Potentia[illegible]oelectrics for Occupan[illegible]uel Efficiency Ga[illegible]lications

Lon E. [illegible]eur, Dan Coker

[illegible]ust 24, 2006

BSST
innovative solutions
in temperature control

Detroit, Michigan- DEER 2006
August 20-24, 2006

Overview

- Background o bar ers tc broader usage of thermoelectr
- TED heatir oadmap
  - First app lectric devices in pass Climate Controlle
  - Liquid tc for cooling electro es
  - Liquid to ai for supplemental heating/cooling p senger cabin
- Waste heat recovery using thermoelectrics to increase fuel efficiency
- Summary and conclusions

Background on Barriers to the Broader Usage of Thermoelectrics

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Commercial Interest in Thermoelectrics

Solid-state cooling, heating and power generation

Small, light-weight. Potentially very reliable and rugged

Electrically powered with very few (or no) moving parts

Distributed (and spot) cooling/heating/temperature control

No gaseous pollutants

What Has Limited Us age

Efficiency has been ¼ at of 2 phase r

- Inadequa or r y hi pow
- Limi usa t cooler
- Too i

Therma

- Volum at high pow levels
- Form ble to some application ne
- Poor inter er density applications

Lack of design knowle e and effective simulation tools

- Performance often poorer than predicted
- Characteristics and hence response, can be a strong function of operating conditions

Sources of TE System Performance Increase

Materials	
BiTe Thermoelectrics (1960s)	Baseline
Heterostructures (2000-2002)	+70 to 160%
Materials/Design	
Incremental improvements (1960-2002)	5 to 15%
[illegible] ancillary materials and components (1960-2002)	5 to 10%
Thermodynamic Cycle	
Isolated Element (2000-2002)	100 to 120%
Convection (2001-2002)	30 to 80%
Power Density	
Sintered micropower (2002)	Up to 25 X Increase
Heterostructure (2001)	30 to 300 X Increase

Product Roadmap for Therm[illegible]electric Heating/Cooli[illegible]

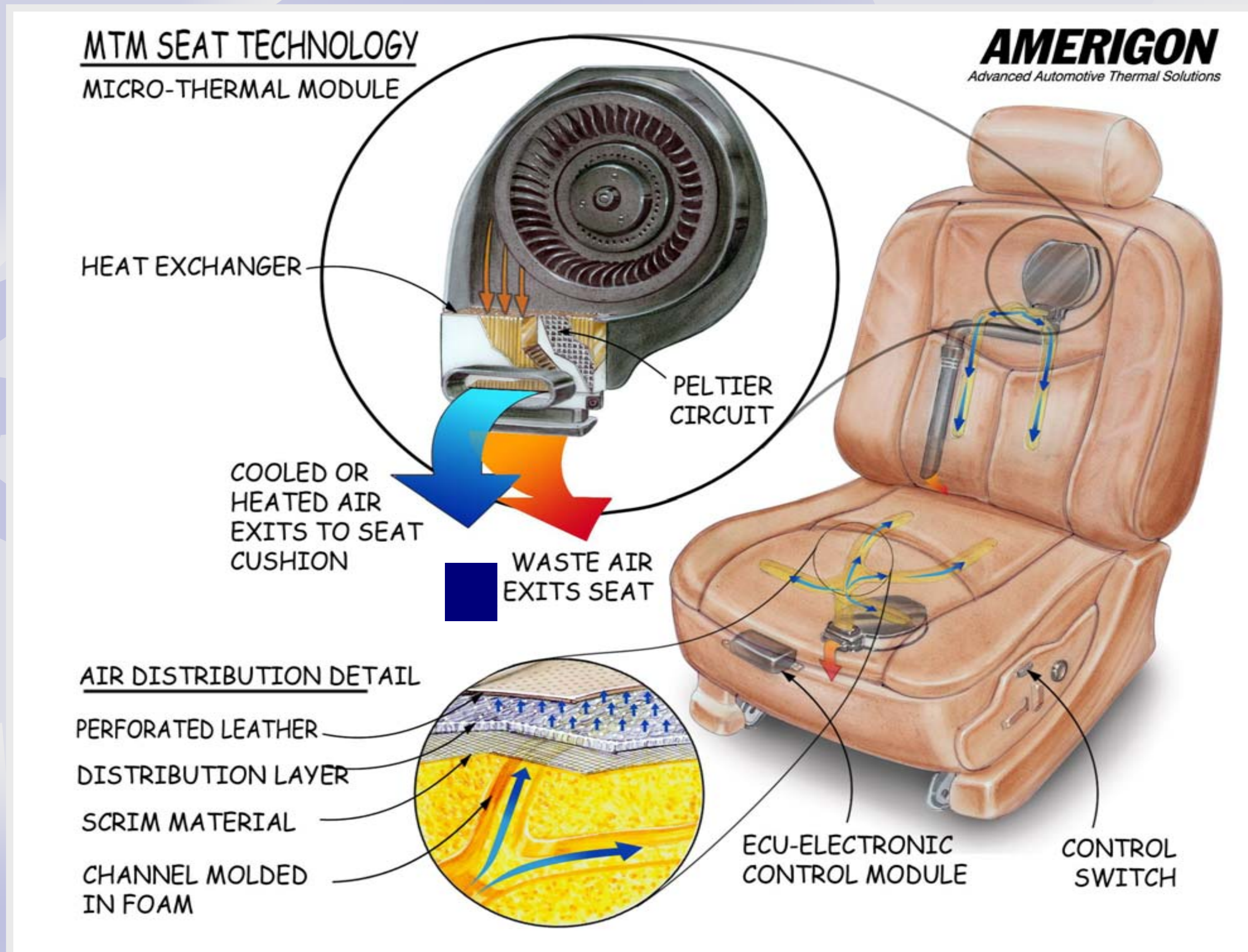
Current applica[illegible]

- Amerig[illegible]
- Cooling [illegible] uid to [illegible] Ds
- Supplem[illegible] cooling usi[illegible]g liquid to air TEDs
- Spot coolin[illegible] air TEDs

Long term goa[illegible]

- Primary HVAC systems

Product Roadmap: Amerigon's CCS



Amerigon Current CCS™ Vehicle Lines

2007 Escalade (ESV, EXT)

Nissan

ac (XLR, DTS)

Toyota Century

Toyota Celsior*

Lin

xpedition

Nissan Fuga

2006 Buick Lucerne

Lincoln LS

Lincoln Aviator

Lexus LS 430*

Hyundai Equus*

2006 Lincoln Zephyr

Infiniti (Q45, M45)

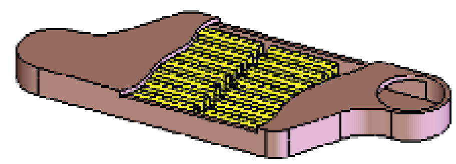
Mercury Monterey

* Four Seat Systems

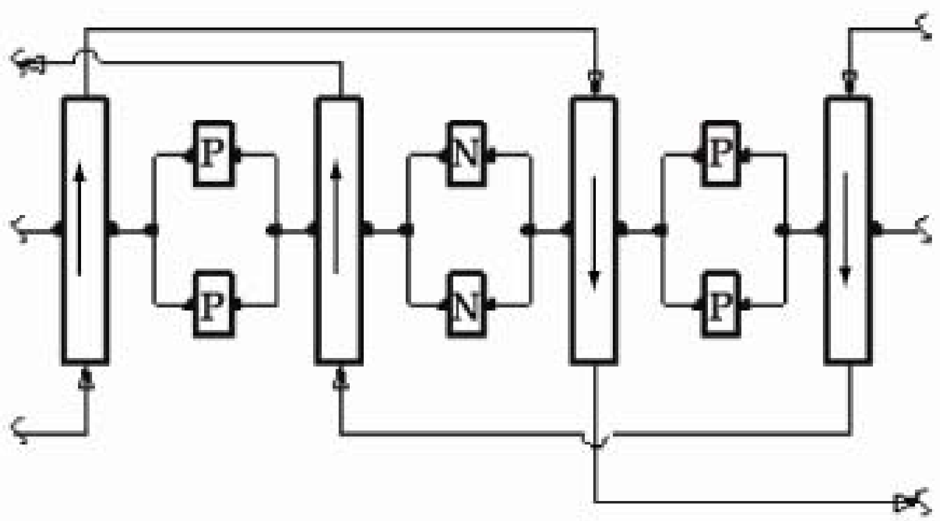
Product Roadmap: Liquid to Liquid TED for Cooling Electronics

1. The device shall e … efficiencies at least 50% greater thar … echnology;
2. TE material us … 5% that of commercial TE modules
3. The device sha … ured and have the prospect of being low … m weight;
4. The design shall … rical redundancy;
5. The design shall be sca … e to larger and smaller sizes between 50 and 5,000 watt thermal capacity.

