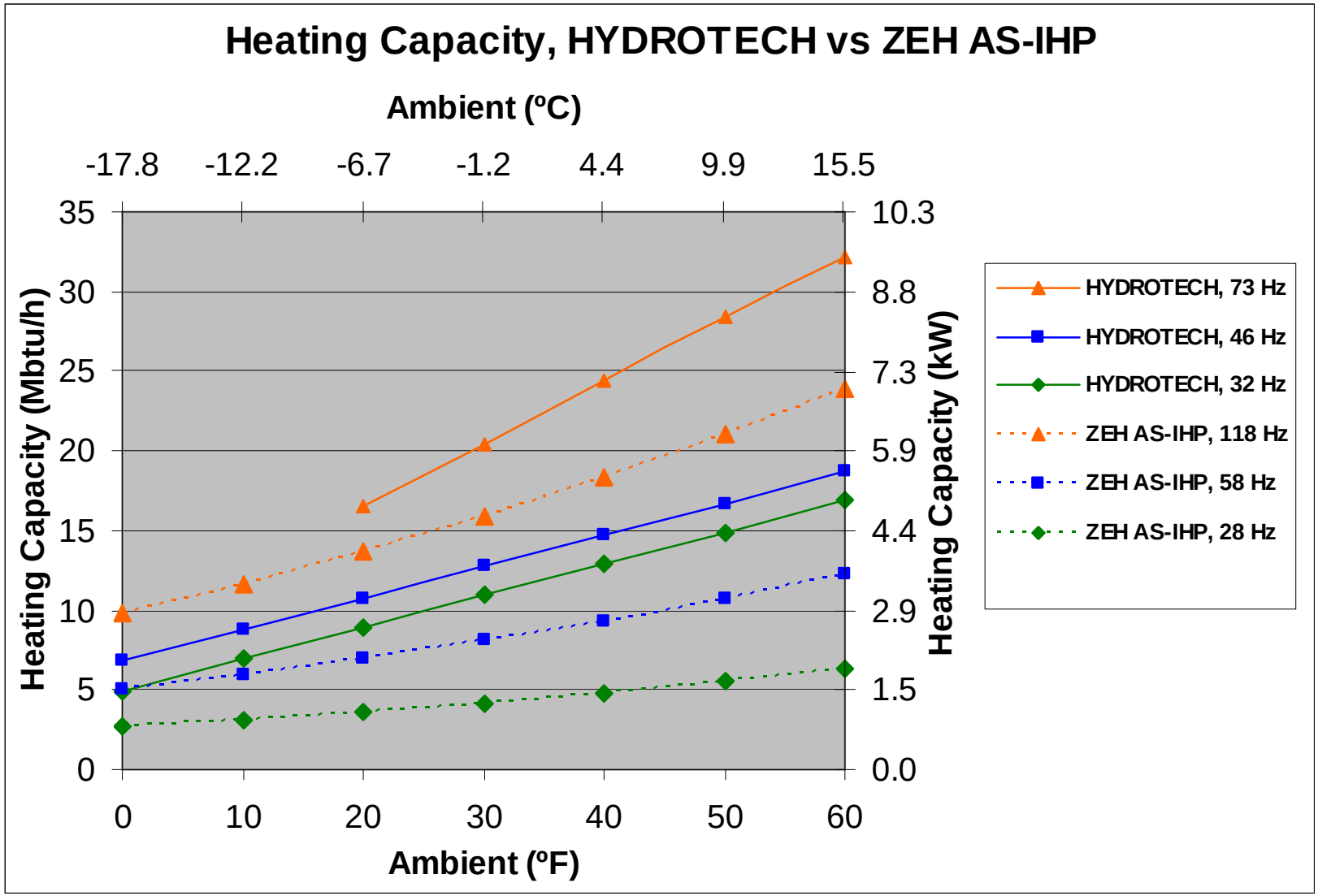

