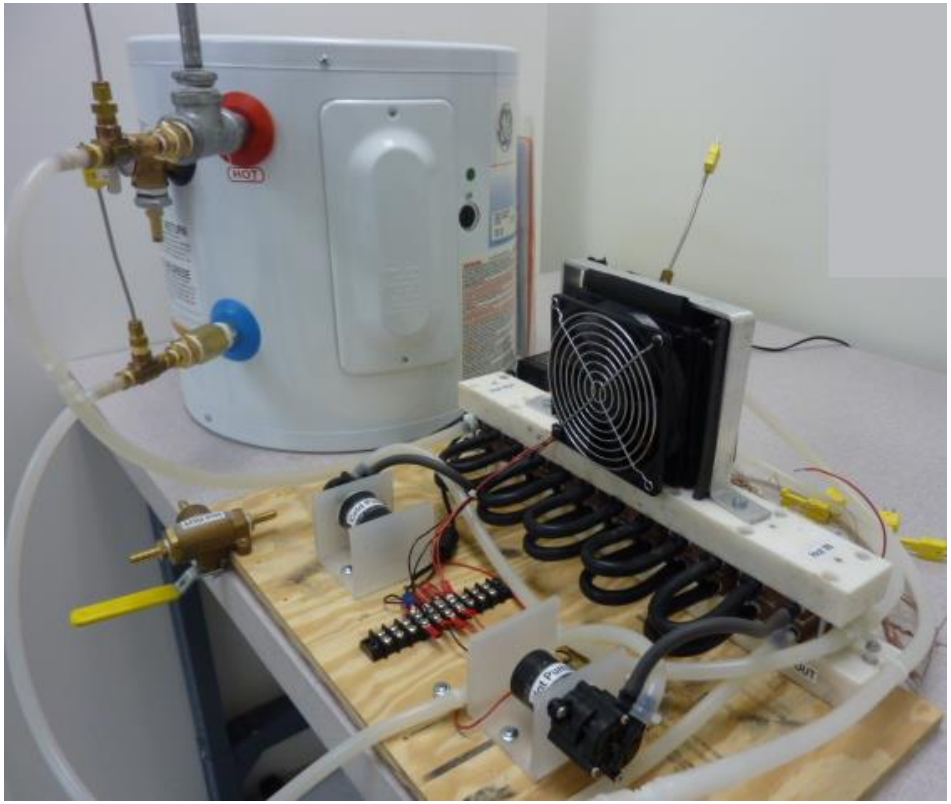
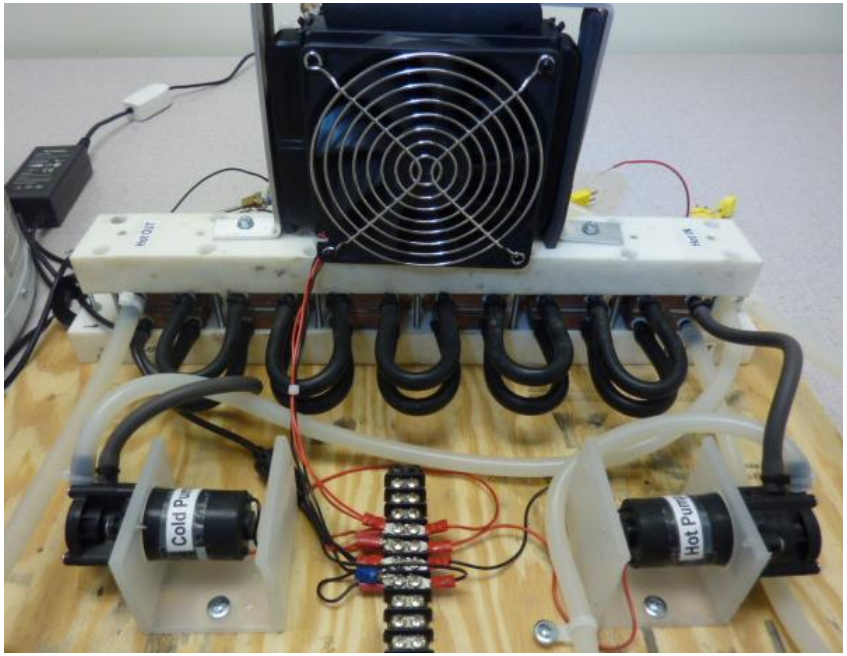
Heat Pump Water Heater Using Solid-State Energy Converters

2016 Building Technologies Office Peer Review





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Sheetak Inc.