Product Design



Heat Exchanger



Fluids and Current Paths

TED Subassembly

TE element l

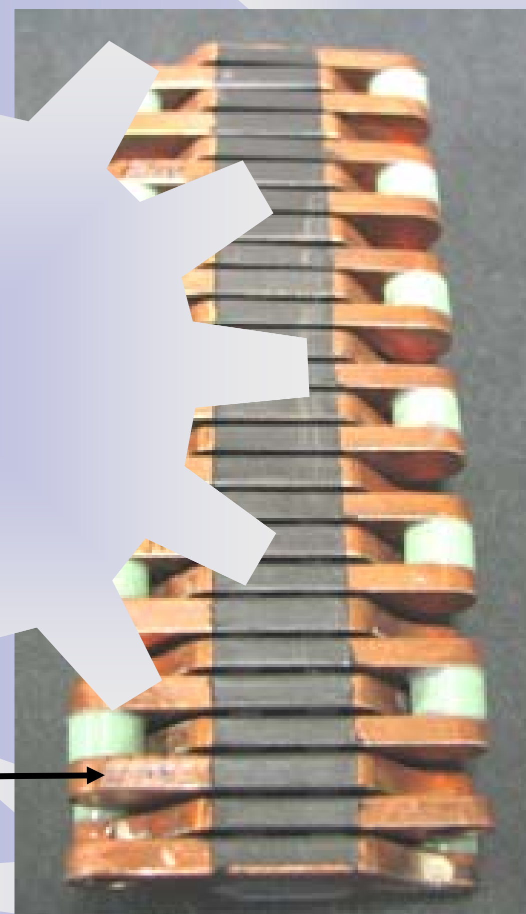
exchangers

Fluid duc

hea exch

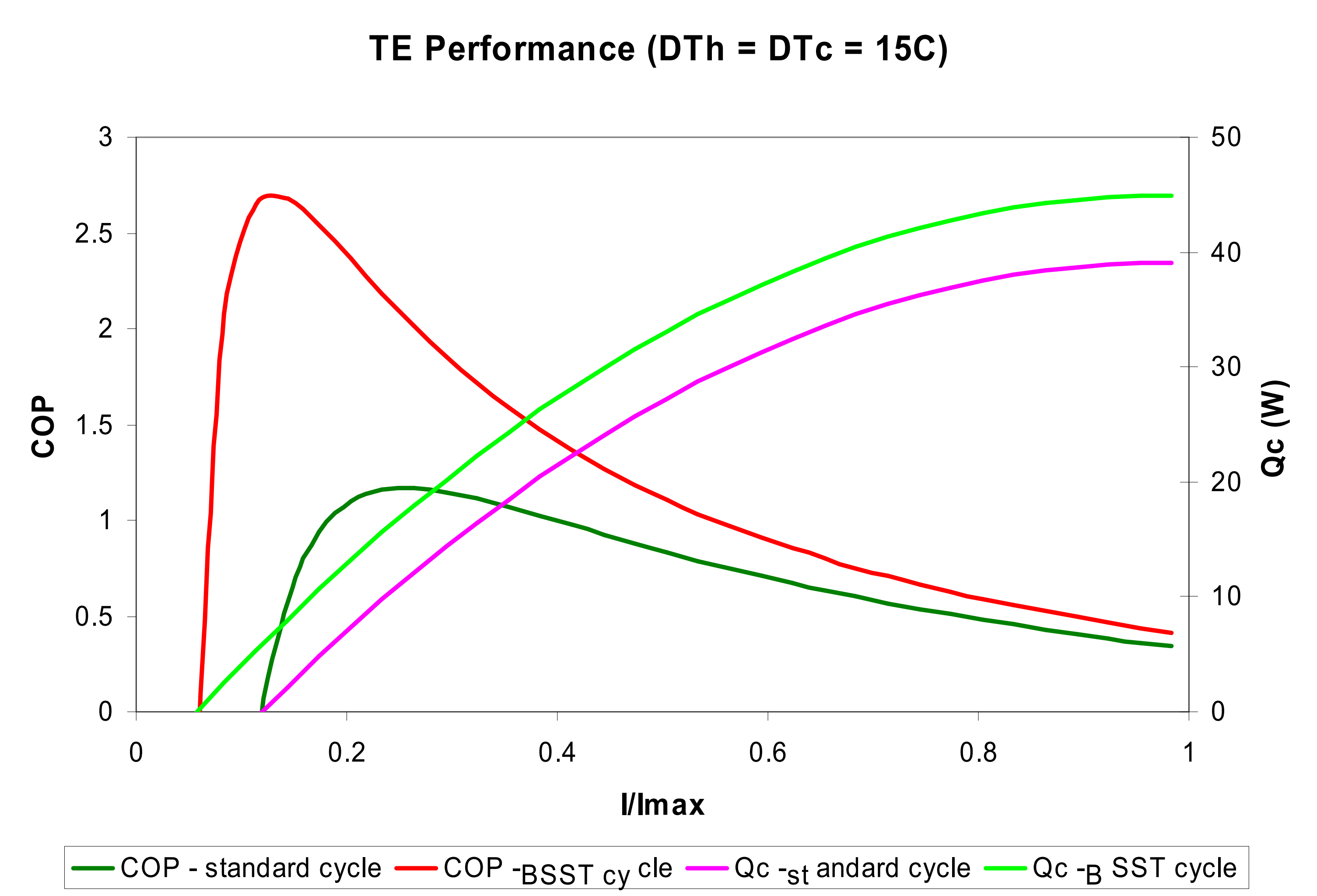
Heat exc angers

(26 Total)

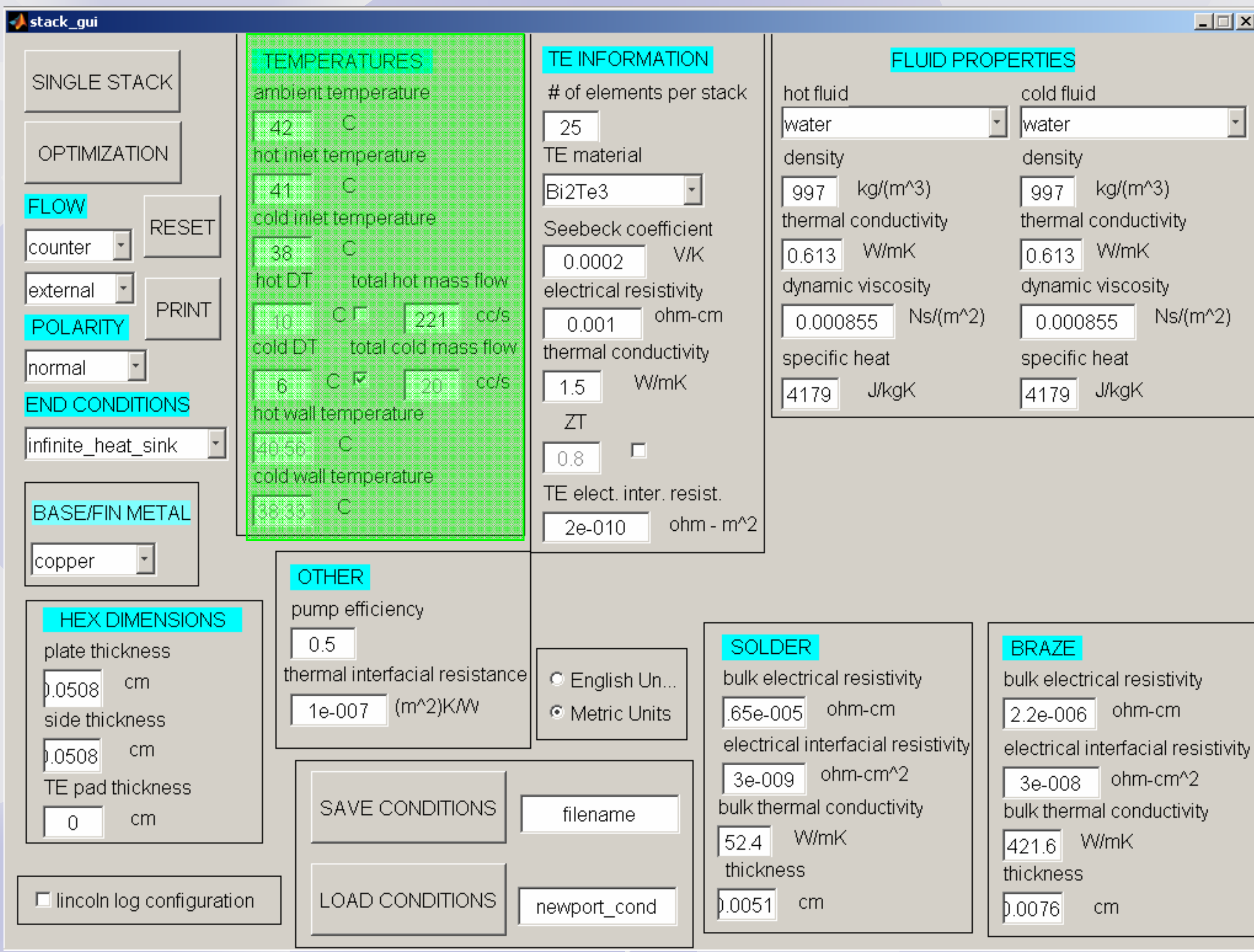


Breadboard subassembly.

Power Density Characteristics



Modeling Inputs (Properties)



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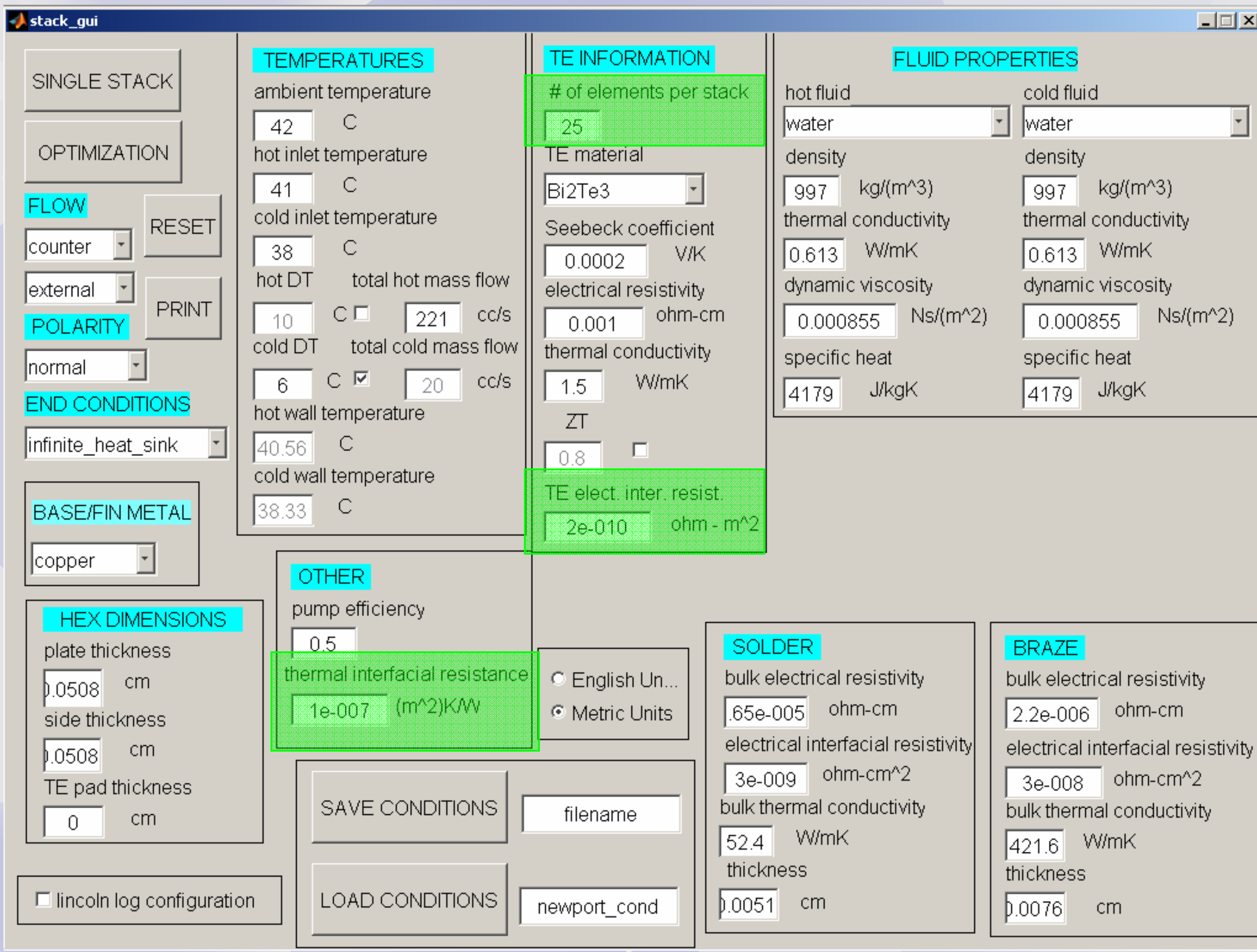

