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Refrigerant-Free Heat Pump Water Heaters

Using Solid-State Energy Converters

Presented at the 2019 ACEEE Hot Water Forum

March 13, 2019

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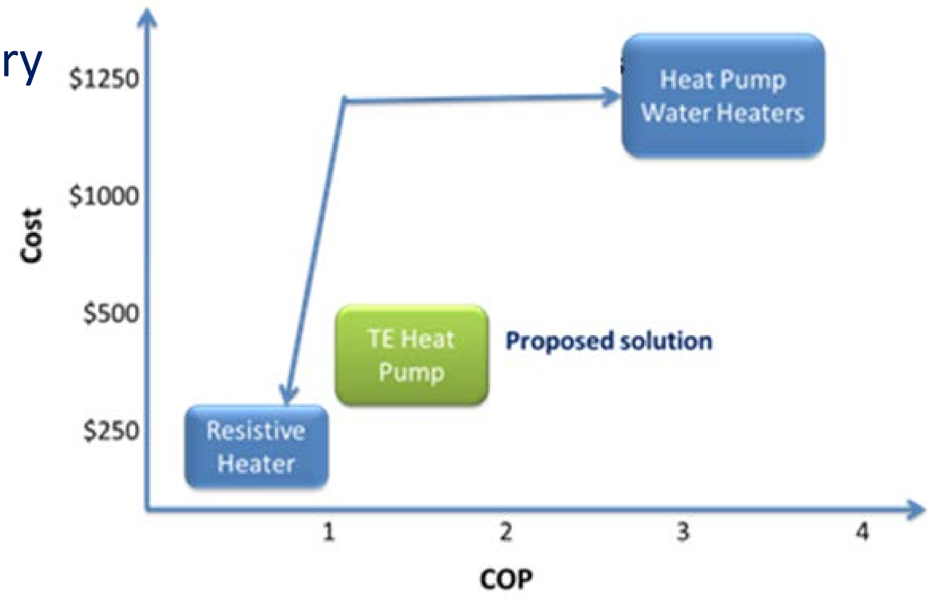
Purpose

Residential Water Heaters

- 15% of energy consumption. 45% are electric heaters: ~ 1.34 Quads of primary energy
- $300- $700 per year energy cost
- Vapor compression based heat pump water heater are very expensive, and limiting in modularity and flexibility



Source: DOE/EIA

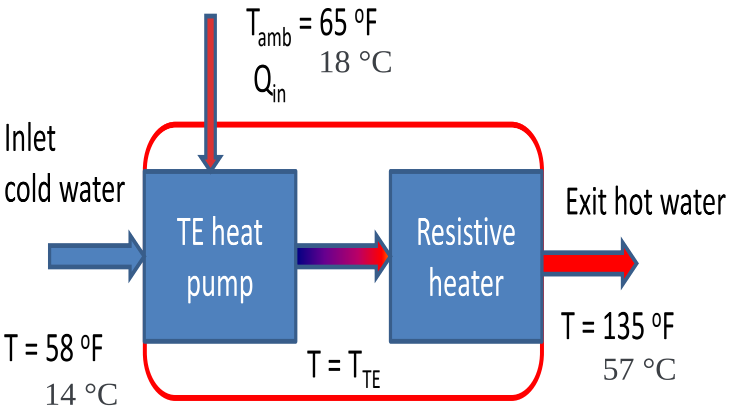
Background

- DOE Program: DE-SC0009231/ Program Manager: Antonio Bouza
- Goal: Demonstrate a home water heater product with affordable and reliable solid-state heat pumps with COP > 1.1 The project includes development of high cooling power thermoelectric modules as well as development of bottom-mount 4-engine and 8-engine heat pumps.