Project Summary

Timeline:

Start date: 11/15/2012

Planned end date: 5/14/2016

Key Milestones:

1. Development of Bottom Mount 4-Engine Thermoelectric Heat Pump; 5/14/2014
2. Development of High Cooling Power Thermoelectric Modules for Heat Pumps; 5/14/2015
3. Performance (COP > 1.1) and Reliability Thermoelectric Heat Pumps ; 6/14/2016

Budget:

Total DOE $ to date: $1,149,900.00

Total future DOE $: $0.00

Target Market/Audience:

Home Water Heaters with Affordable, Reliable Solid-State Heat Pumps

Key Partners:

Whirlpool Appliance (Consultation for Specs)

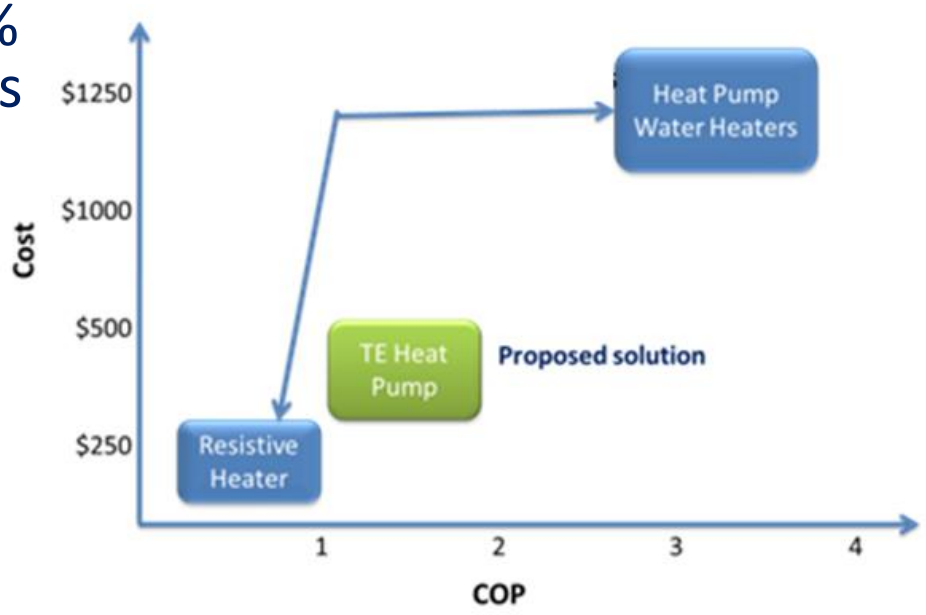
Project Goal:

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.

Purpose and Objectives

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



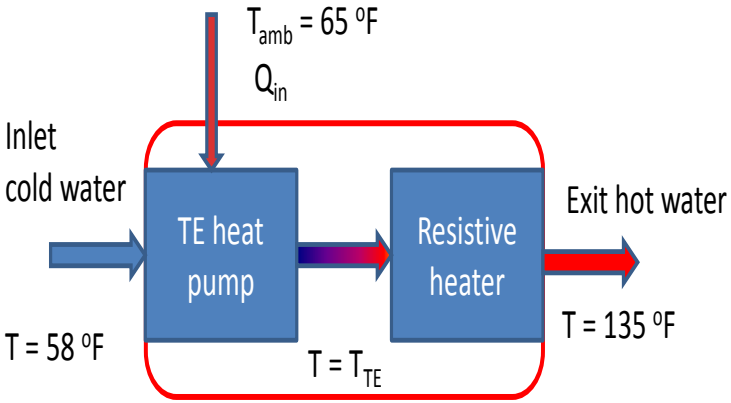
Sheetak's Solution

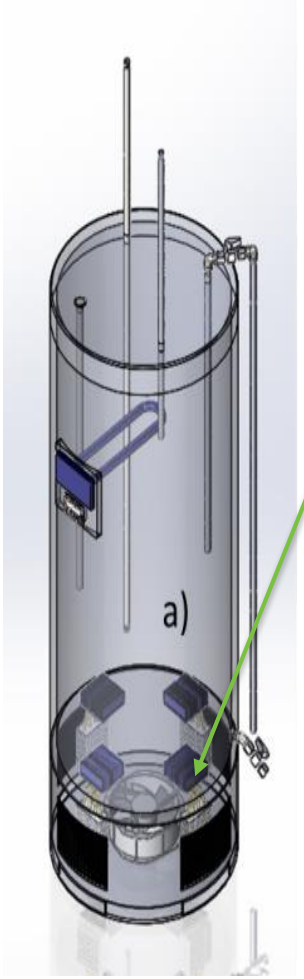
Low-Cost Thermoelectric (TE) Heat Pump Water Heater