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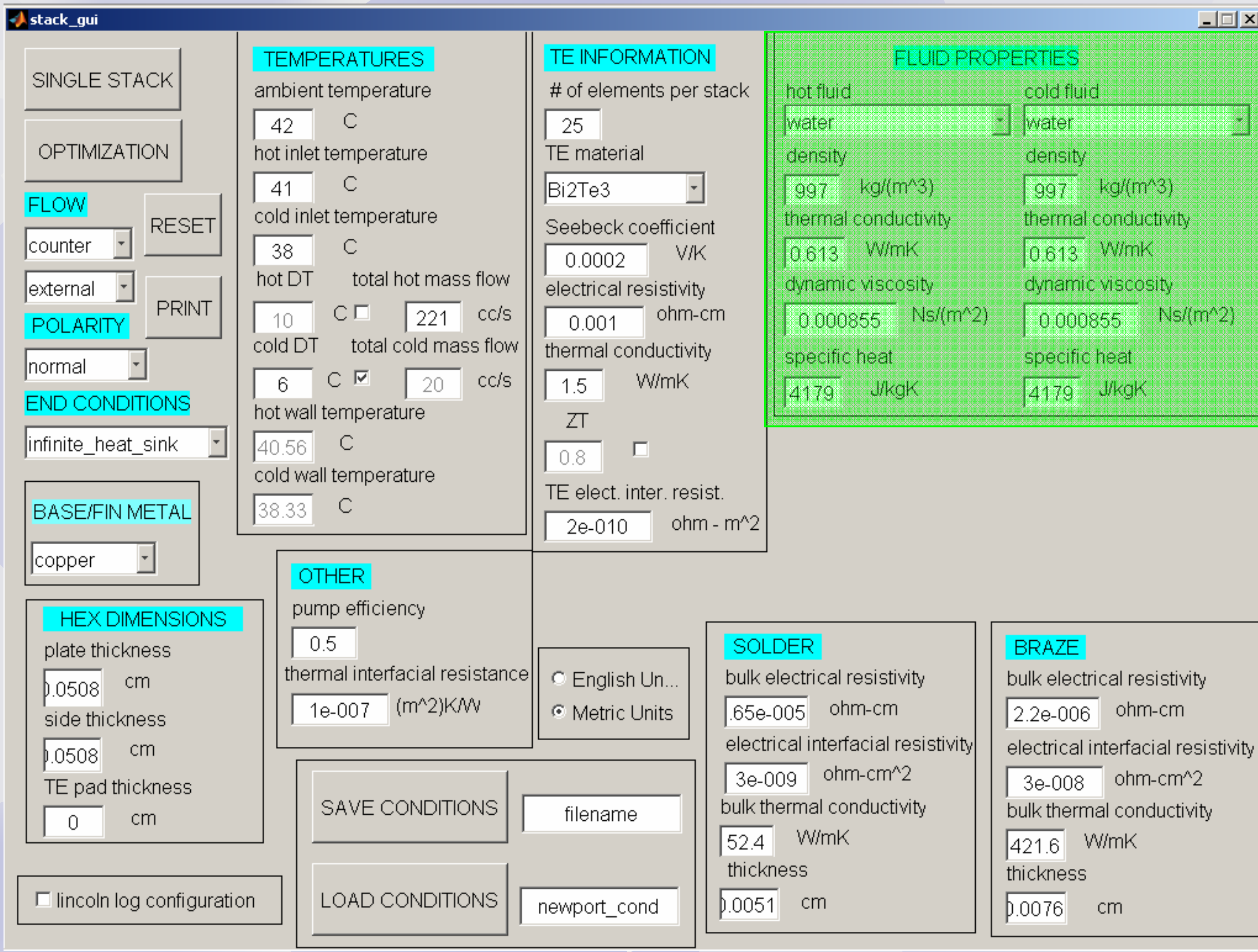
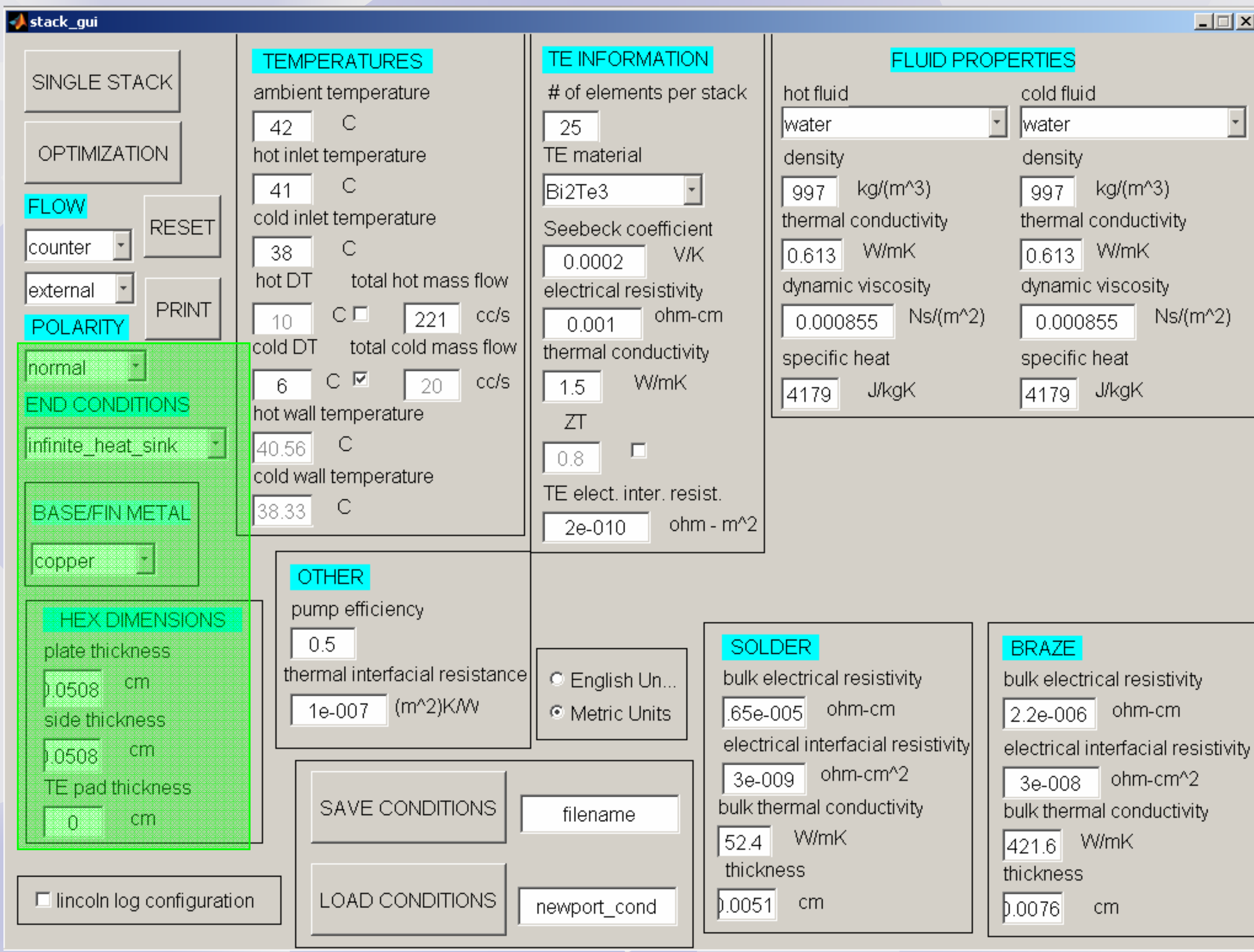
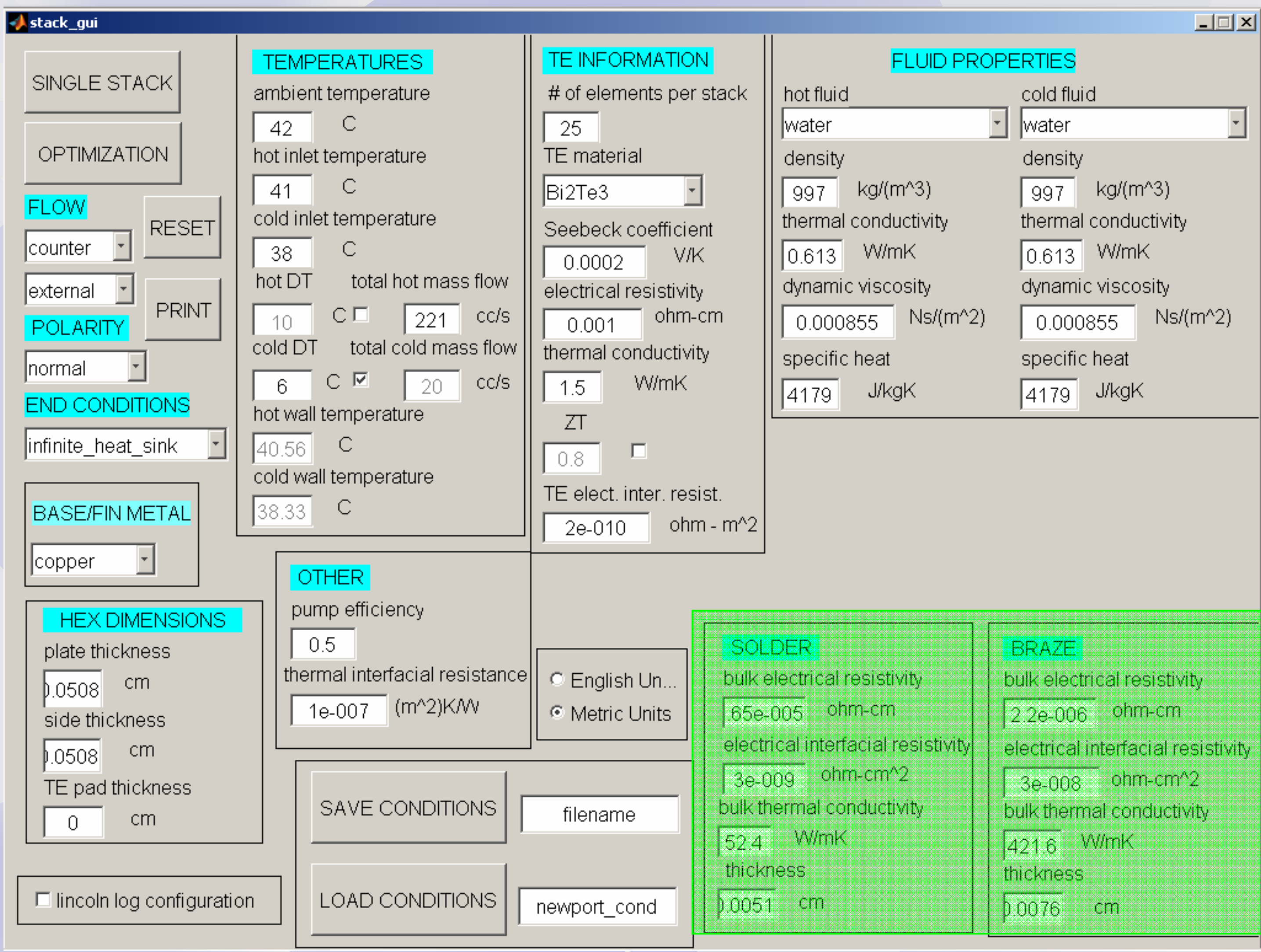