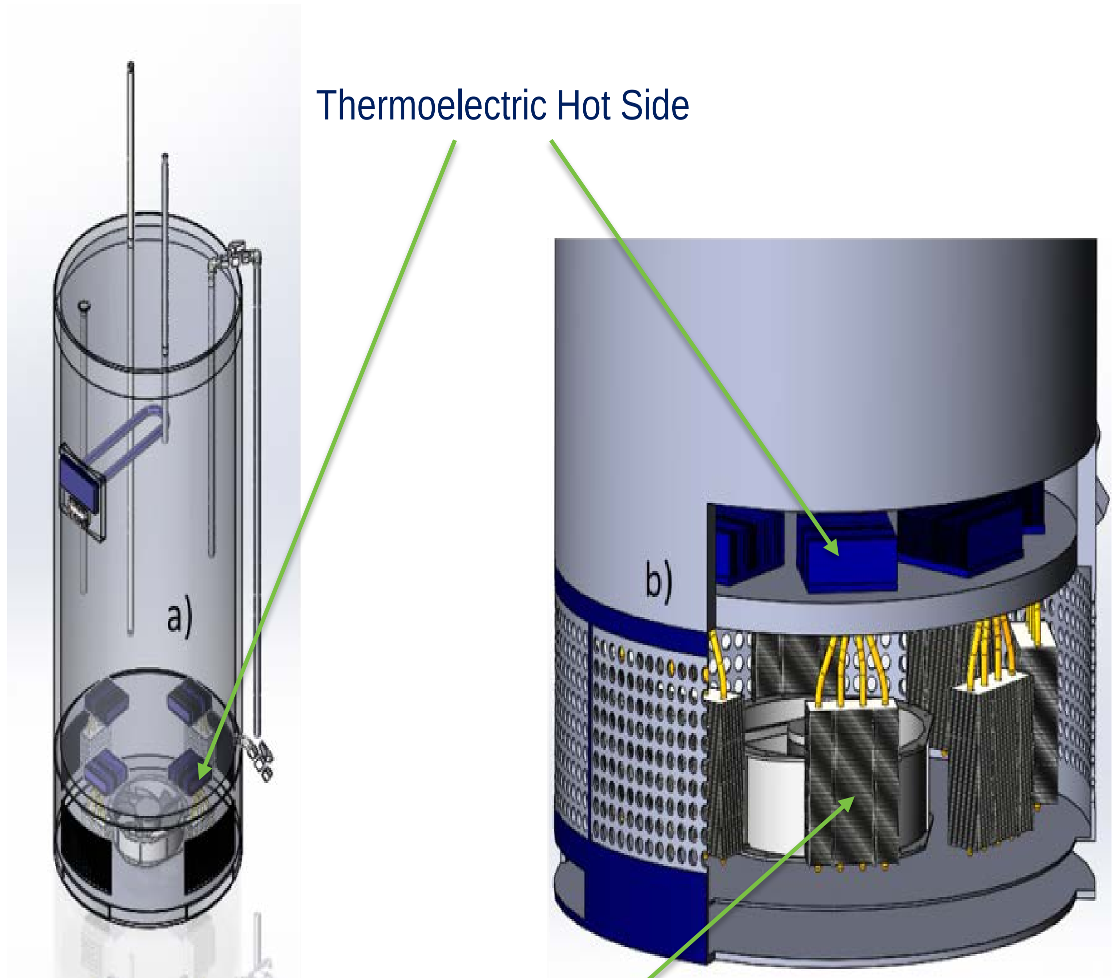
Technical Milestones:

- High Cooling Power Thermoelectric Modules for Heat Pumps
- Bottom Mount 4-Engine Thermoelectric Heat Pump (COP>1.1)
- Plug-In Heat Pump Water Heater (COP>1.5)
- Next Generation Solid State Water Heater (COP>2)