Impact of the Project

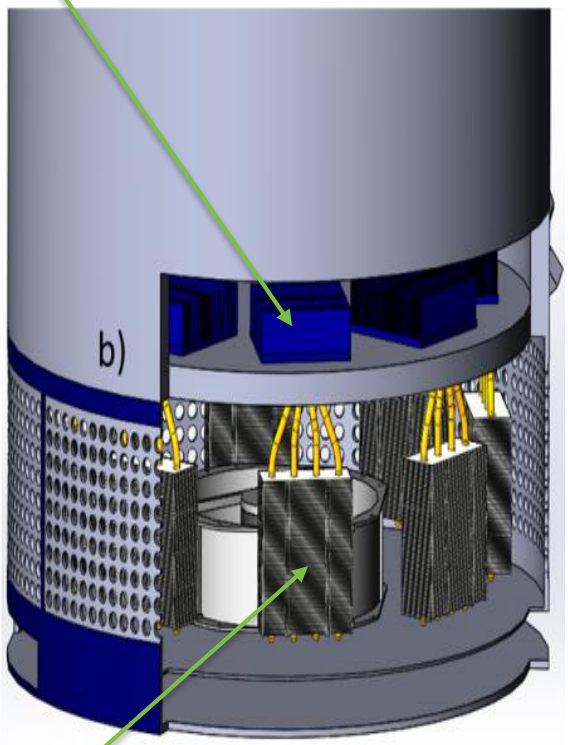
- Demonstration of first TE-based 50 gallon heat pump water heater
- COP >> 1.1 (goal of the SBIR was COP > 1.1)
- High volume manufacturing of thermoelectric coolers and heat pumps for refrigeration and heat pump applications
- Development of novel system-level hardware including self-controllers and fault-tolerant heat-pumps
- Cost-effective modular heat pump water heater
- Achievements
  - COP > 1.5 with modular plug-in thermoelectric engines
  - Long term: Launch of TE based water heater in the market