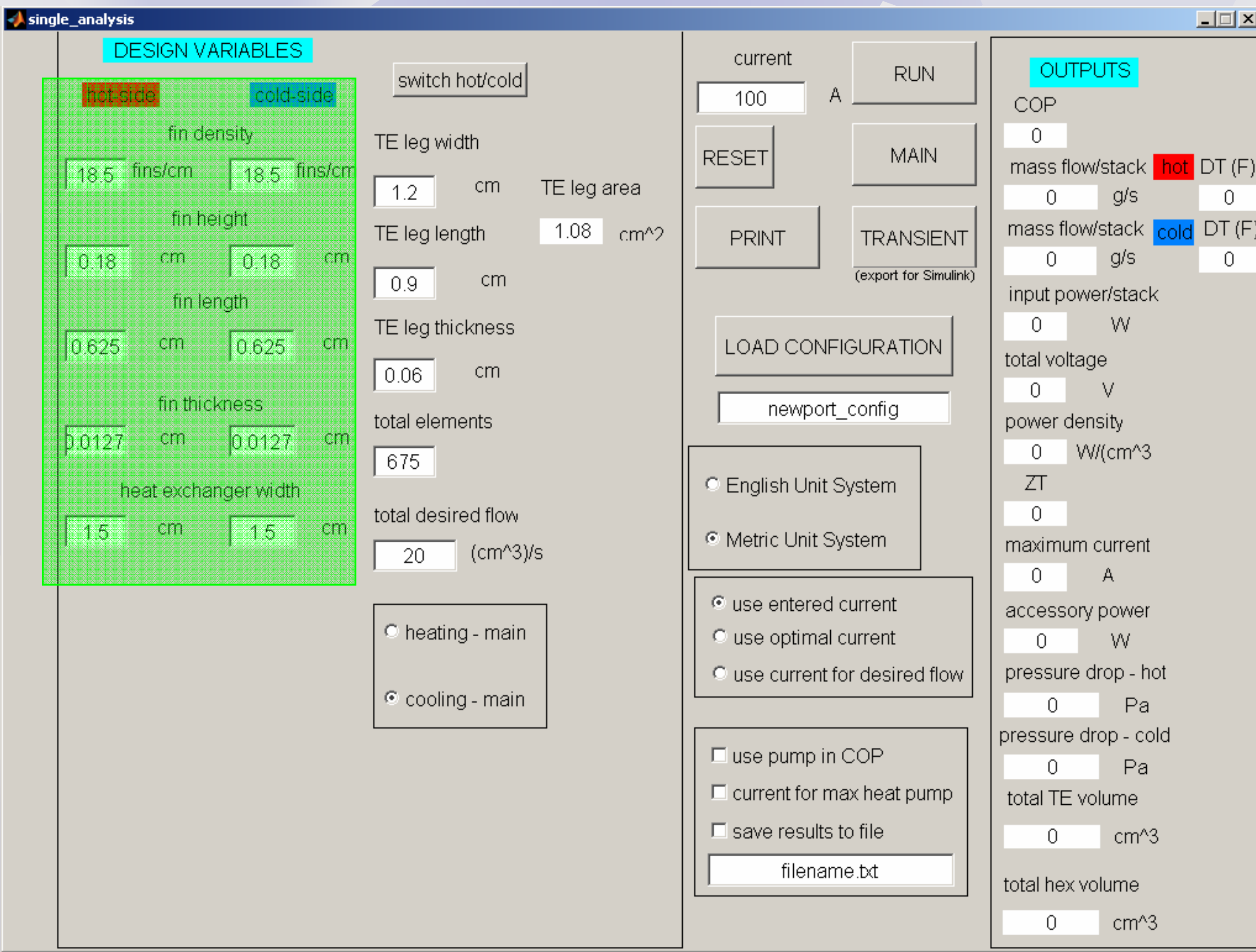
Modeling Inputs (Properties)



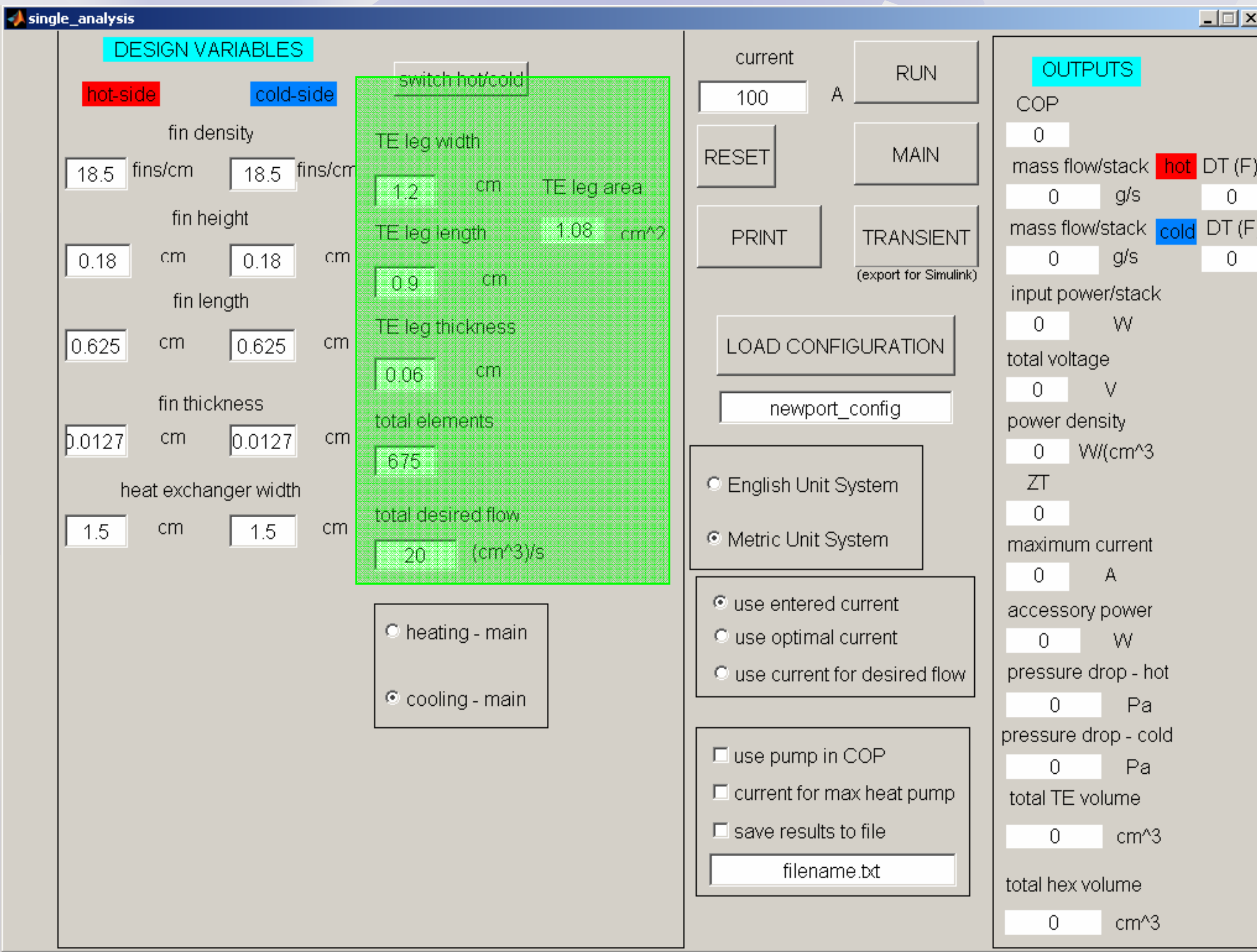
Modeling Inputs (Properties)



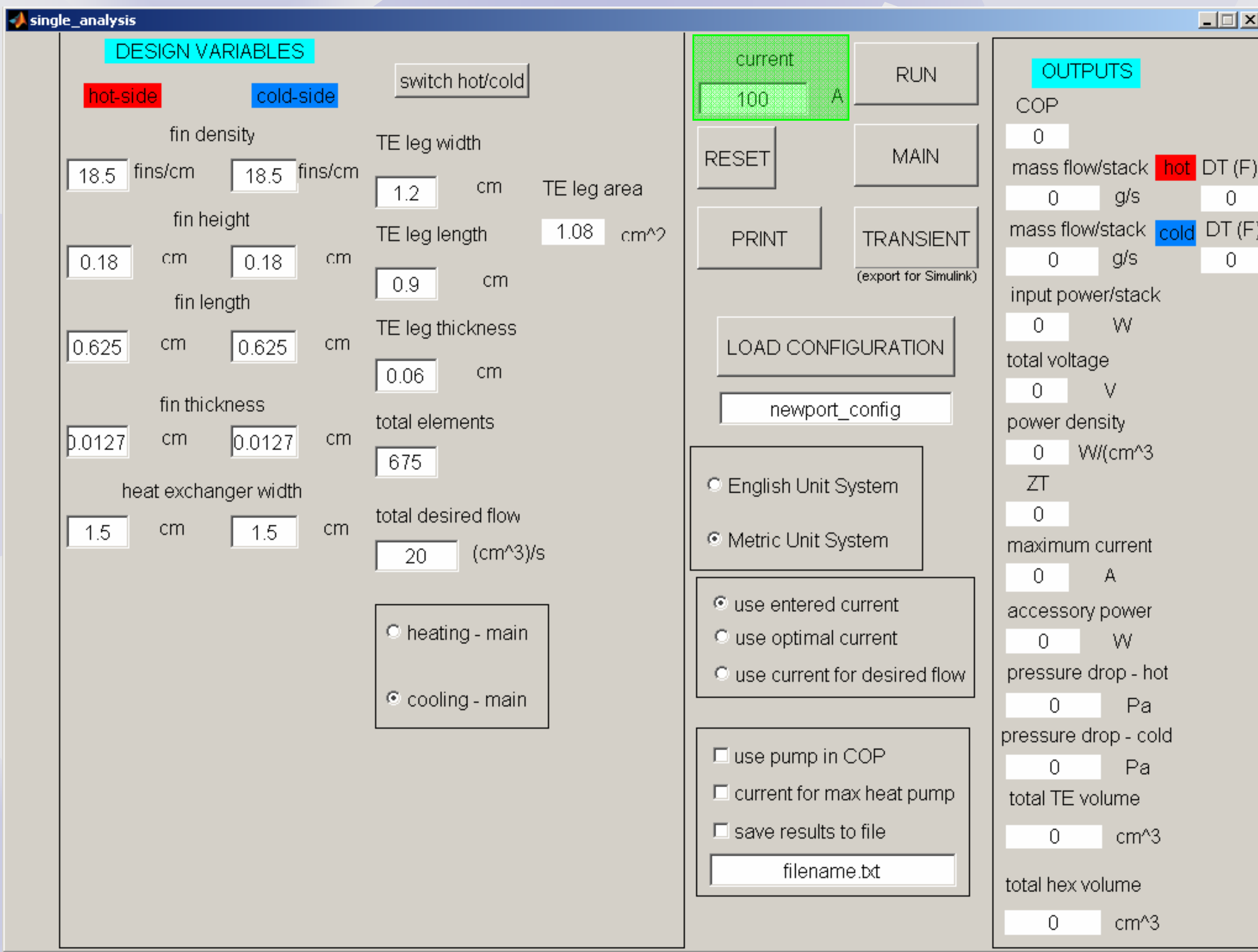
Modeling Inputs (Dimensions)