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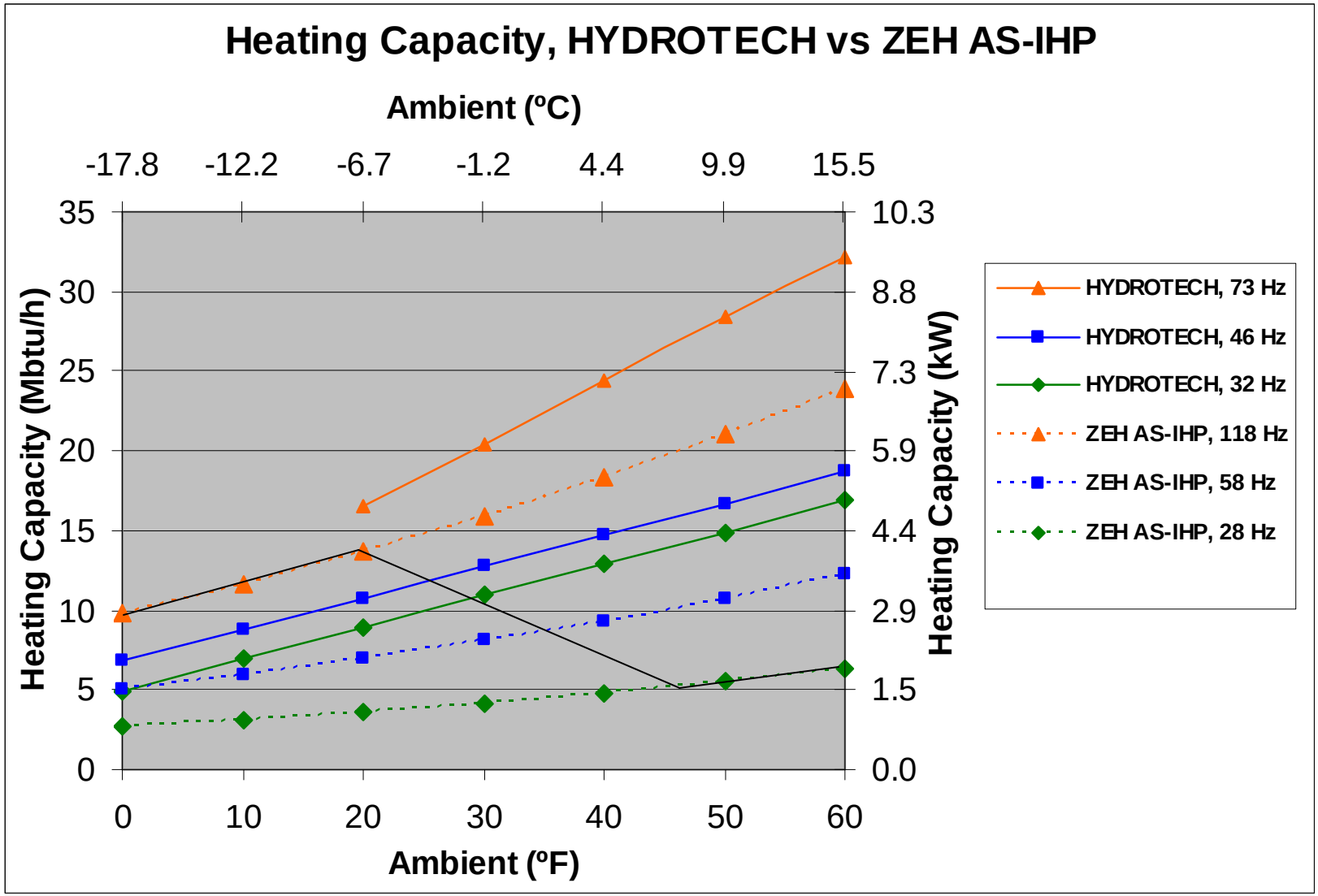