Original Thermoelectric Heat Pump Water Heater Concept



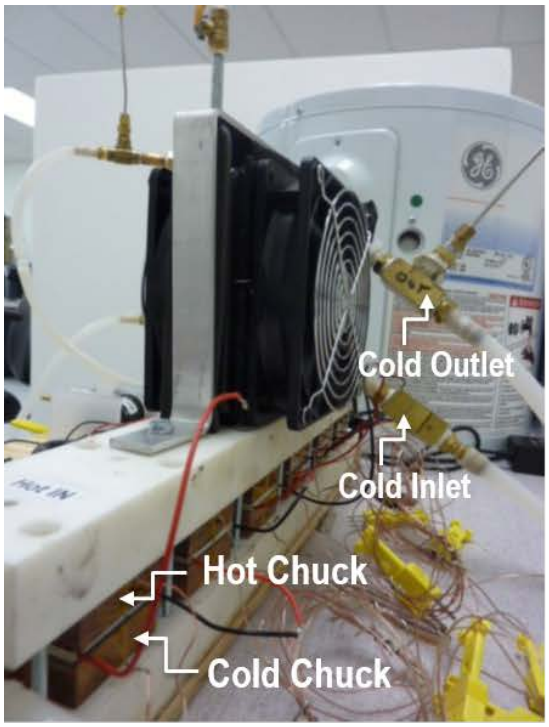


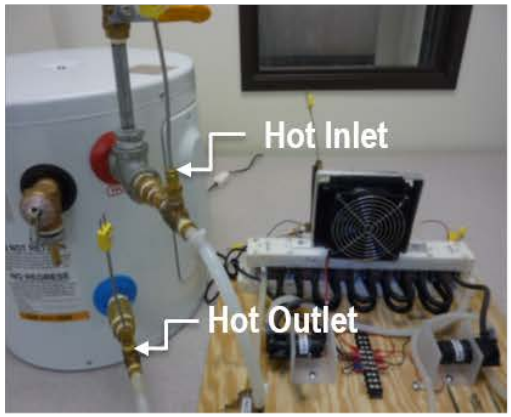
Thermoelectric Hot Side

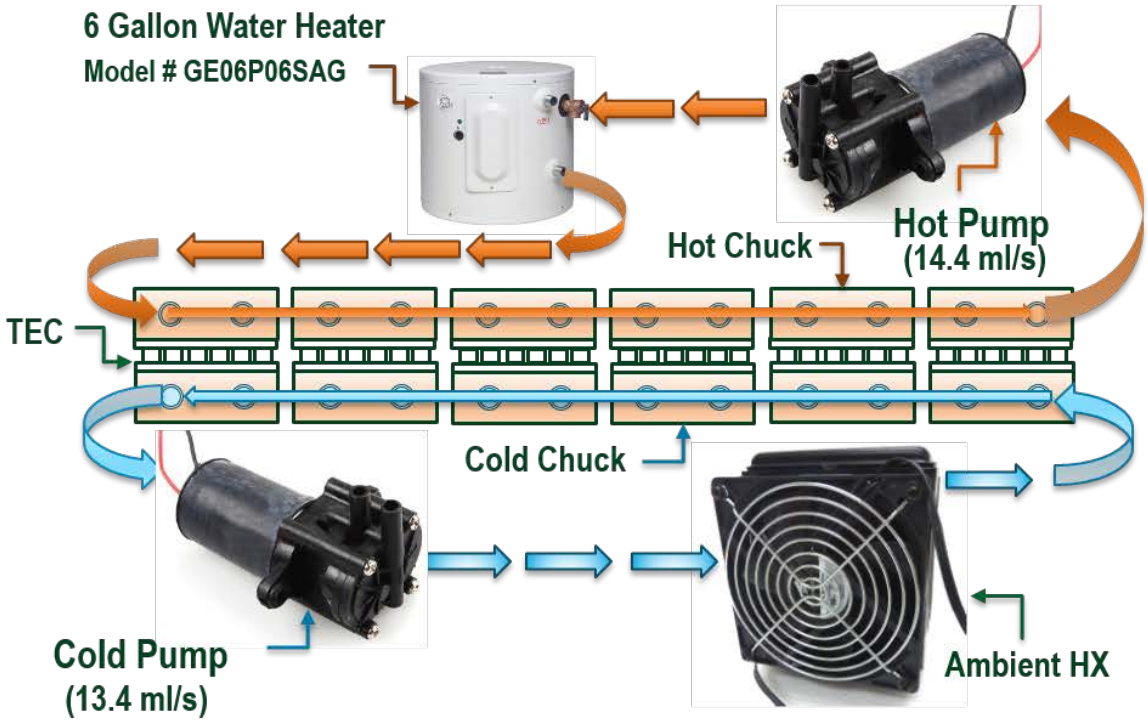


Thermoelectric Cold Side (Heat-Pipe Heat Sink)

Plug-In Thermoelectric Heat Pump Water Heater







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

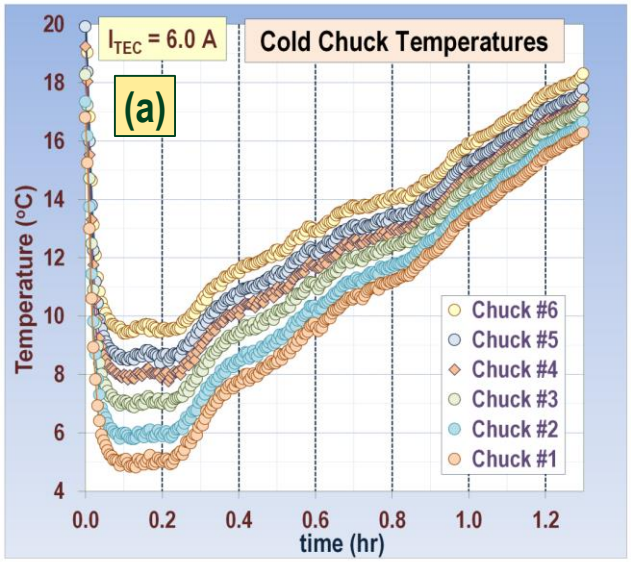
Water Heater Operation for I_{TEC} = 6A

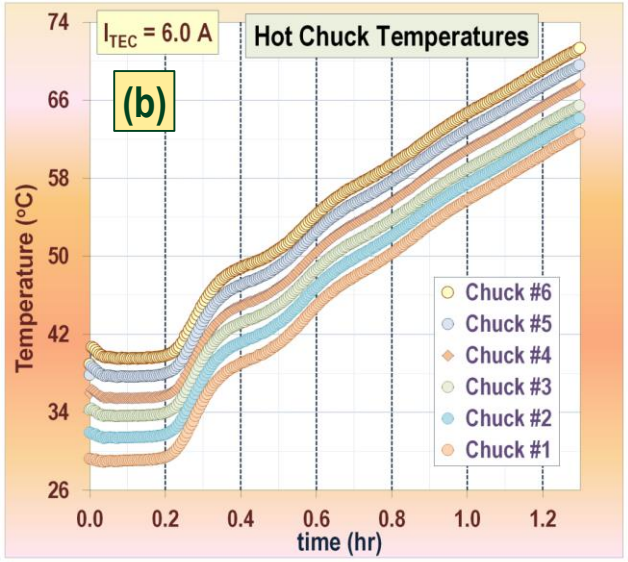
Fig. (a) Difference between the 6 Cold Chuck temperatures decreases for t > 0.9 hrs.