Original TE Heat Pump Water Heater Concept

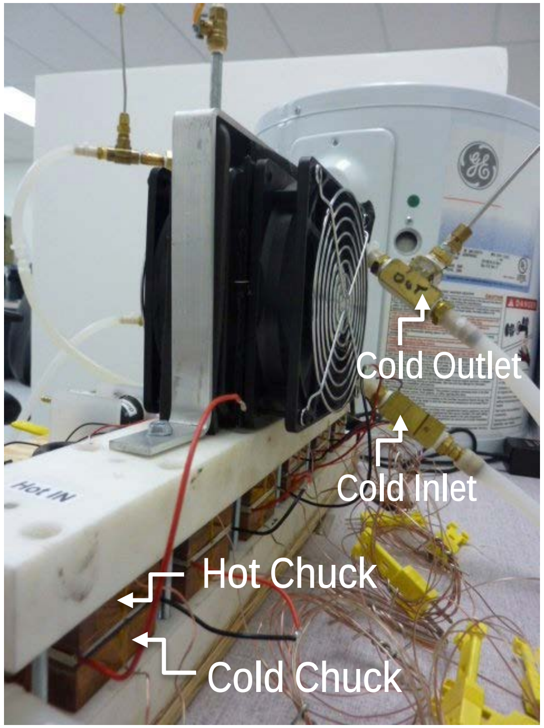


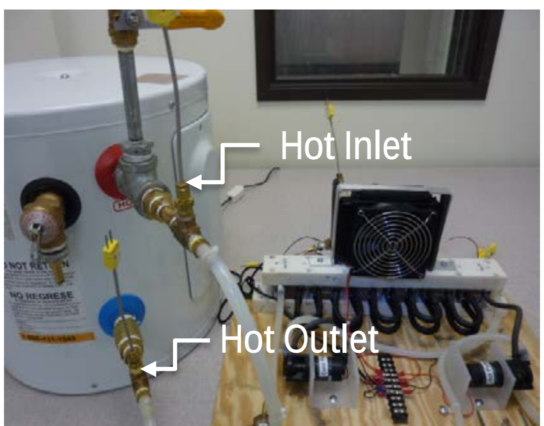
Thermoelectric Hot Side

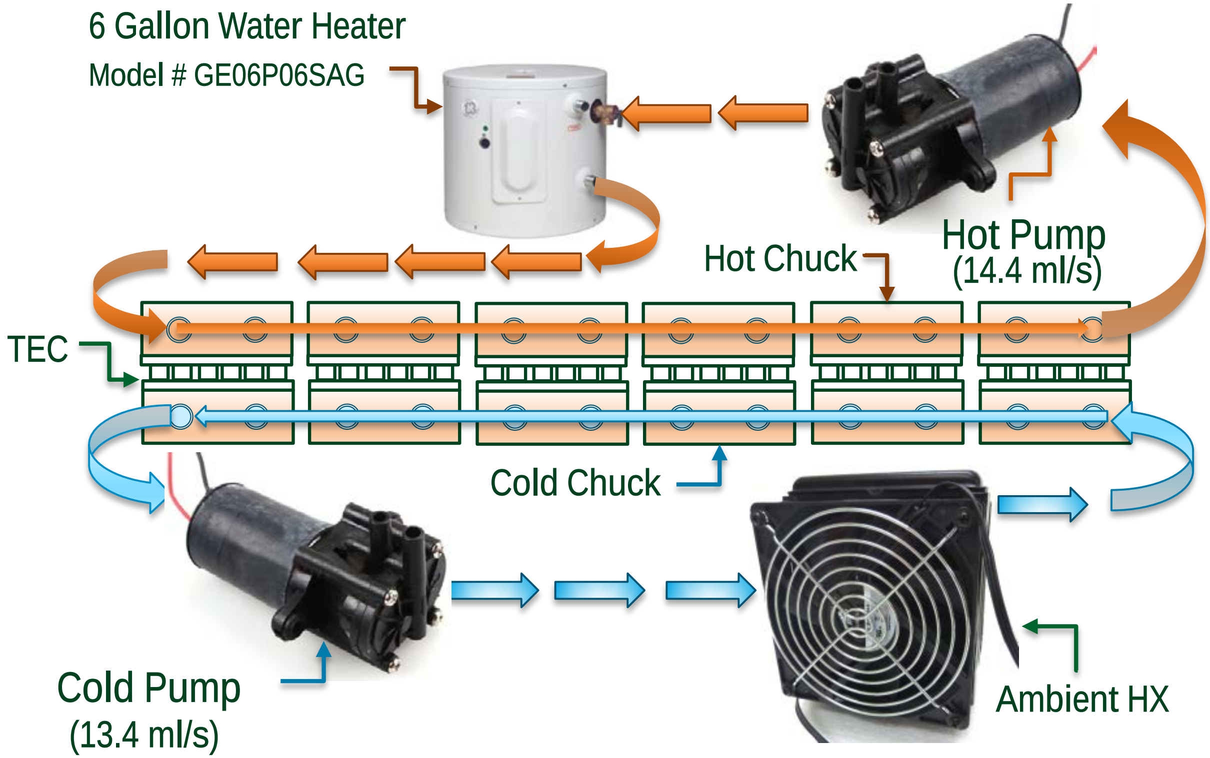


Thermoelectric Cold Side (Heat-Pipe Heat Sink)

Plug-In TE Heat Pump Water Heater







- Modular, scalable, and compatible
- Addresses needs for capacities 0-100 gallons
- Self controlled loops
- High COP