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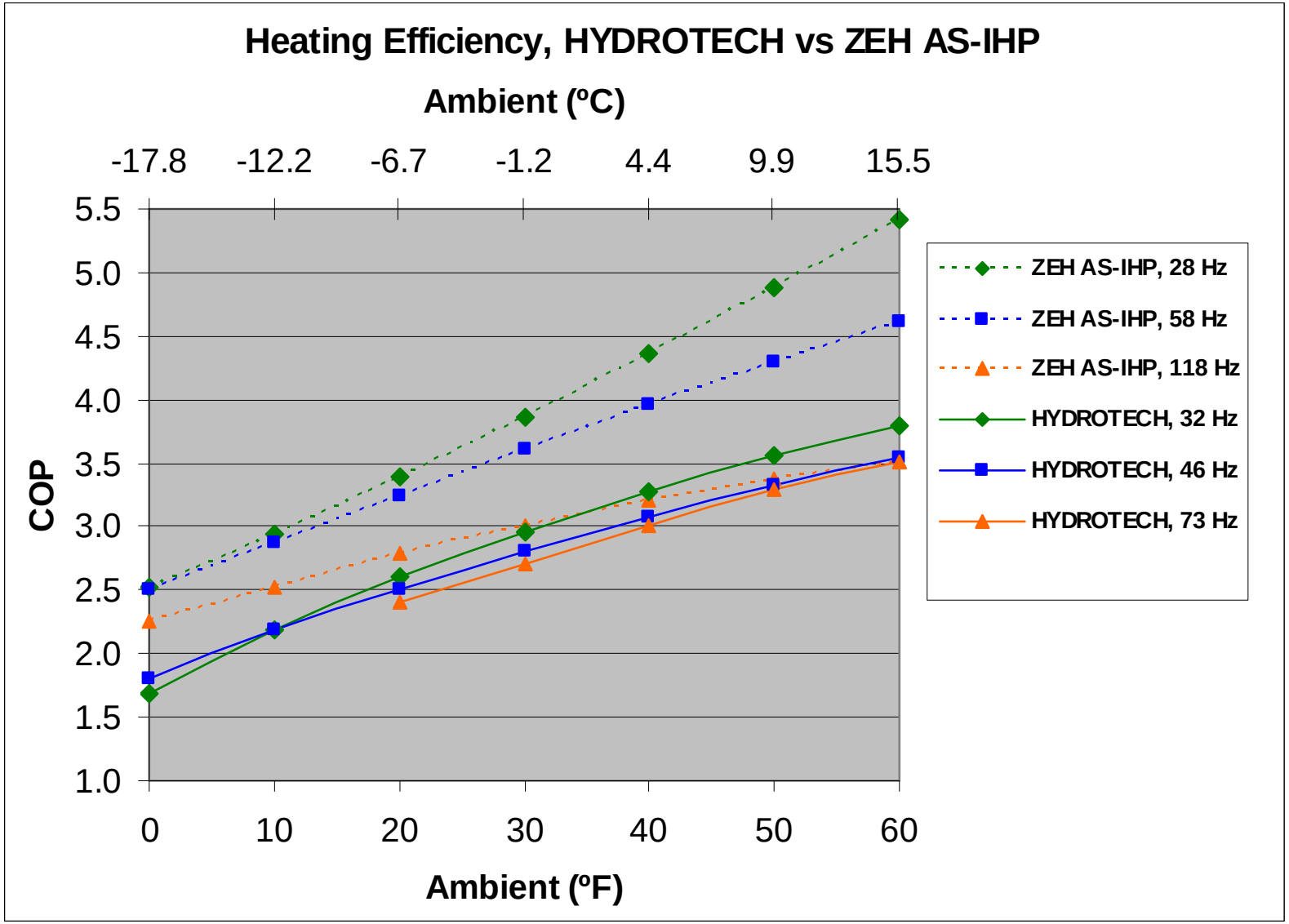