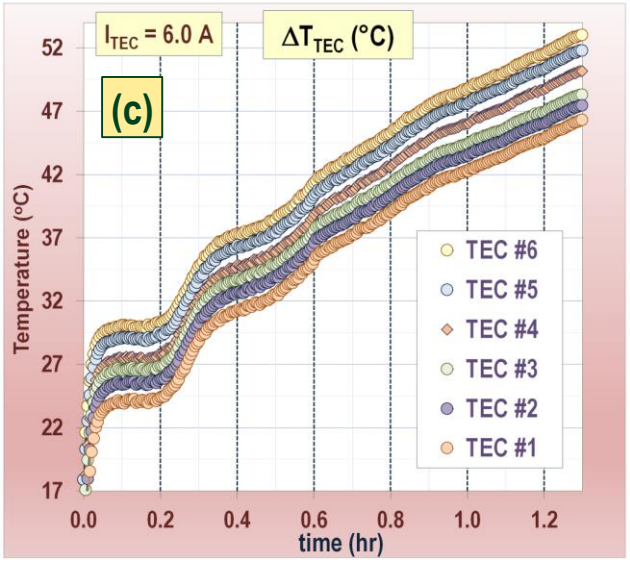
Fig. (b) Hot Chuck temperatures (for t < 0.2 hours, the thermocline in the container prevent hot temperatures from rising)

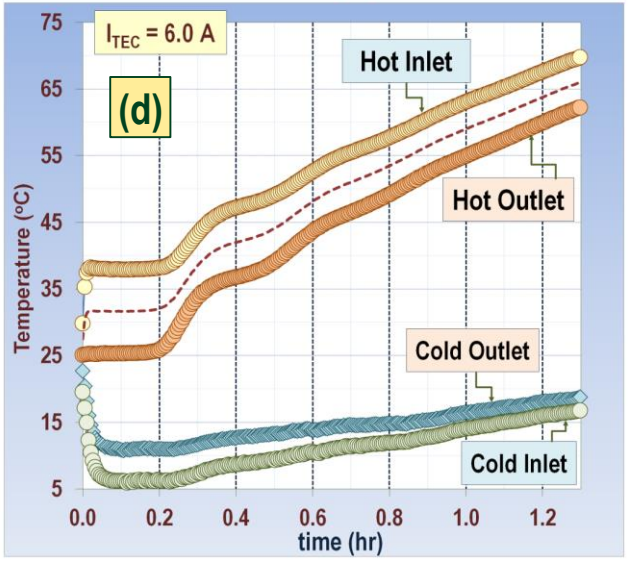
Fig. (c) Heat pumping decreases as ΔT_{TEC} increases (@ t = 1.3 hrs ΔT_{TEC} ~ 46°C - 53°C