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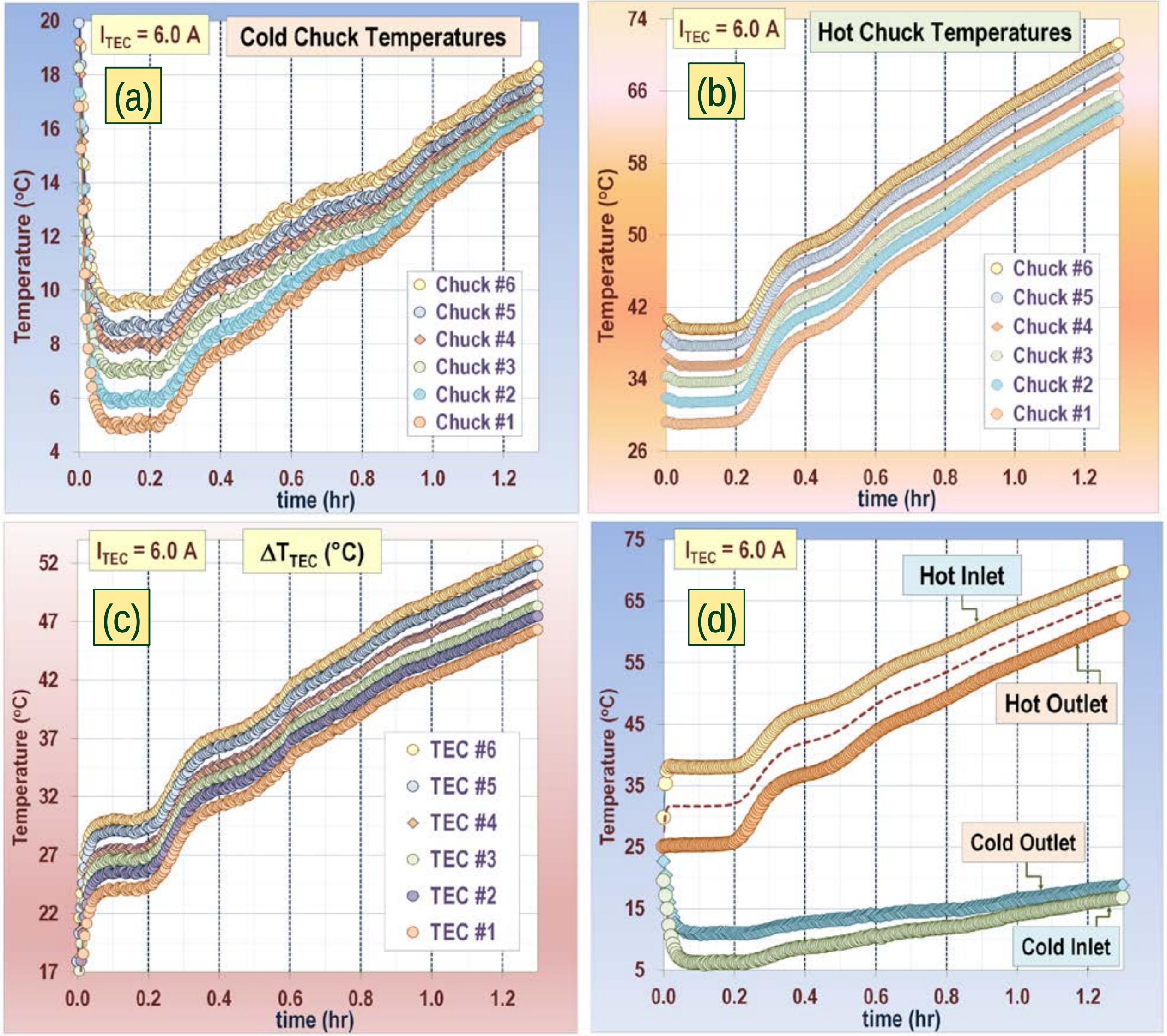
Water Heater Operation for I_{TEC} = 6A

Fig. (a) Difference between the 6 Cold Chuck temperatures decreases for t > 1 hrs.

Fig. (b) Hot Chuck temperatures (for t < 0.2 hours, the thermocline in the container prevent hot temperatures from rising)

Fig. (c) Heat pumping decreases as ΔT_{TEC} increases (@ t = 1.3 hrs ΔT_{TEC} ~ 46°C - 53°C

Fig. (d) Decrease in heat pumping is indicated as $(T_{cold\text{-}outlet} - T_{cold\text{-}inlet}) \rightarrow 0$ Average $(T_{hot\text{-}inlet}, T_{hot\text{-}outlet})$ is indicated by the dotted line.