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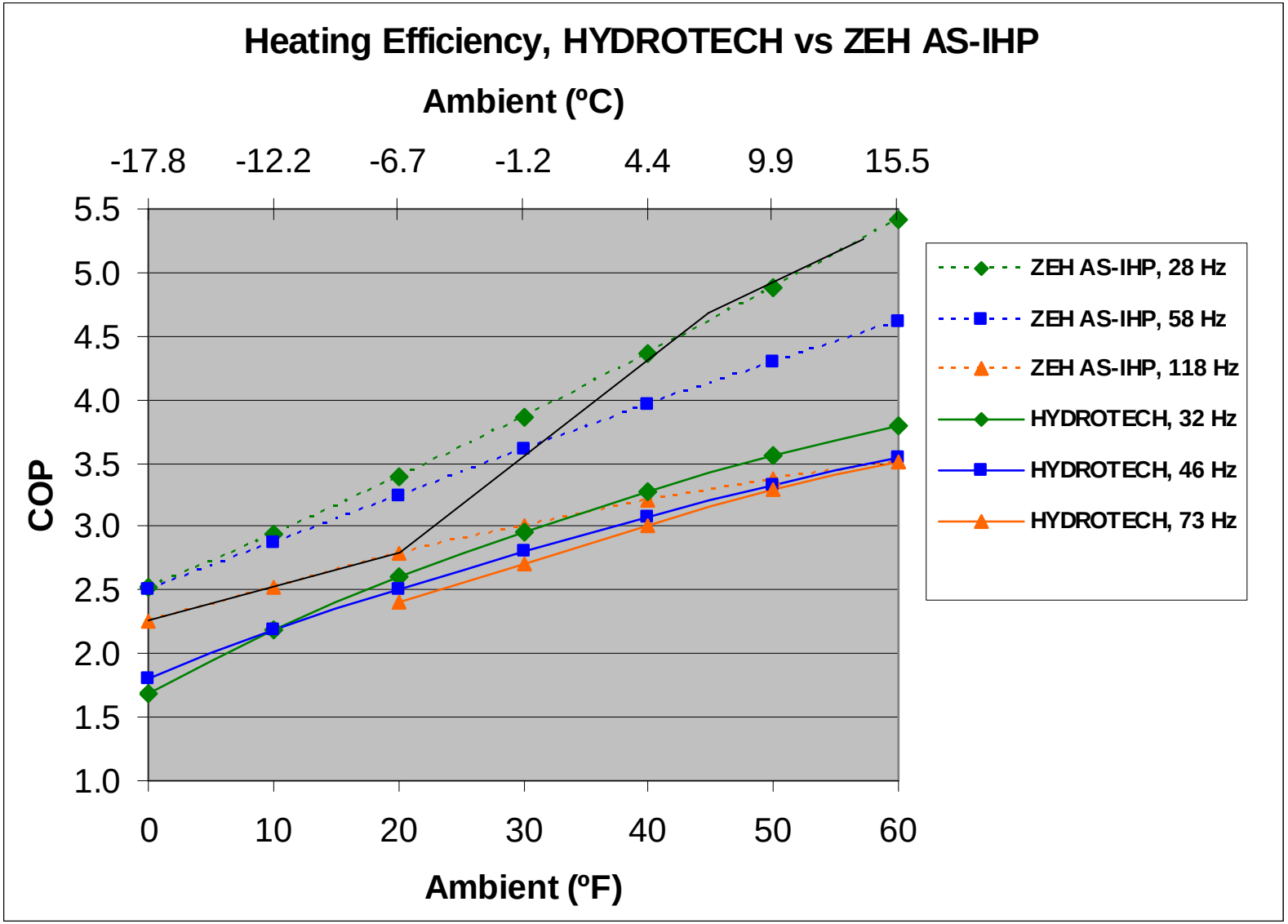
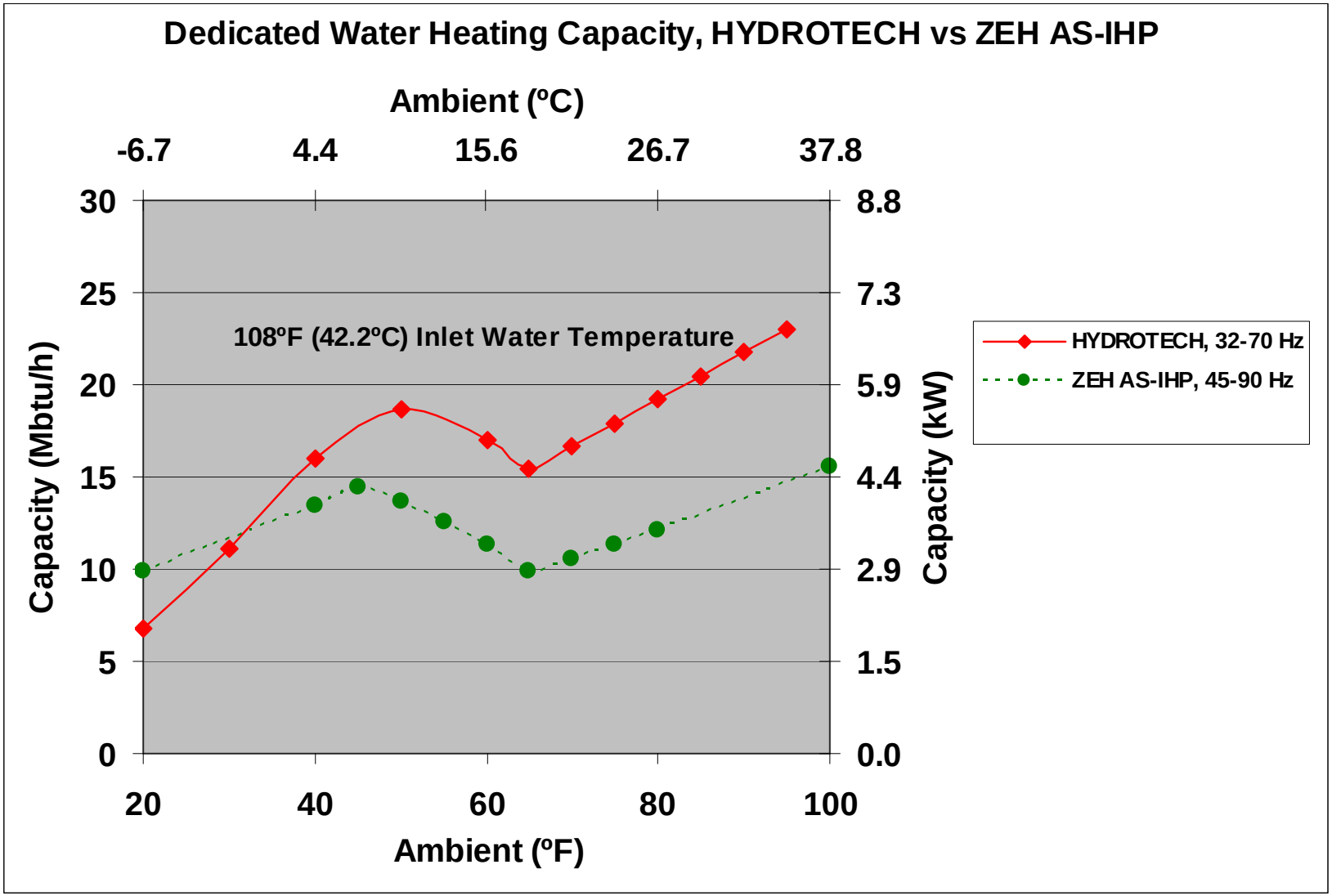


