EPSRC – Thermoelectric Network

University of Glasgow | College of Science & Engineering

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Considerations on the Applications of Thermoelectric Devices

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Contents

I. Thermoelectric generation

- ❖ Constant temperature vs constant heat TEG characterization.
- ❖ Maximum power point (MPP) in constant heat.
- ❖ TEG test and application Glasgow systems – description and system issues discussion.

II. Thermoelectric cooling

- ❖ THP characterization.
- ❖ Heat battery system – design and system issues.

PART I

THERMOELECTRIC GENERATION

University of Glasgow

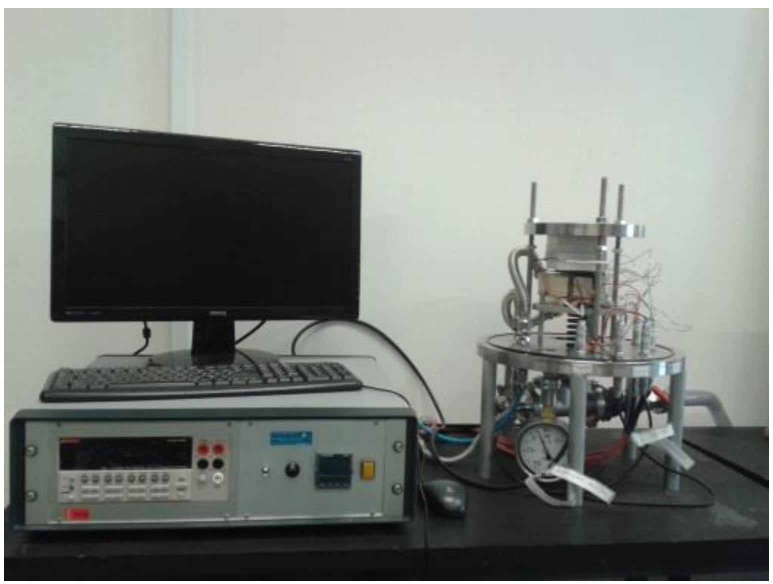
“Constant temperature” characterization

SUNTRAP

What does it mean?

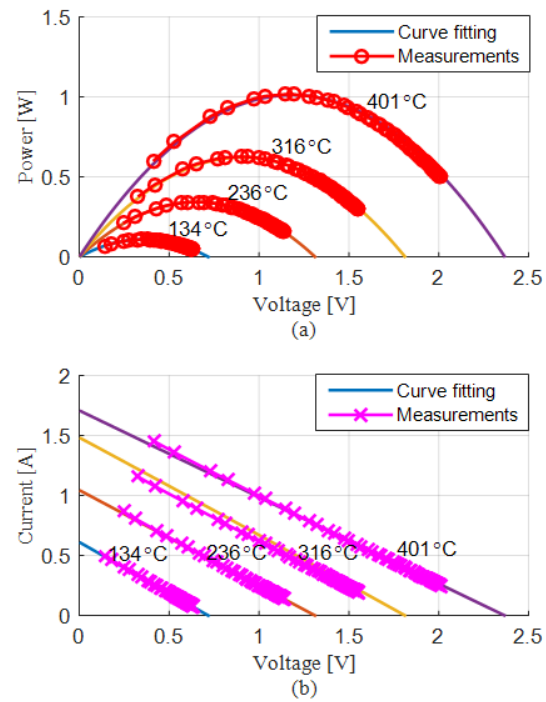
- Maintaining a constant temperature difference across a TE module using a controllable setup, independent of any other parameters in the system.

How?