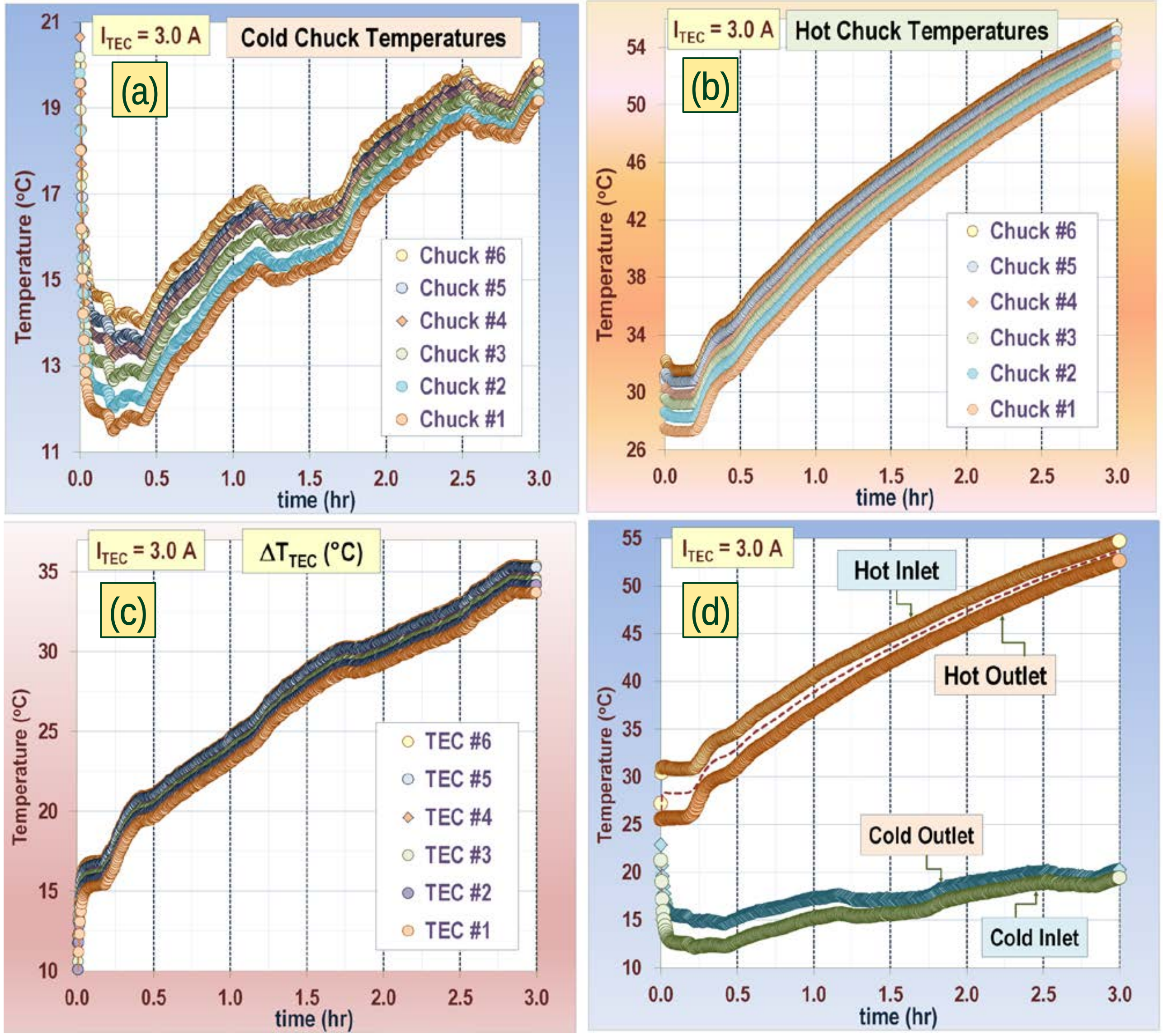
Water Heater Operation for I_{TEC} = 3A

Fig. (a) Difference between the 6 Cold Chuck temperatures decreases for t > 1.5 hrs.

Fig. (b) Hot Chuck temperatures are closer to each other as compared to I_{TEC} = 6A

Fig. (c) Heat pumping → 0 $\Delta T_{TEC} \rightarrow \Delta T_{max}$ (I = 3A). After 3 hours, ΔT_{TEC} ~ 36°C - 38°C.