Dedicated Water Heating, Capacity Comparisons



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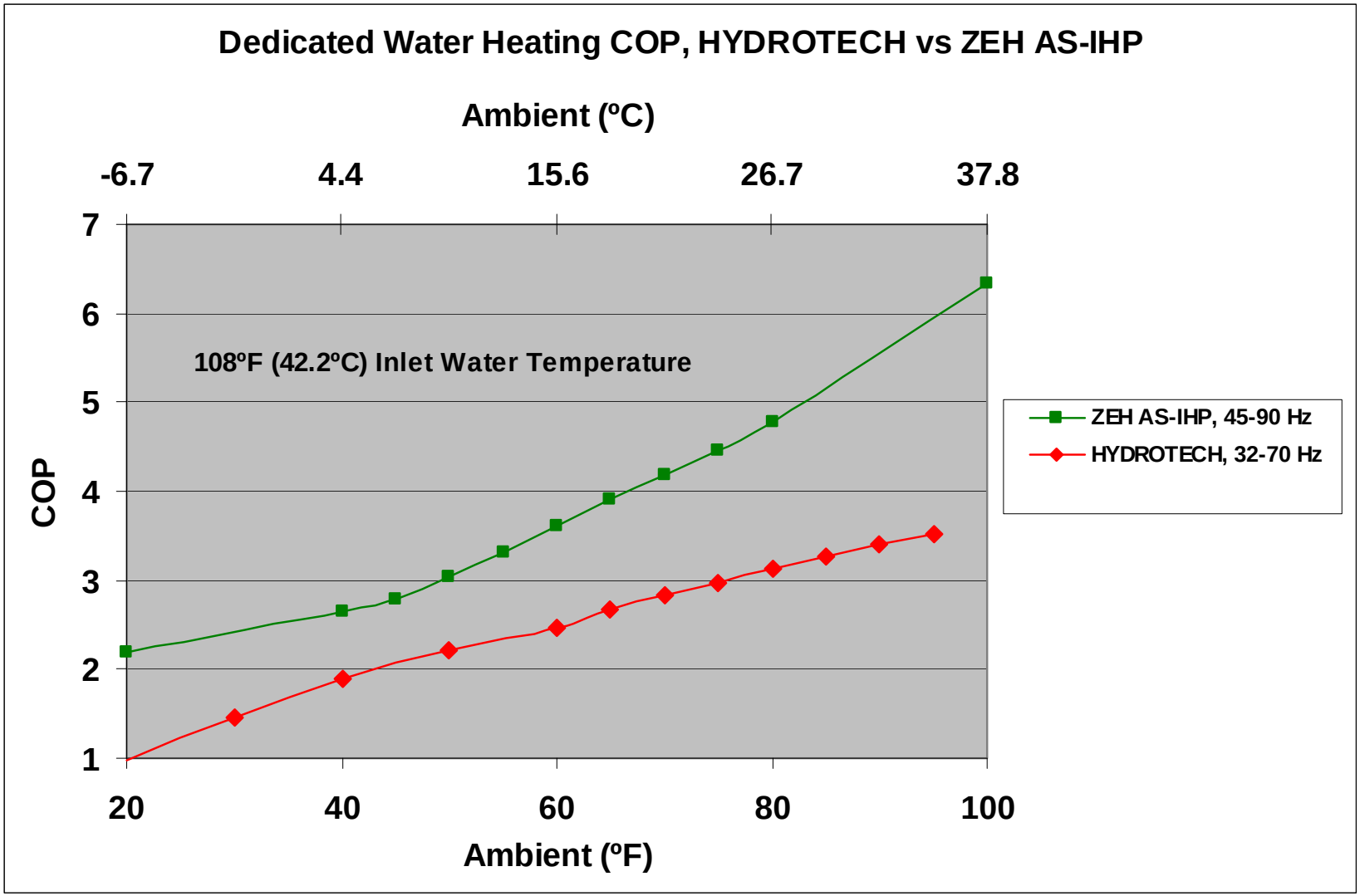
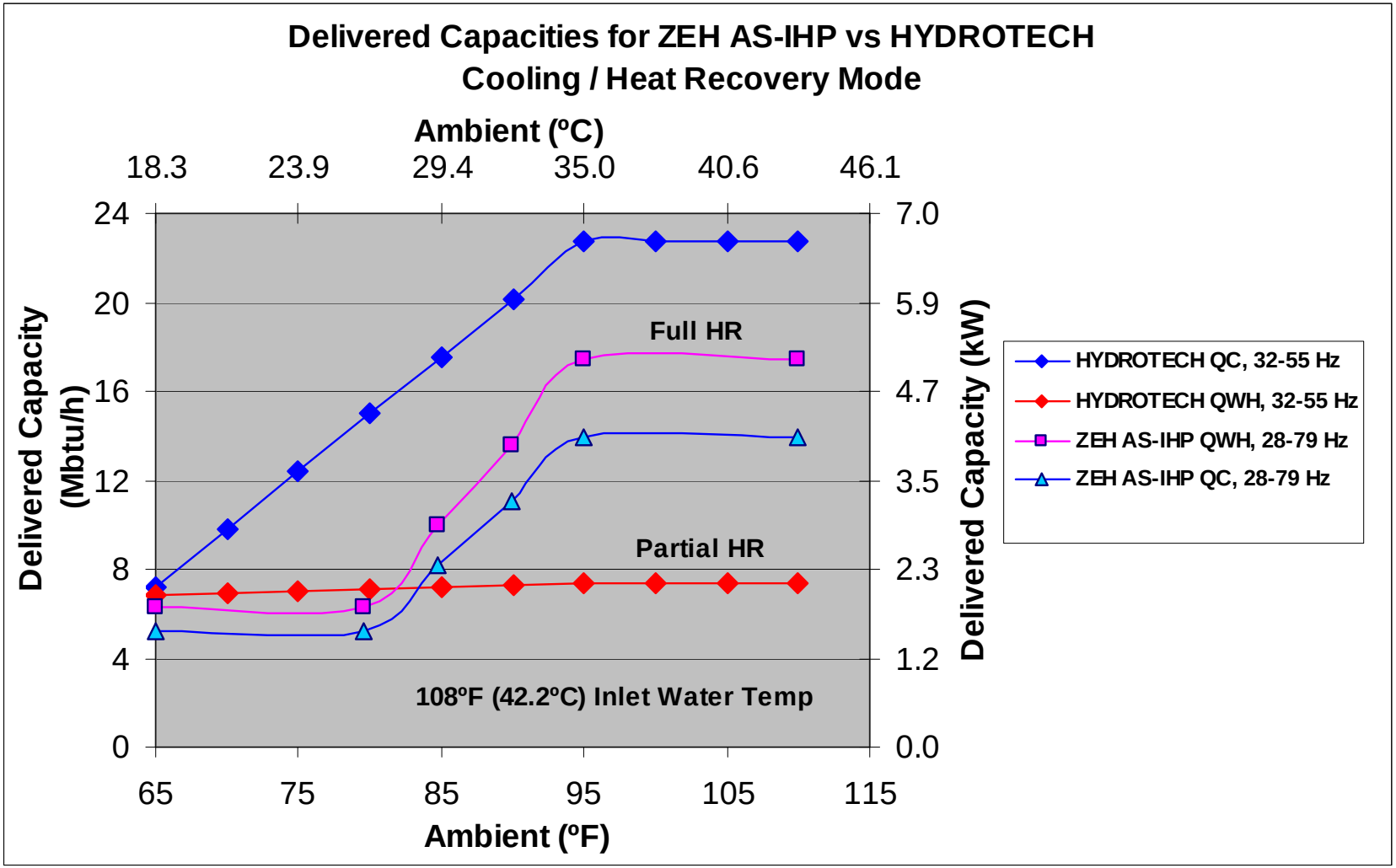