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









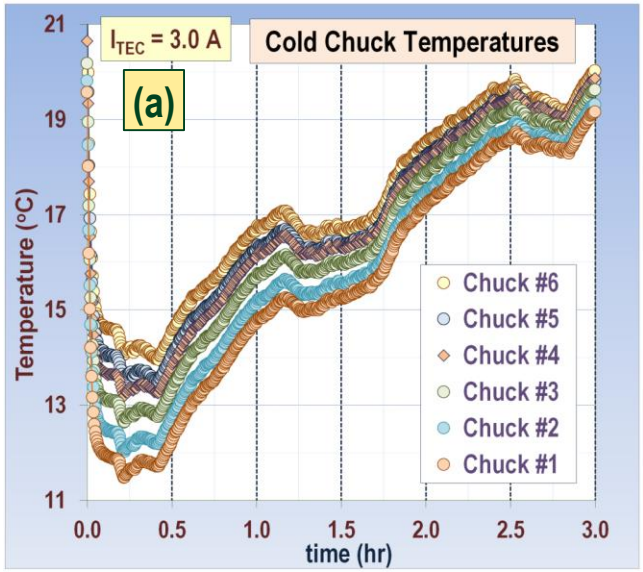
Water Heater Operation for I_{TEC} = 3A

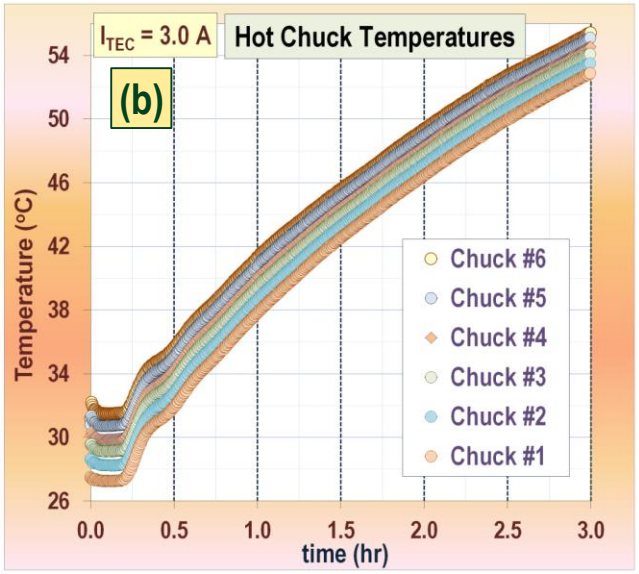
Fig. (a) Difference between the 6 Cold Chuck temperatures decreases for t > 1.5 hrs.

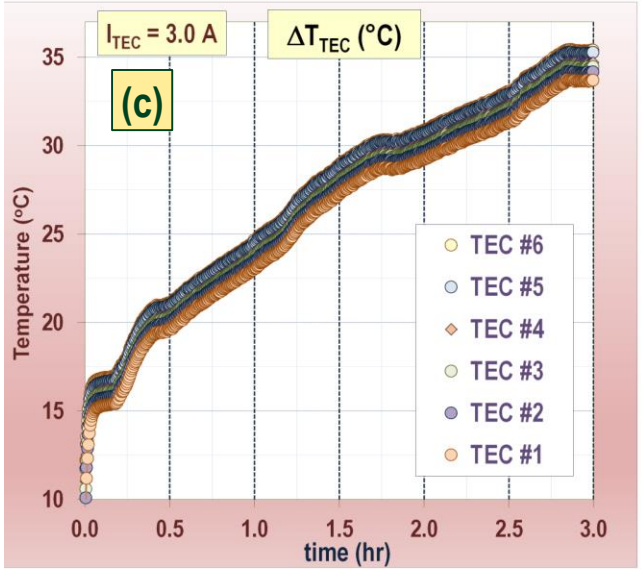
Fig. (b) Hot Chuck temperatures are closer to each other as compared to I_{TEC} = 6A

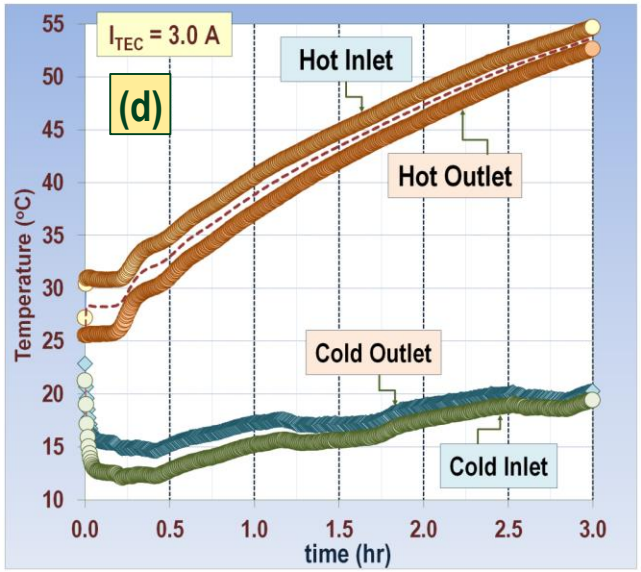
Fig. (c) Heat pumping → 0 $\Delta T_{TEC} \rightarrow \Delta T_{max}$ (I = 3A). After 3 hours, ΔT_{TEC} ~ 36°C - 38°C.

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









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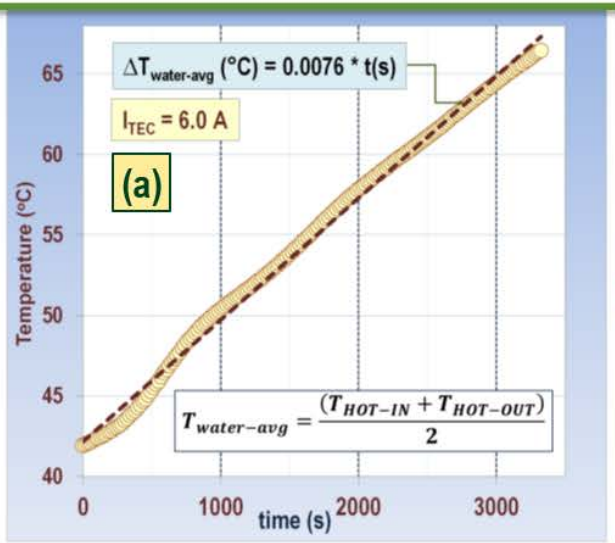
Measured Coefficient of Performance (COP)