Fig. (d) Decrease in heat pumping is indicated as $(T_{cold\text{-}outlet} - T_{cold\text{-}inlet}) \rightarrow$ **0** Average $(T_{hold\text{-}inlet}, T_{hot\text{-}outlet})$ is indicated by the dotted line. $(T_{hot\text{-}inlet} - T_{hot\text{-}outlet})$ ~ 2°C for t > 2.5 hrs



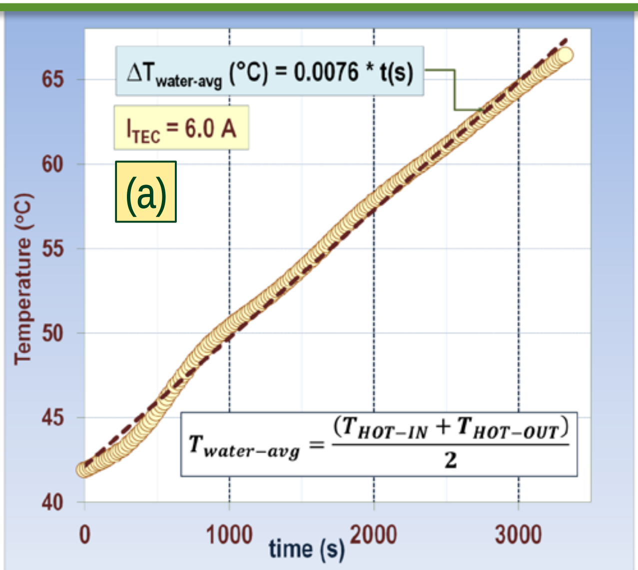
Measured Coefficient of Performance (COP)

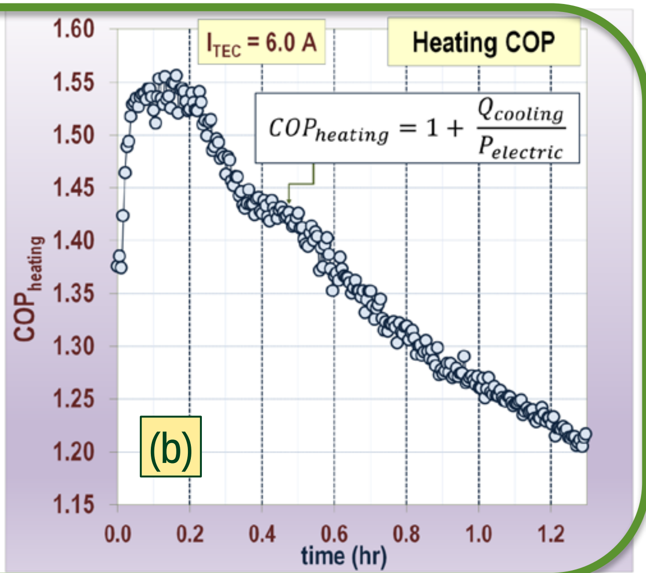
I_{TEC} = 6A

Fig. (a) COP based on the rate of rise of average hot water temperature

m (kg)	δΔT/δt	$Q_{heating}$ (W)	$P_{electric}$ (W)	COP
22.0	0.0076	702	521	1.3

Corroborated with COP estimated from $Q_{cooling}$ in Fig. (b).