Combined SC & HR, Capacity Comparisons



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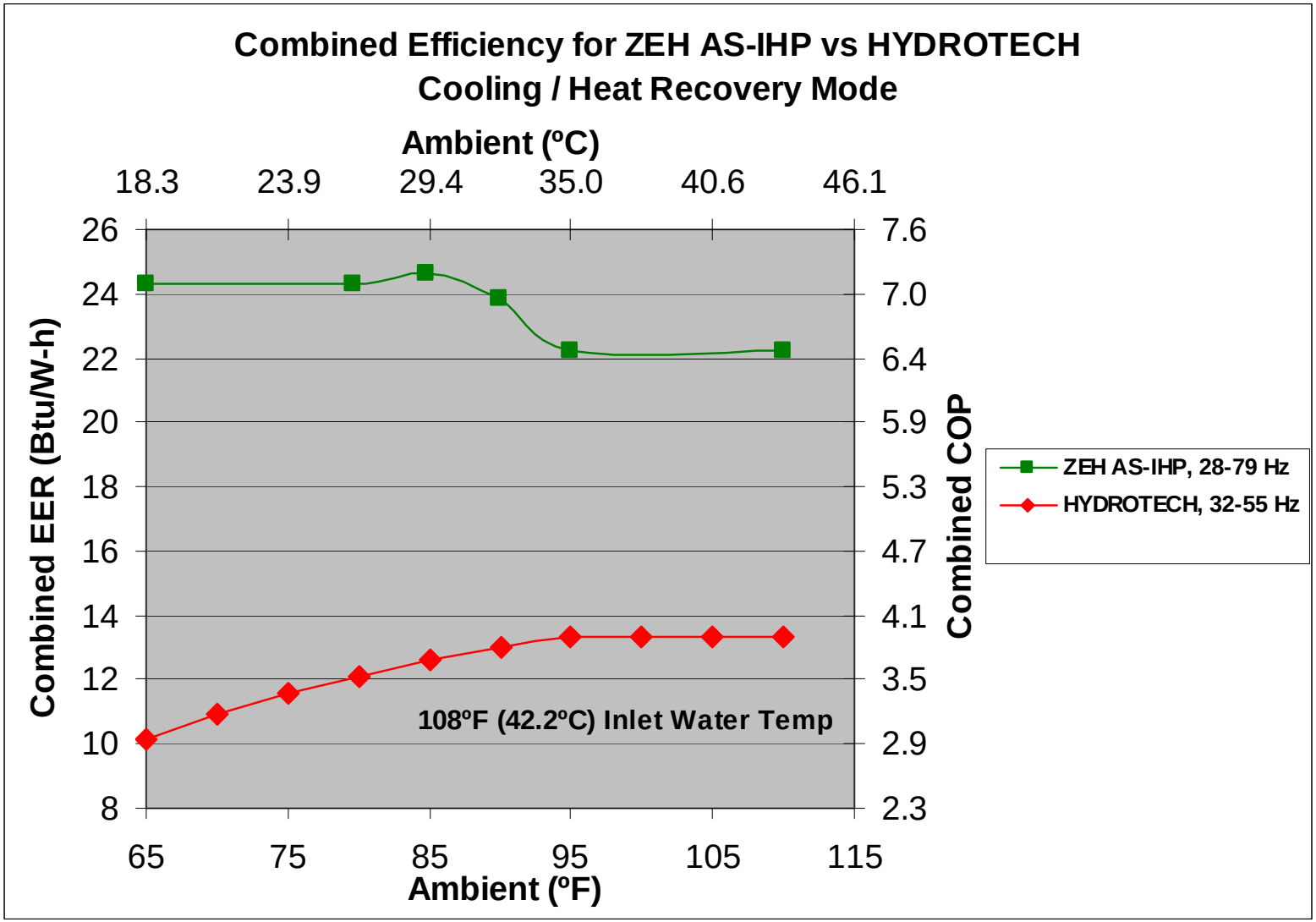