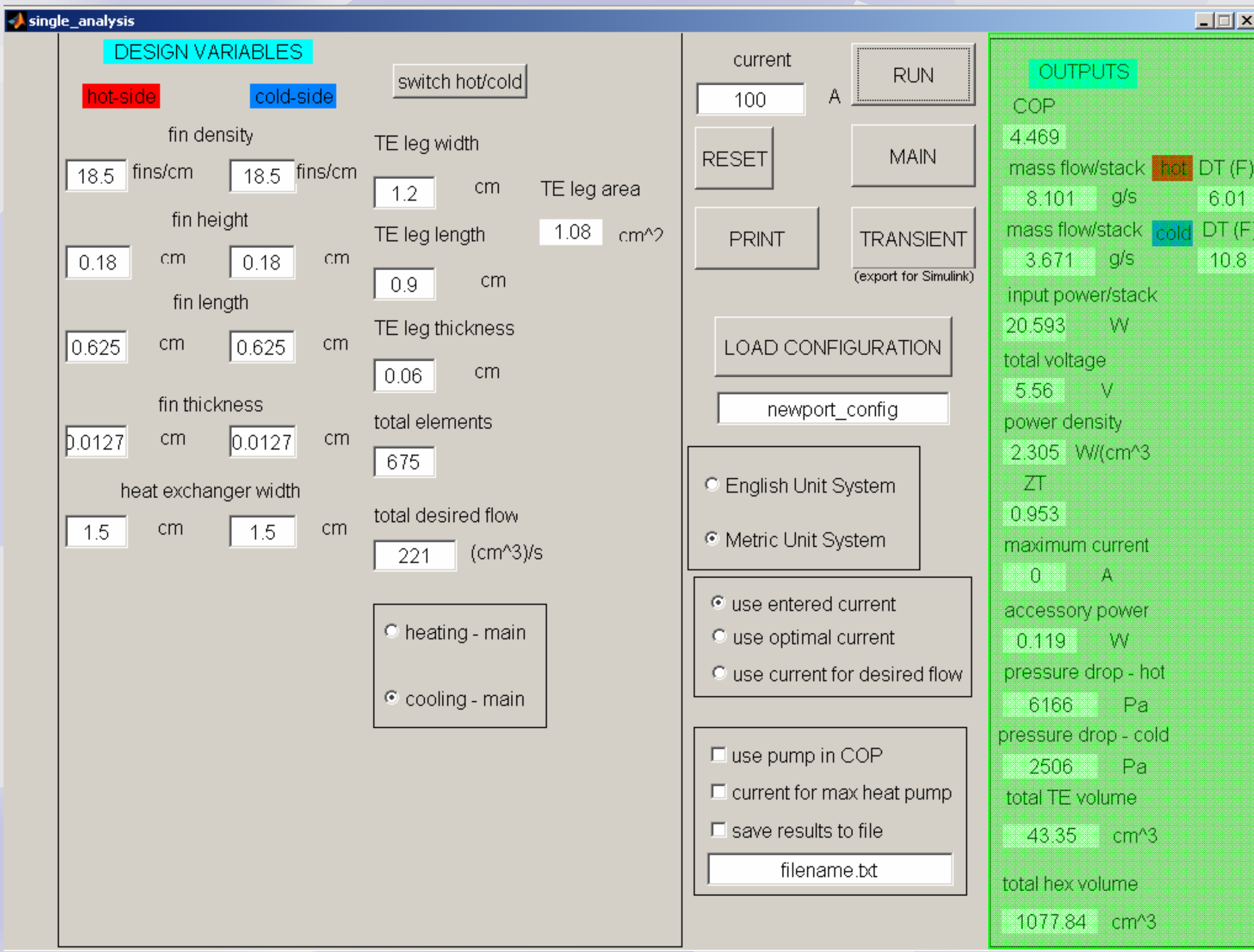
Modeling Inputs (Dimensions)



Modeling Inputs (Dimensions)



Modeling Outputs



TE Subassembly

TE element l

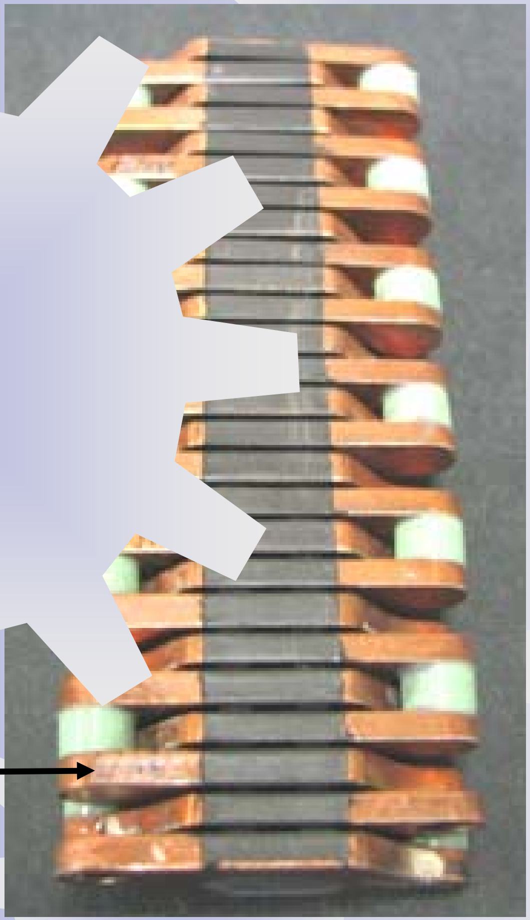
exchangers

Fluid duc

hea exch

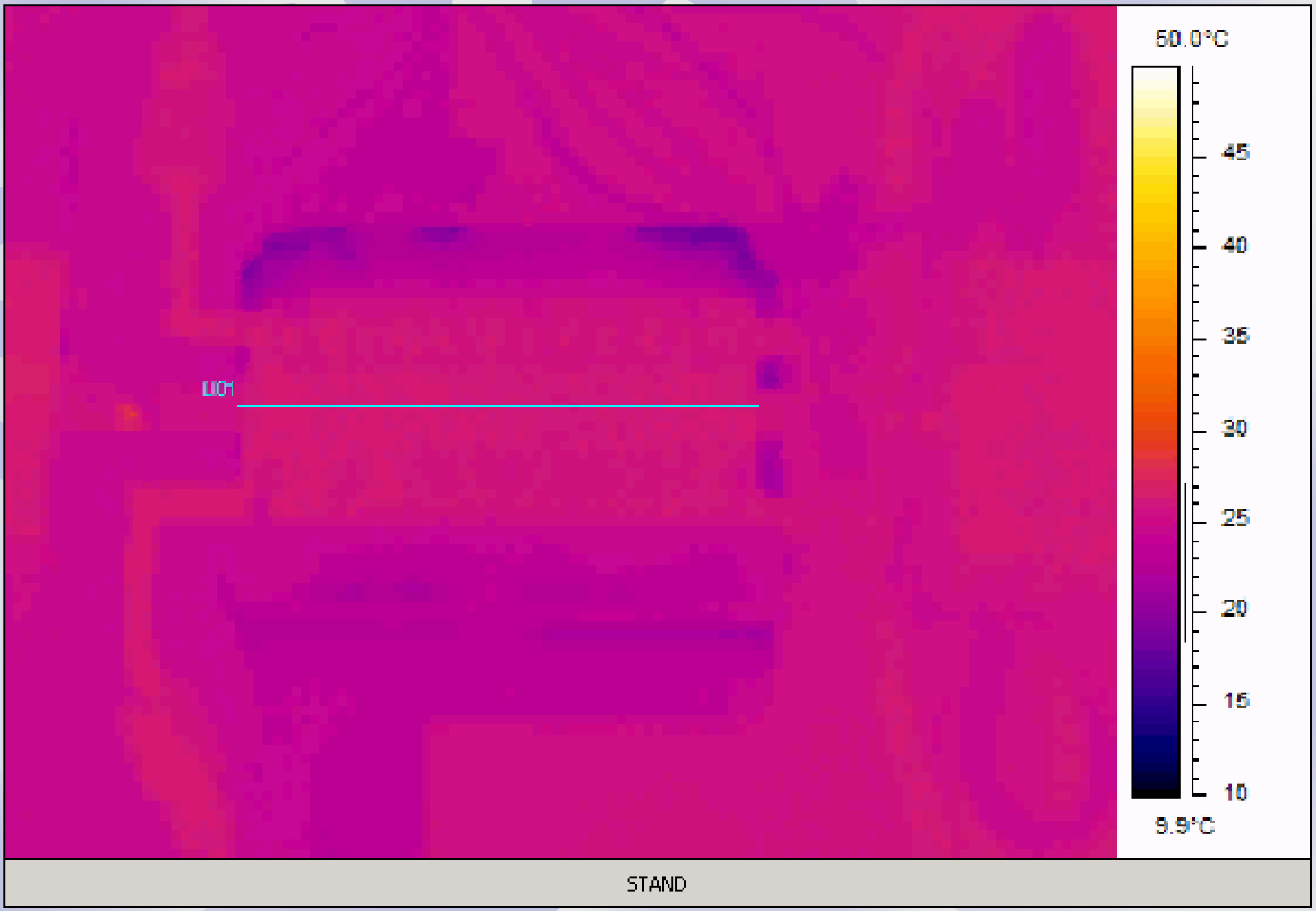
Heat exc angers

(26 Total,

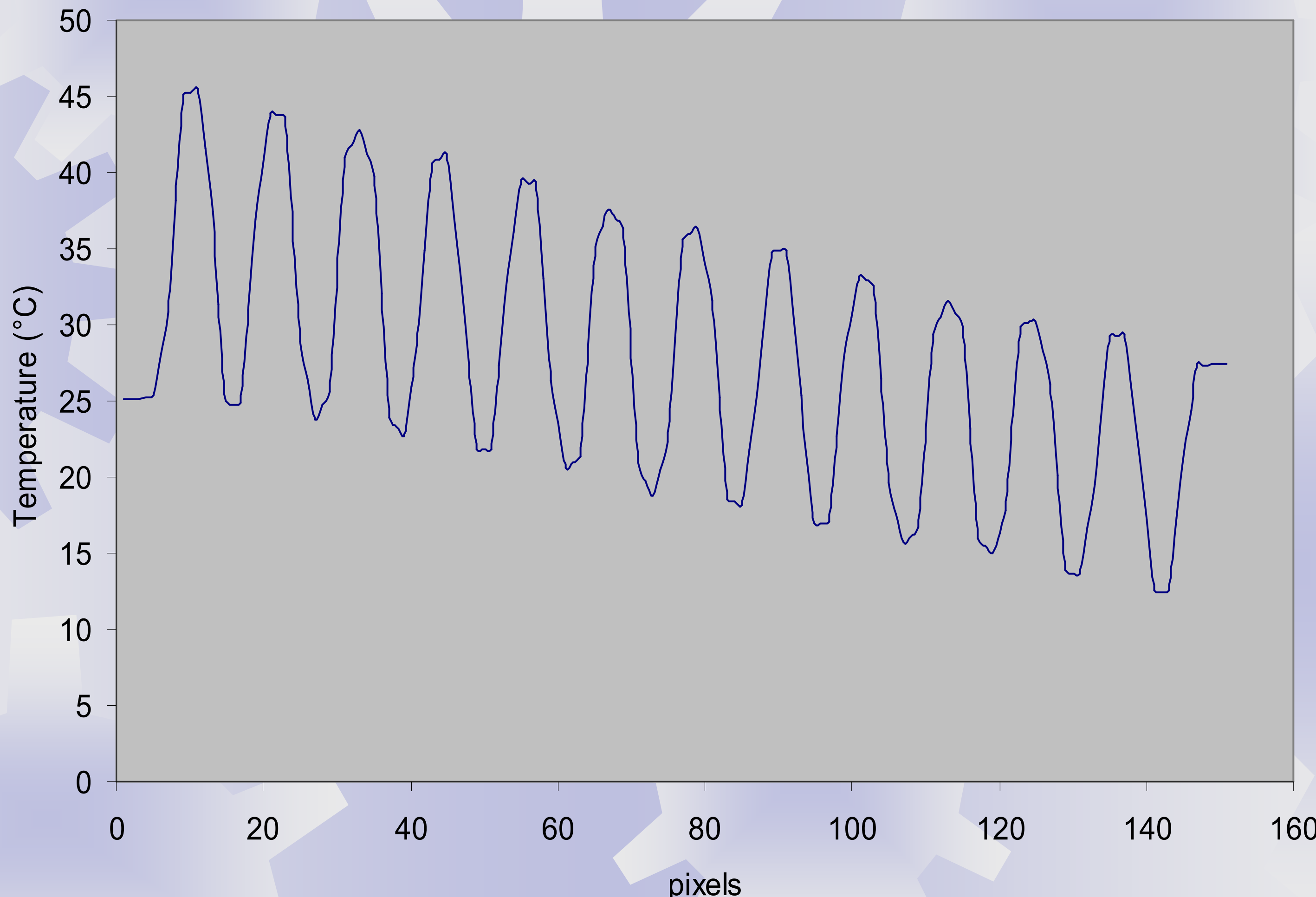


Breadboard subassembly.