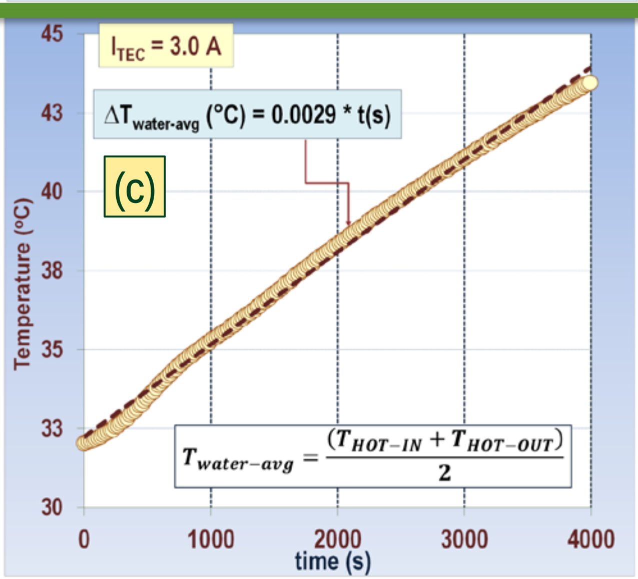
I_{TEC} = 3A

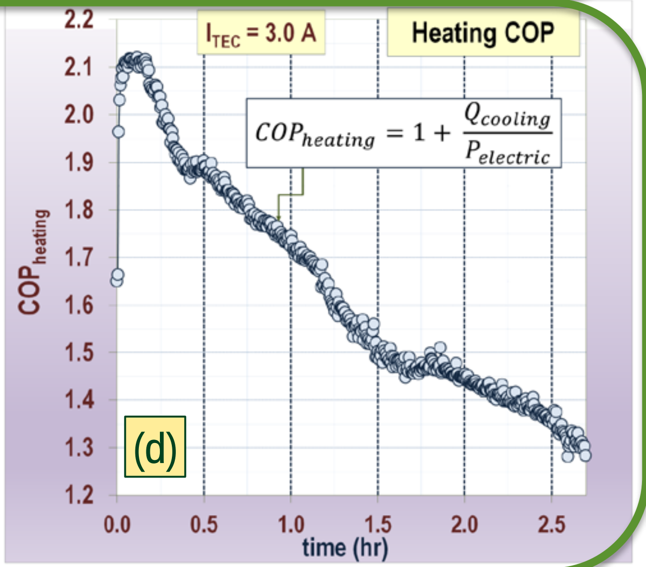
Fig. (c) COP estimated from the rate of rise of average hot water Temperature

m (kg)	δΔT/δt	$Q_{heating}$ (W)	$P_{electric}$ (W)	COP
22.0	0.0029	268	159	1.7

Corroborated with Fig. (d) - COP estimated from $Q_{cooling}$

$$P_{Fan} + P_{pump} = 26.8W$$





$$Q_{cooling} = m_c C_p (T_{OUT} - T_{In})_{Cold} \quad P_{electric} = I_{TEC} V_{TEC} + P_{Fan} + P_{pump}$$