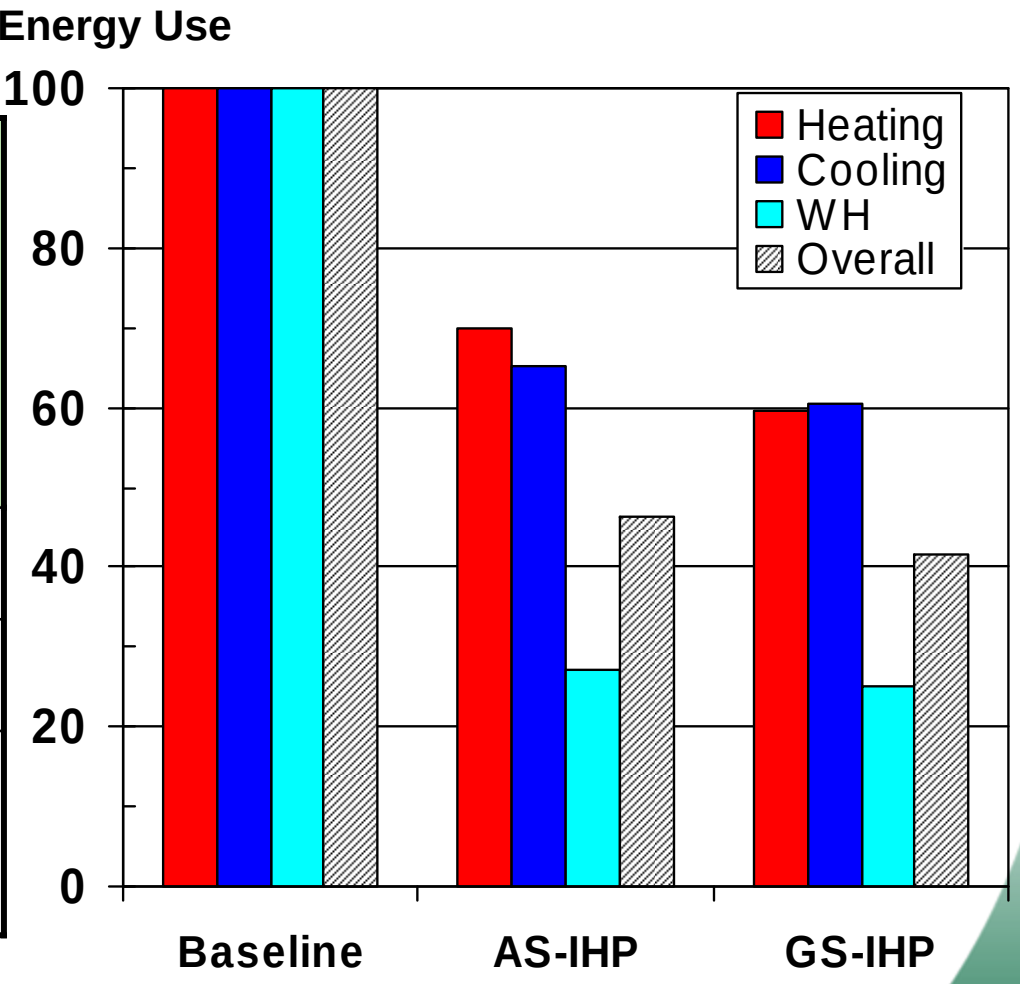
IHP – Seasonal Performance Analysis

- Calibrated HPDM linked to TRNSYS simulation engine
  - Enabled sub-hourly analysis of IHP annual performance
    - using optimized R-410A based design
    - simulated multiple modes of operation per t-stat calls
    - linked with domestic water tank for inlet water temp history
- Later used offline-HPDM-generated modal performance maps
  - With multi-parameter interpolation
  - Faster more robust approach than direct call
- Baseline system – individual systems to deliver same energy services
  - air-source heat pump + electric storage water heater + stand alone dehumidifier + whole-house ventilation system
  - current or proposed minimum efficiency levels
- Predicted performance on following slides

IHP – Performance Comparison in 167m² NZEH in Atlanta, GA

Efficiency Equivalent

	Baseline (air/air heat pump + electric resistance water heater)	AS-IHP	GS-IHP
HSPF (W/W)	2.67	3.82	4.48
CSPF (W/W)	3.49	5.34	5.76
WH Energy Factor (W/W)	0.89	3.30	3.57



Base system – Rated SEER/HSPF/EF – 13/7.7/0.90

IHP – Unit Sizing and Energy Savings Predictions for 1800 ft² (167 m²) ZEH in 5 U.S Locations

Location	Heat Pump Cooling Capacity Tons (kW)	% Energy Savings Versus Baseline HP w Electric WH	
		AS-IHP	GS-IHP
Atlanta	1.25 (4.4)	53.7	58.4
Houston	1.25 (4.4)	53.7	55.4
Phoenix	1.5 (5.3)	48.4	55.4
San Francisco	1.0 (3.5)	67.2	65.8
Chicago	1.25 (4.4)	45.6	52.4

IHP – Conclusions

- **Somewhat higher system efficiency possible with present VS technology applied to smaller capacity designs**
  - relative to previous U.S. product in early 90's
- **IHP system simulations show significant energy savings compared to current baseline equipment system for ZEH application over a range of US climate types**
  - AS-IHP: Meeting target savings except in hot/dry or cold climates
  - GS-IHP: Above 52% target savings in all 5 climates
- **Findings suggest areas to improve some aspects of ZEH AS-IHP performance**
  - cooling performance in hot/dry climates
  - combined space conditioning and water heating
    - by simultaneous use of both available condensers
      - especially in colder climates

- **Questions or Comments?**