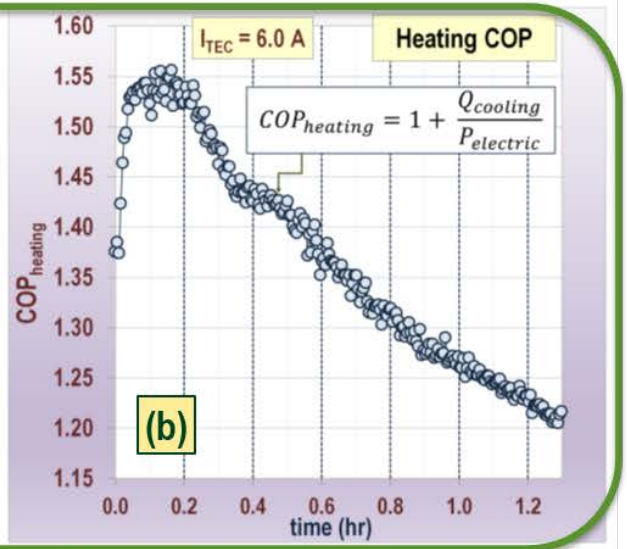
I_{TEC} = 6A

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).



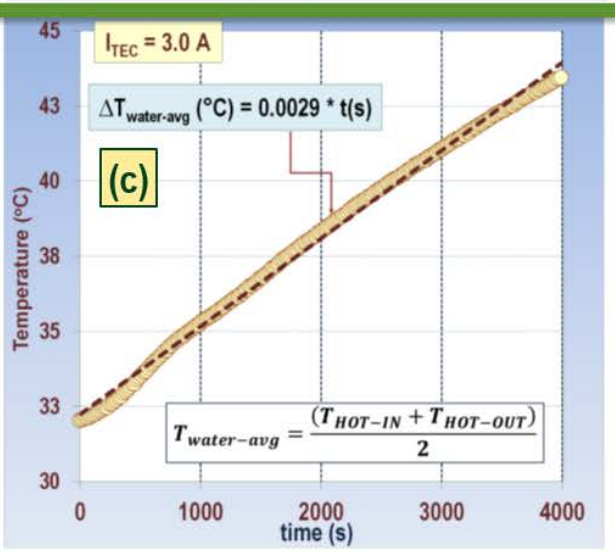


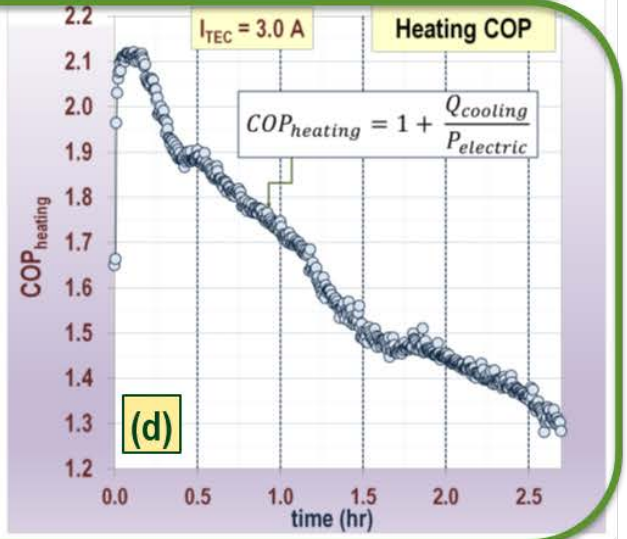
I_{TEC} = 3A

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 $Q_{cooling}$





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

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

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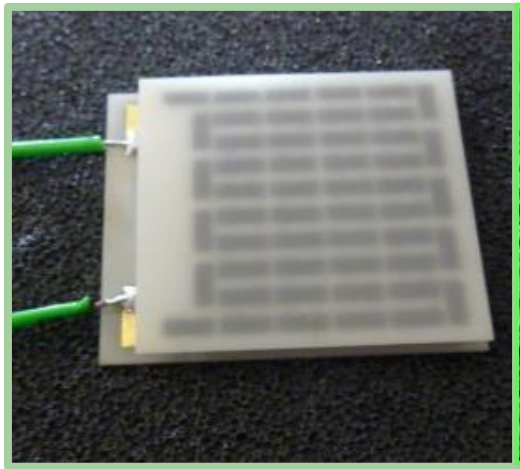
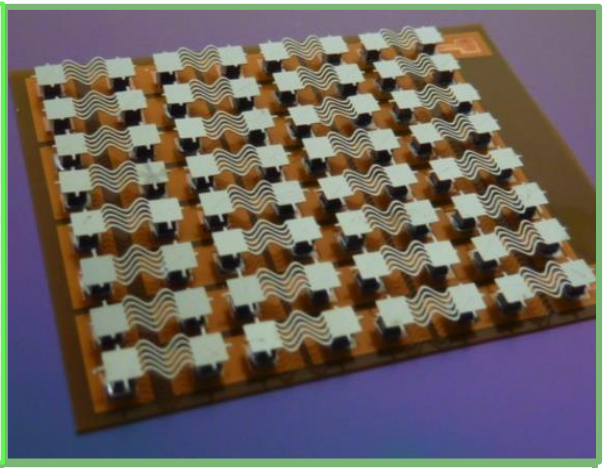
Industry-Best Cooling Chips