New Generation Solid State Water Heater

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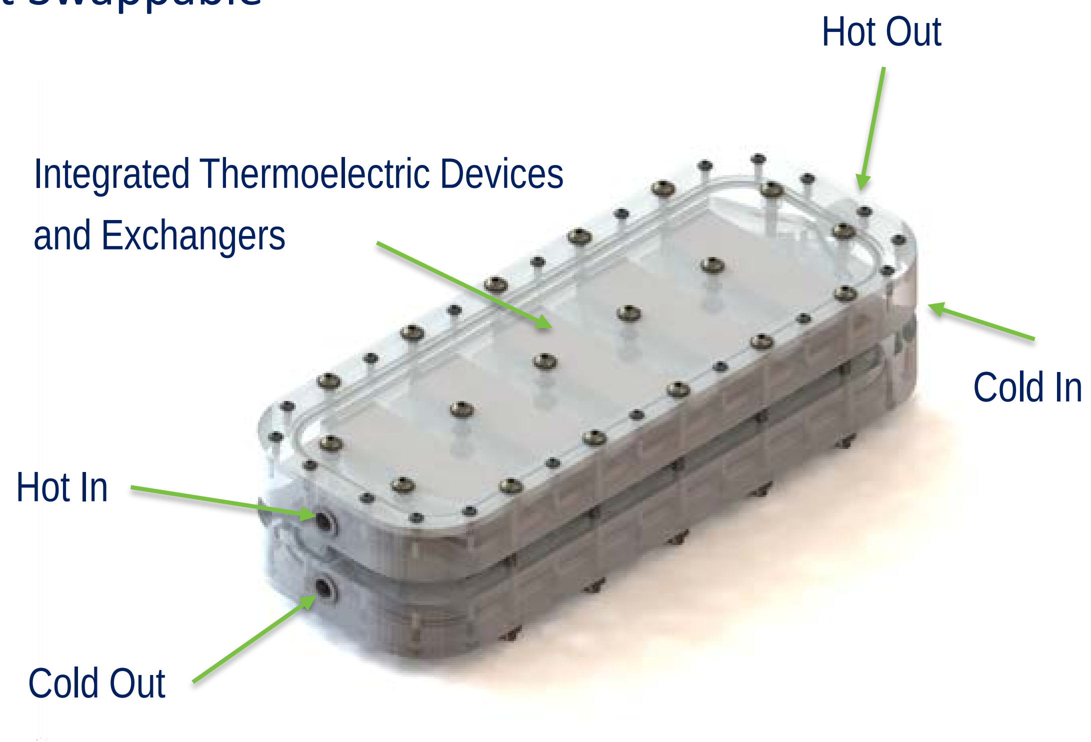
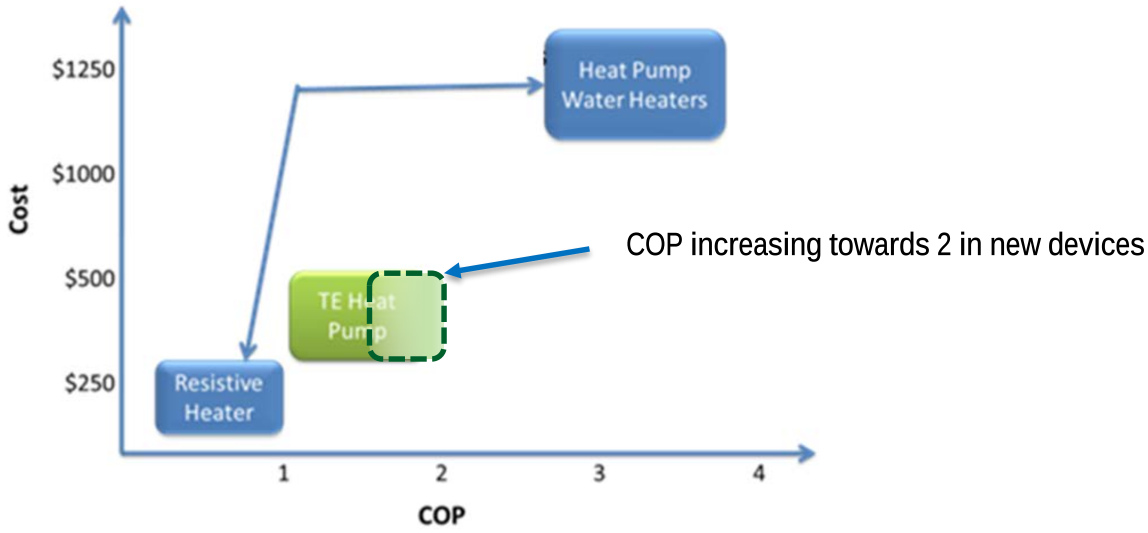
- Multi-Stage TEC Module Design
- Hi Efficiency and Hi Q TEC Devices
- Counter Flow Configuration for High COP
- Plug & Play/Scalable/Hot Swappable



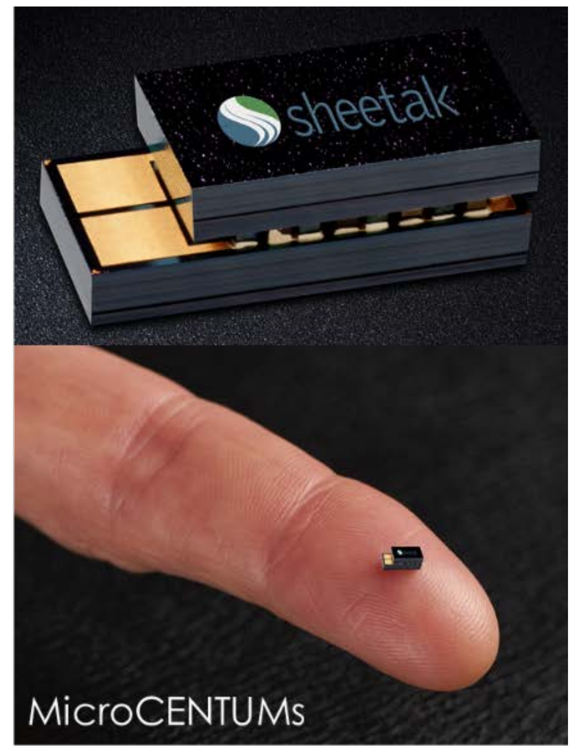
Next Steps and Future Plans

- Continue leading in development and commercialization of efficient thermoelectric heat pumps for refrigeration, water cooling and water heating
- Develop self-controllers for modular heat pumps and extend the plug-in capabilities for variety of cooling/heating applications
- Partner with appliance manufacturers for licensing and sales



Sheetak Technology

- CENTUM® High Performance Thermoelectric Devices
  - High heat density due to short transport lengths
  - High efficiency due to higher ZT and nanostructured contacts



Q&A

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