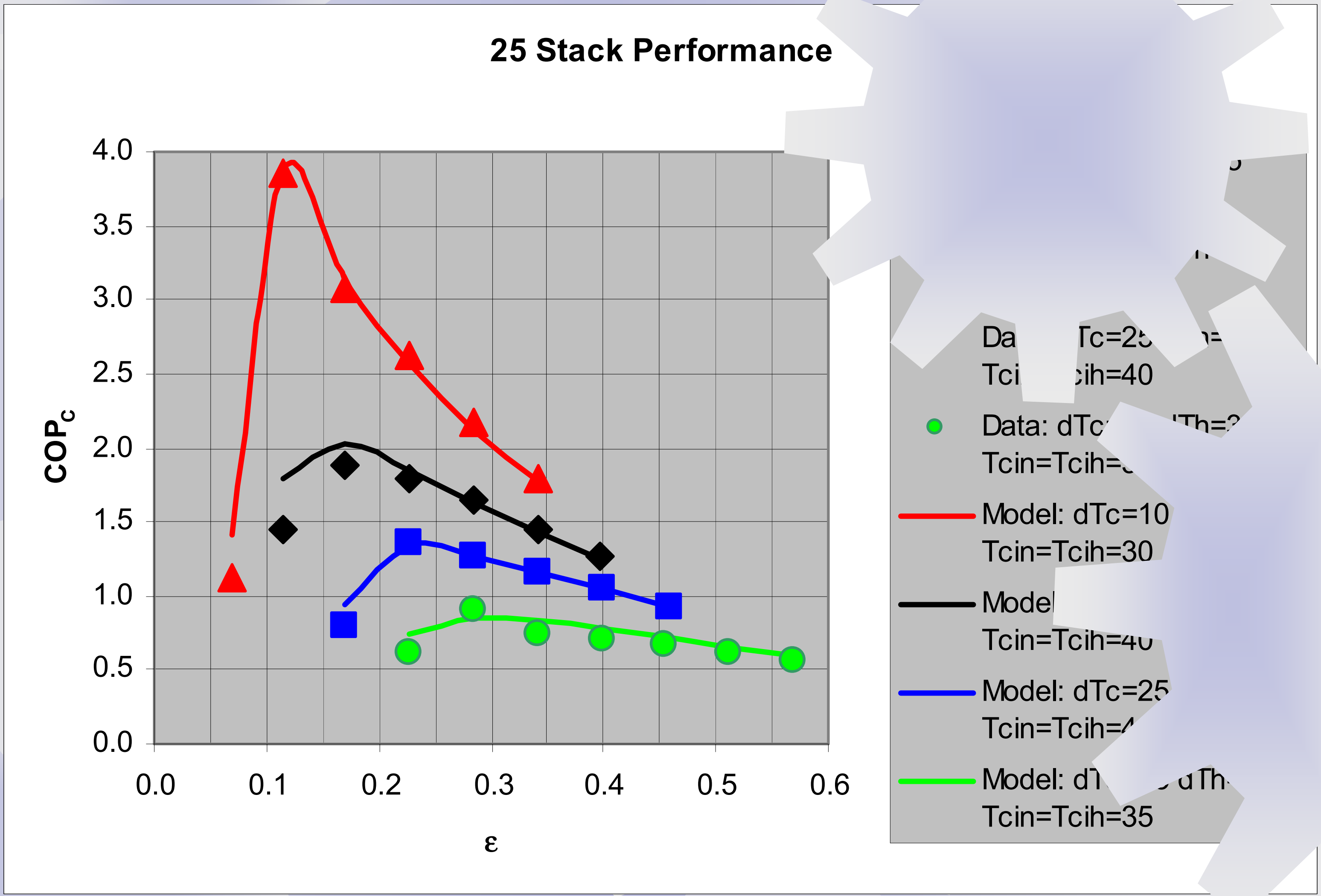
Infared Camera Image of TED Subassembly



Temperature Profile of TED Subassembly (using IR camera)



TE Subassembly Simulated and Measured Performance Results



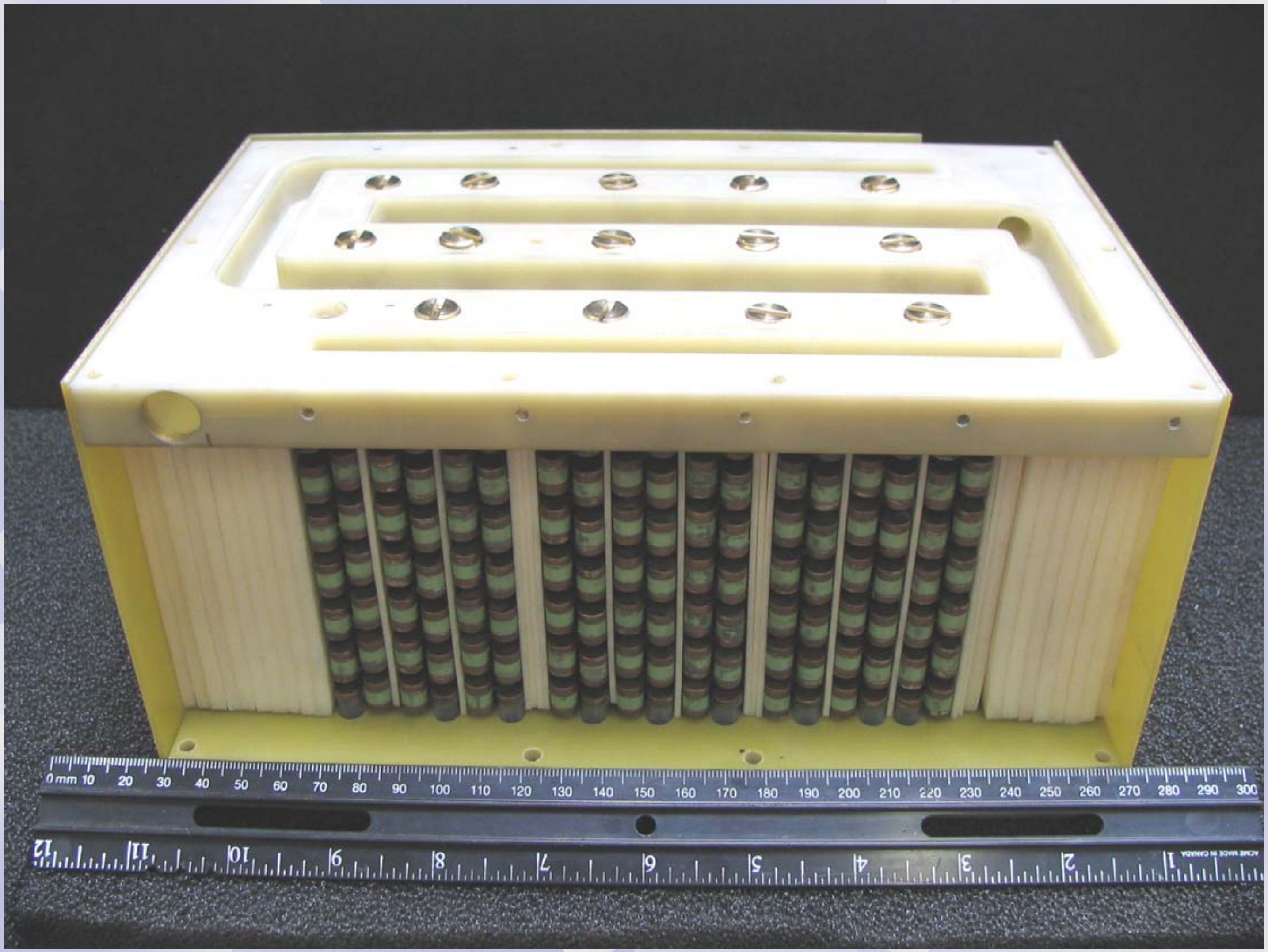
Properties Comparison of Stand rd and Stack Design TE Mod

Parameter	Standa od	ack
Thermal cooling p ΔT_c = 10°C; ΔT_h = 5	[illegible]	10
TE material weight (g	[illegible]	[illegible]
Heat Exchanger weig	290.0	129.4
Weight of other mat substrates, sealan , wir	[illegible]	[illegible]
Total subsystem weight ams)	485.3	146.8
Volume (liters)	0.0616	0.0521
Power density (watts/liter)	1057	1250
Specific cooling power (watts/gram)	0.134	0.443
Peak efficiency (COP)	2.25	4.20