- Lowest Power Consumption (~½)
- Tunable Cooling Density(1-100 W/cm^2)
- High Reliability (MTBF >> 100,000 h)
- High Volume Manufacturing (> 2M pa)
- Flexible–Geometry Complaint
- Enables battery-based portables
- Mechanically robust
- Fault-tolerant



51-Couple 30W TEC

Flexible 30W TEC

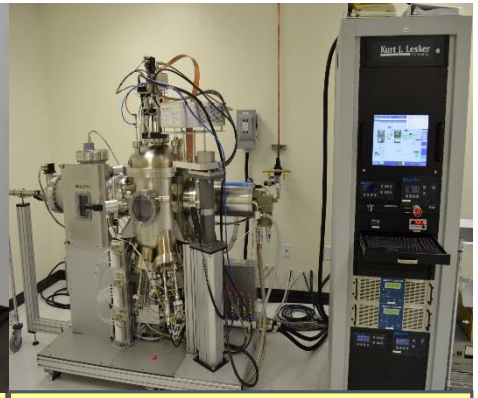


Flexible 32-Couple TEC

Disruptive Wafer-Level Processes

Ball Milling

SPS



Barrier Metallization/Plating

sheetak

Bi, Sb, Te, Se

Zone Melting
Crystal Growth,
Dicing Plating

TRADITIONAL

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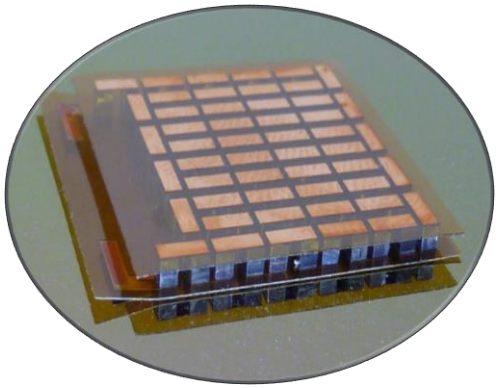
Transformative Assembly Methods

Volumes >>1M

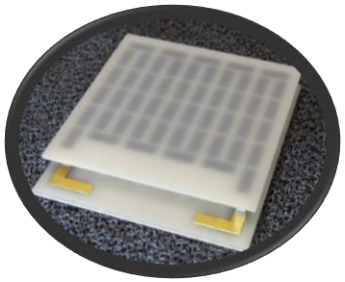
Die Sorting for Tape & Reel

Automated
Pick &Place



Highly Automated & Parallel Assembly Lowers Cost and Leverages LED Manufacturing

Semi-Manual
Pick &Place



Volumes <1M

Progress and Accomplishments

Accomplishments

- Bottom-mount TE heat pump water heaters fabricated and demonstrated
- High volume, high efficiency thermoelectric cooler manufacturing capability for heat pumps established
- Novel modular heat pumps for add-on/plug-in applications demonstrated and tested

Challenges

- Funding for high volume thermoelectric heat pump manufacturing in the US and globally
- Industrial design, controllers for modular fault-tolerant heat pumps with fluid pumps with > 20 years MTBF

Commercialization Strategy

- Initial contacts with Whirlpool in the US and Godrej & Boyce in India
  - Whirlpool for store branded heaters in the US and Asia
  - Godrej and Boyce for developing world markets (India) that focuses on small water capacity

- Commercialization focus for 2016:
  - Leverage beverage refrigeration to manufacture efficient TECs in high volumes and establish revenues
  - Develop industrial designs for plug-in water heater heat pumps and systems for commercialization
  - License system technology for modular heat pumps to water heater appliance manufacturers, and provide volume sourcing of heat pumps

Next Steps and Future Plans

- Become the leader in high volume manufacturing 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

REFERENCE SLIDES

Project Budget

Project Budget: $1,149,900.00
Variances: None
Cost to Date: $926,897.49
Additional Funding: N/A

Budget History					
11/15/2012– FY2015 (past)		FY2016 (current)		FY2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$649,924.57	0	$499,975.00	0	0	0

Project Plan and Schedule