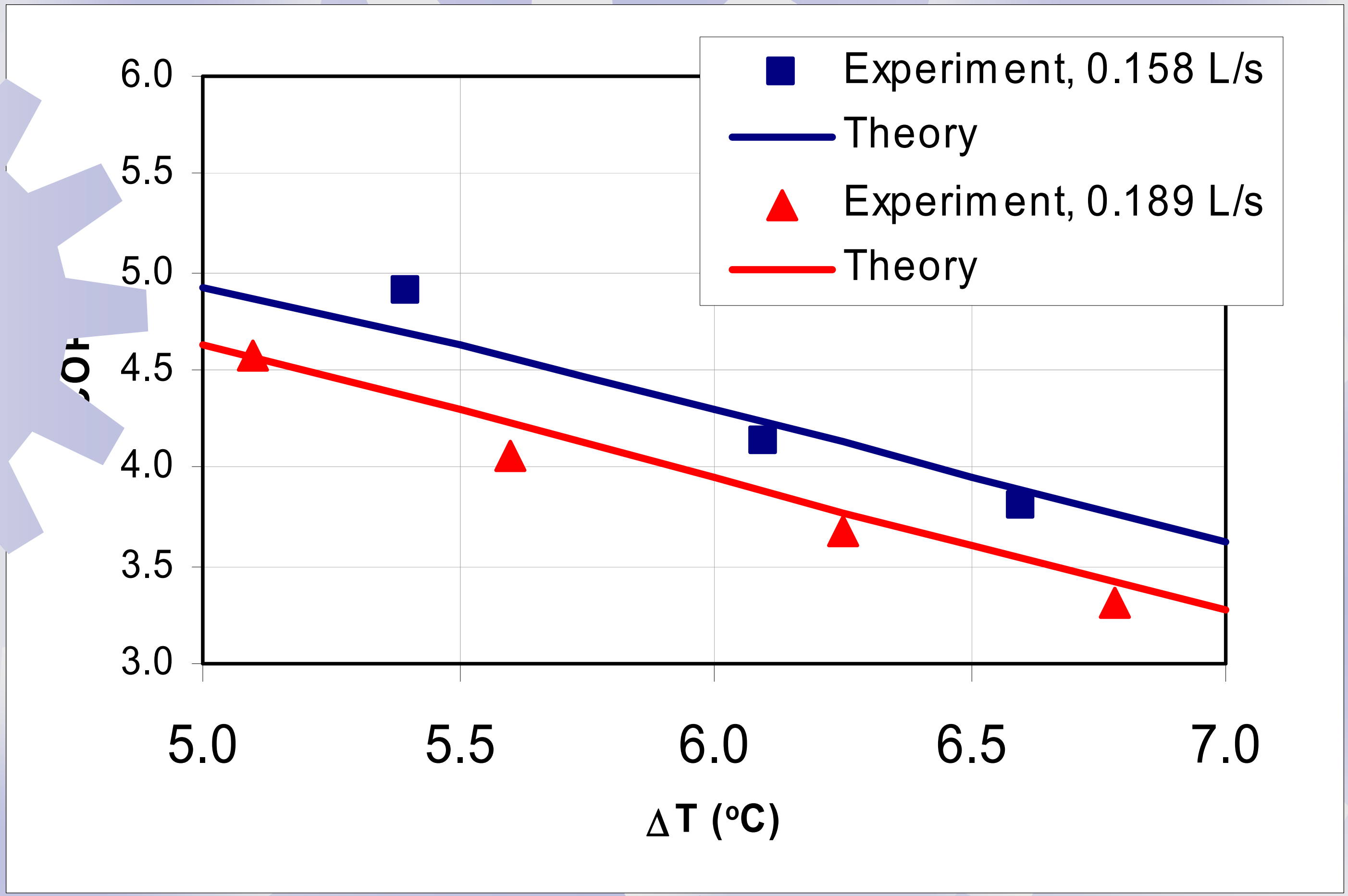
Liquid to Liquid TED Des[illegible]gn Objectives

1. The dev[illegible] s[illegible] [illegible]omi[illegible]al [illegible]ing capacity c[illegible] [illegible]oli[illegible]
2. The sy[illegible] [illegible] cooling [illegible].19 Liters/sec[illegible]
3. Electrical po[illegible] [illegible]ion shall be less than 1,000 watts
4. Maximum weight shall be 4.7 Kg
5. Maximum volume shall be 2.0 Liters

3500 W Cooler System



Comparison of Computed and Experimental Results for 3,500W Cooler



System Performance Results

Parameter	Final Design
Thermal cooling power at $\Delta T_c = 6^\circ C$ (watts)	3500
System weight (Kilograms)	4.4
Weight of other materials (shunts, substrates, sealants, wiring) (Kilograms)	0[illegible]
Total system weight (Kilograms)	4.6
Volume (Liters)	[illegible]
Power density (Kilowatts/liter)	2.26
Specific cooling power (watts/gram)	0.76
Peak efficiency (COP)	4.2[illegible]

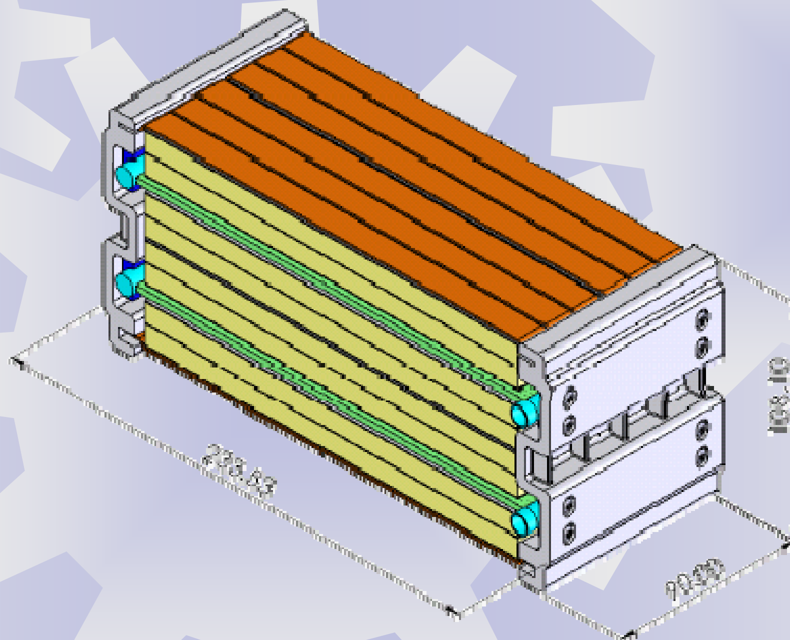
Liquid to Air TED

Designed to pr… tin… vehicle c…

Performance…

- In he… liq… to …e air achieving … 2.5 (250… watts @ 1000 wa… …wer)
- In cool… …eat from air to the liquid and achiev… …5 (1500 watts of cooling @1000 wa… ele… cal i… put power)
- Nominal ΔT in air – 20C lift in heating and 15C depression in cooling

Liquid-air thermoelectric heater/cooler

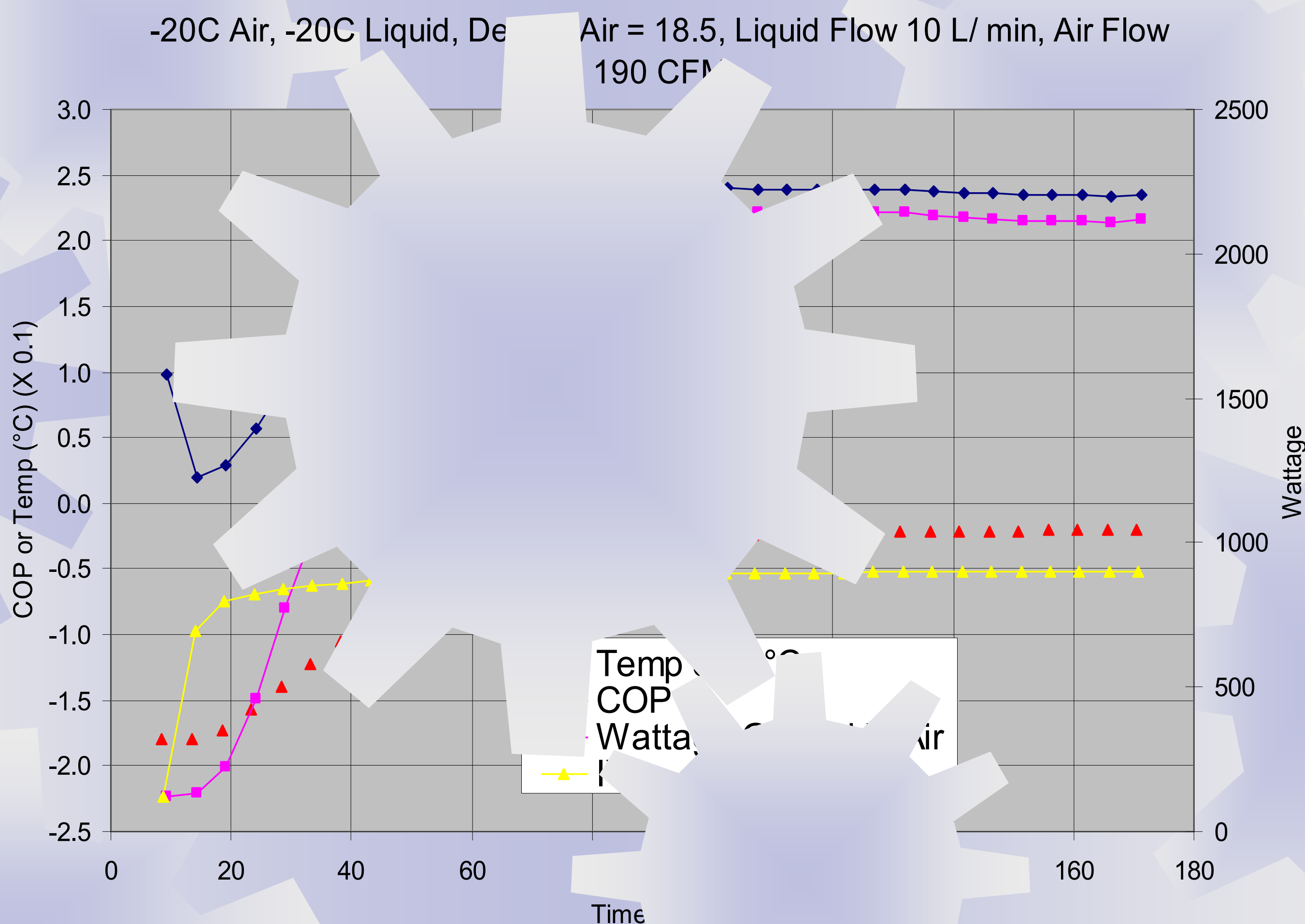


	Heating Mode		Cooling Mode
Qh (W)	600	Qc (W)	330
Qin (W)	240	Qin (W)	220
COP	2.3	COP	1.5
Air flow rate (L/s)	25.5	Air flow rate (L/s)	16.6
water flow rate (cc/s)	60	water flow rate (cc/s)	60
ΔT_air (C)	23	ΔT_air (C)	-18
ΔT_water (C)	-1.4	ΔT_water (C)	2.2
T_air_inlet (C)	25	T_air_inlet (C)	35
T_water_inlet (C)	25	T_water_inlet (C)	35
ΔP_air (KPa)	0.075	ΔP_air (KPa)	0.05
DP_water (KPa)	2.1	DP_water (KPa)	2.1

Volume: 2848cc

DWG NAME: TABLE TOP UNIT
DWG No.: 060044036
REV: A
UNIT: mm
SCALE: 1:2
DATE: 3/1/06

Liquid to Air Heating Performance



COP of 2.5 predicted a ... ally validated

Waste Heat Recovery Using Thermoelectrics to Increase Fuel Efficiency

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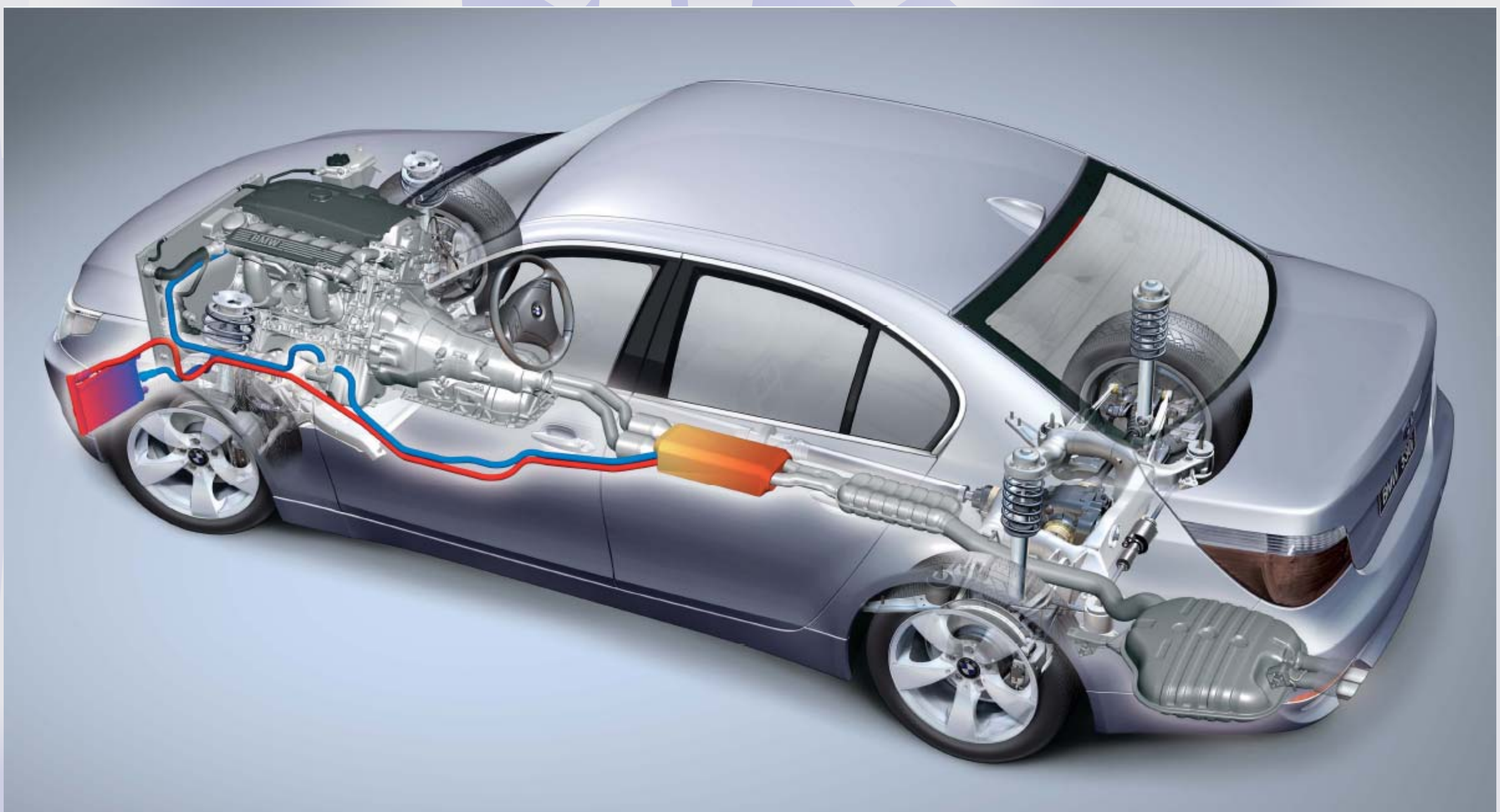
Thermal Management.
Thermoelectric Generator.

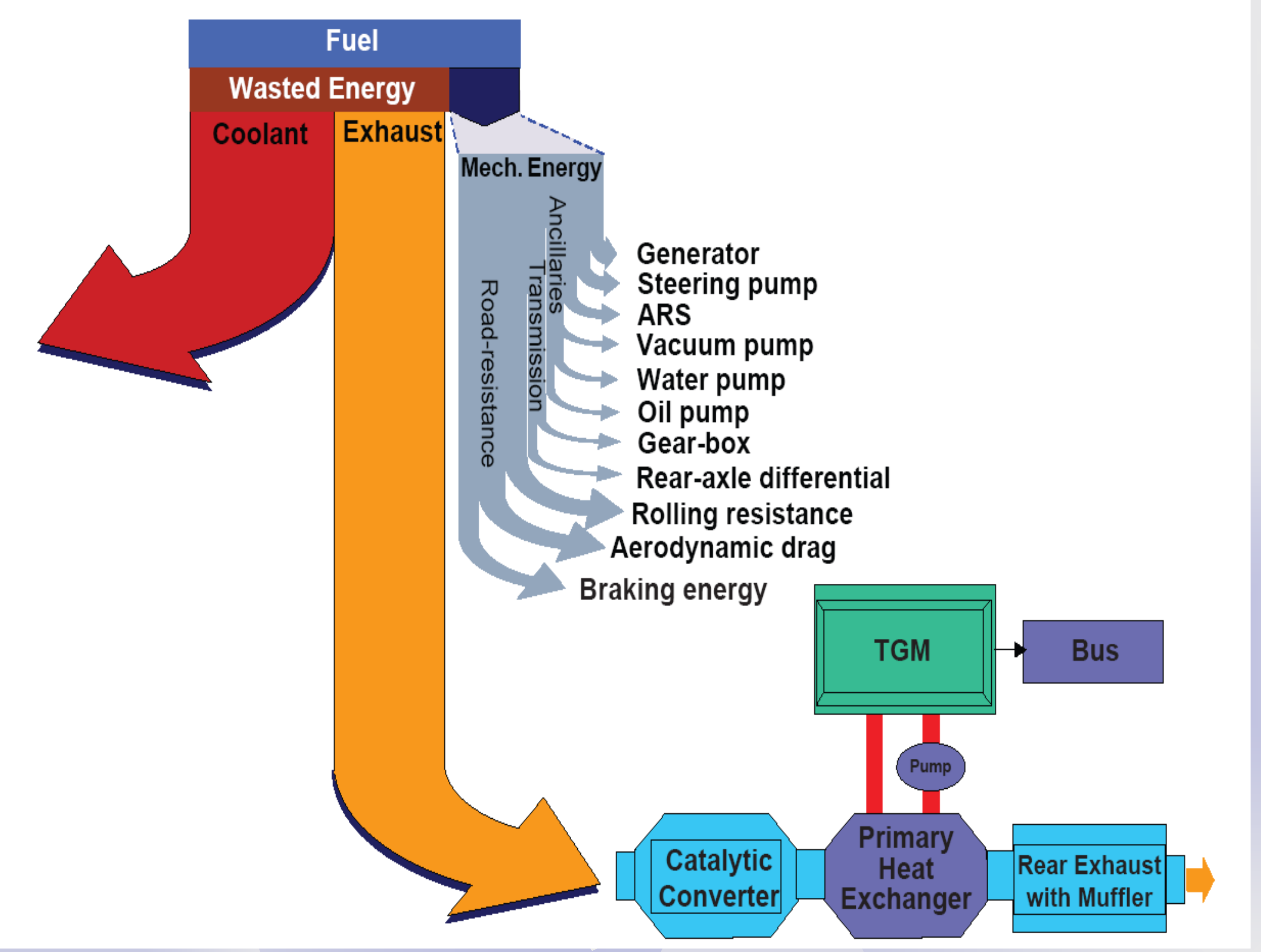


FreedomCAR & Fuel Partnership

Visteon

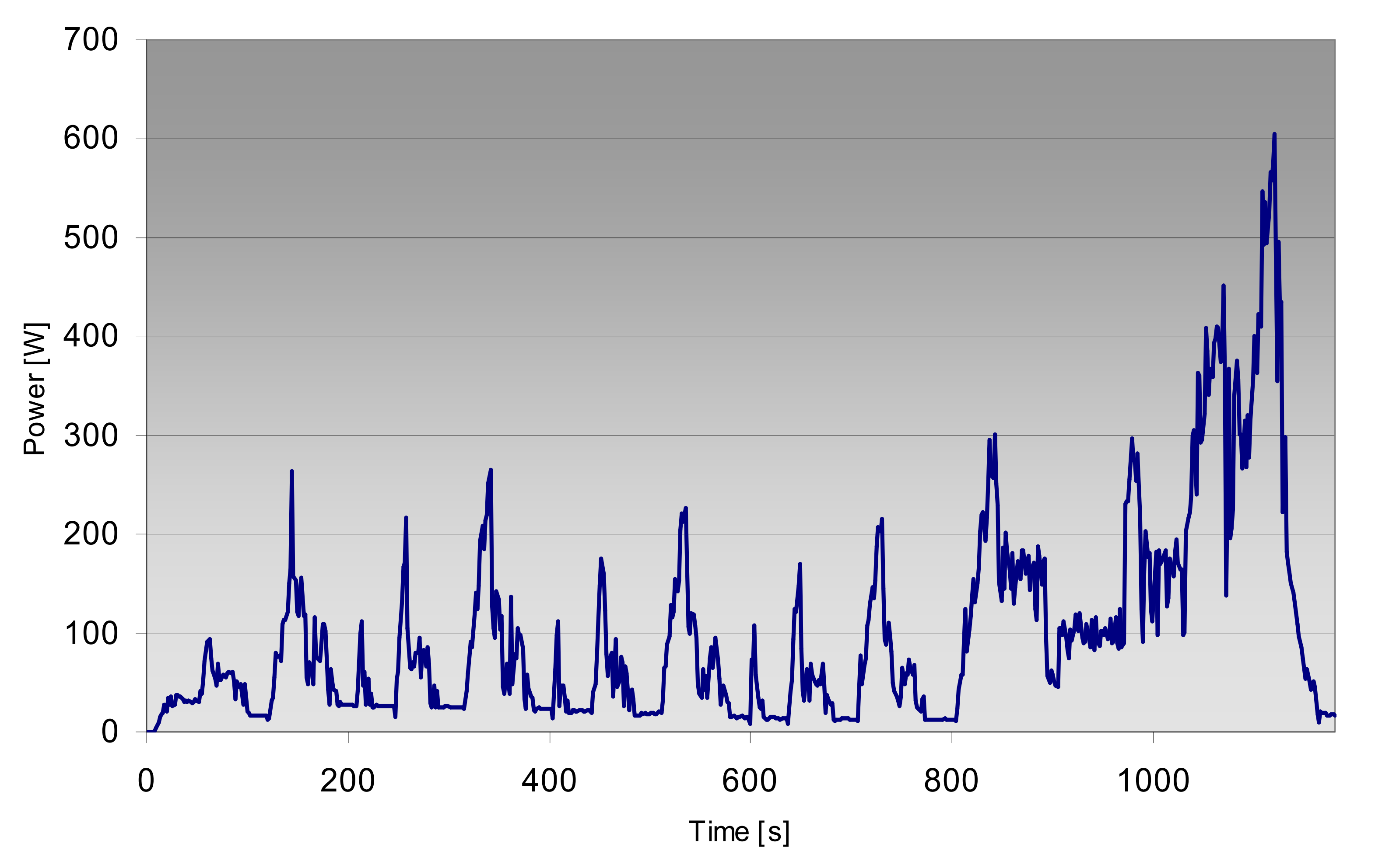
BSST
innovative solutions
in temperature control

System Block Diagram



System Modeling

Electrical power output of the TGM (for NEDC)



Summary & Conclusions

Amerigon's Climate Control Seat has validated the application of thermoelectrics in the automotive industry with over 1,000,000 devices sold in 2005 and scheduled volume increases in the next several years

New applications are in development at Amerigon and BSST that achieve improved performance by employing thermal isolation and high density design and construction

1. Performance is improved by about 90% by employing thermal isolation with thermodynamic cycle
2. TE material usage is reduced by a factor of 4 by;
   a) Using stack design
   b) Design optimization to reduce unnecessary parasitic losses

Compact, light weight, efficient cooler/heater/temperature devices can be produced with up to at least 5,000 thermal watt output

A thermoelectric waste heat recovery has been modeled to demonstrate 10% fuel economy improvement and key systems will be built and tested this year