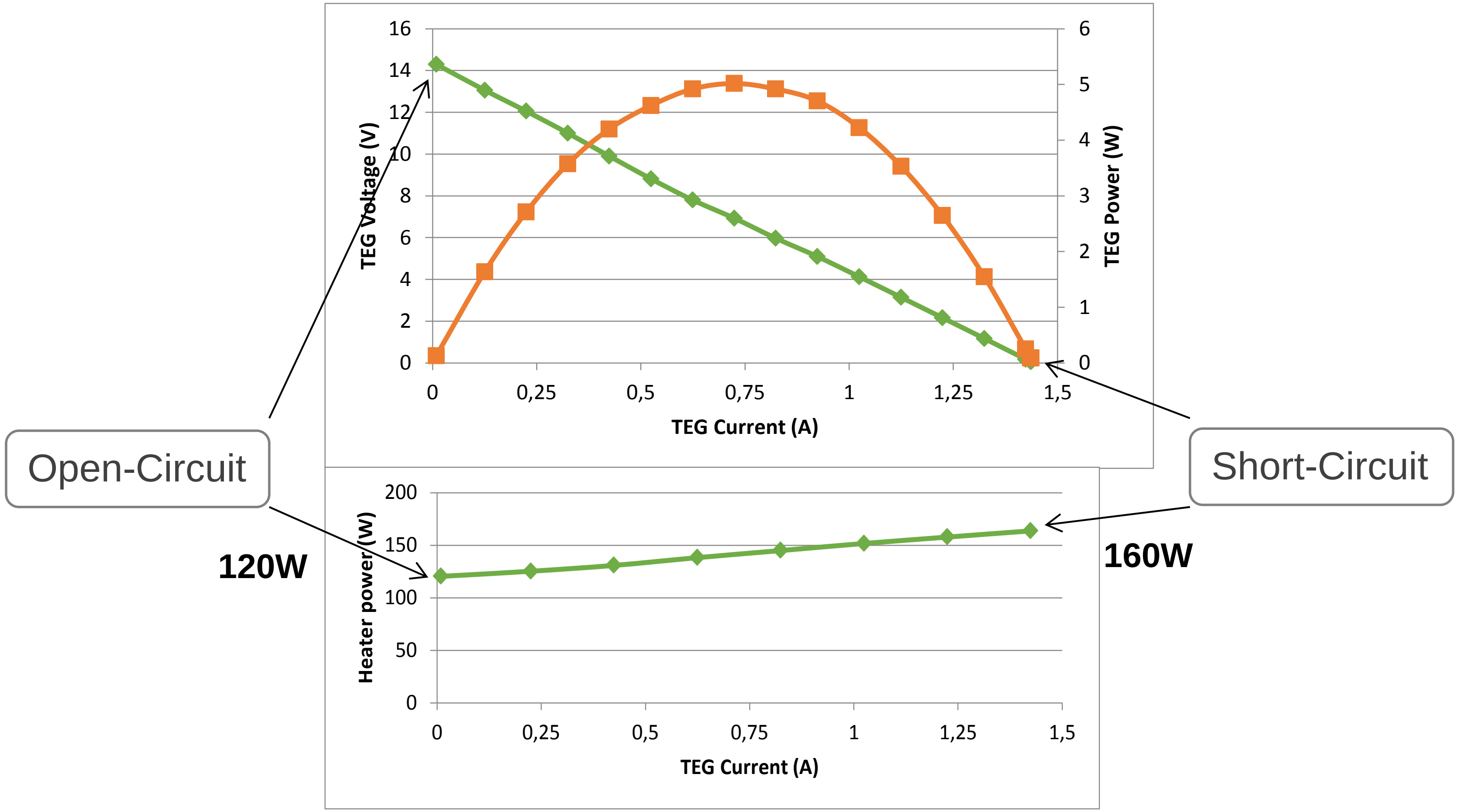
Commercial TE module parameter characterization setup

Why?



Constant temperature a) *P-V* and b) *I-V* curves of a TE module

Constant temperature constraints



Heater power variation during **constant temperature** (ΔT = 154 ºC) testing of thermoelectric module from open-circuit to short-circuit condition.

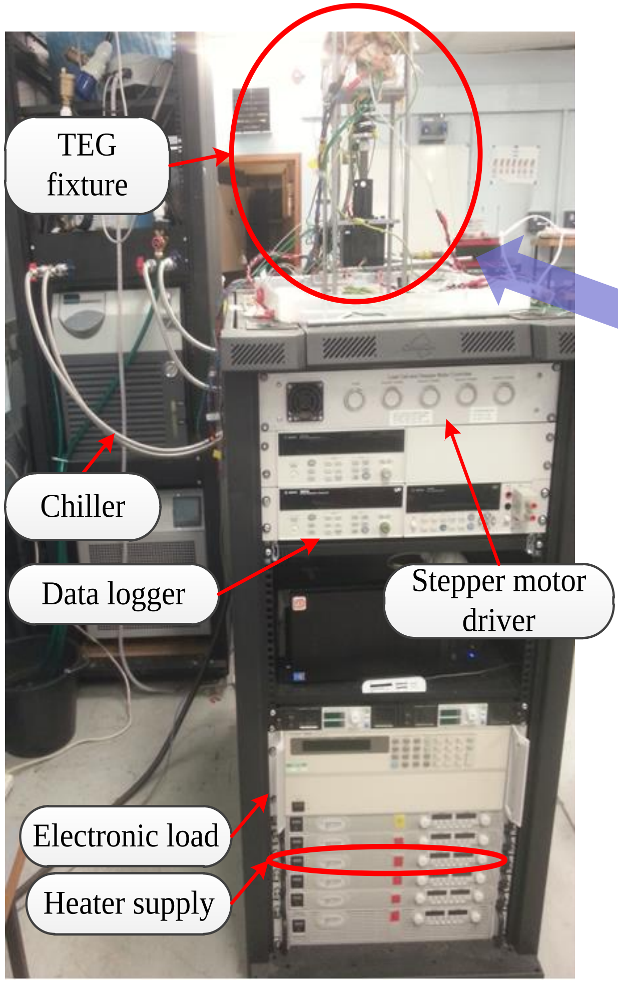
“Constant heat” characterization

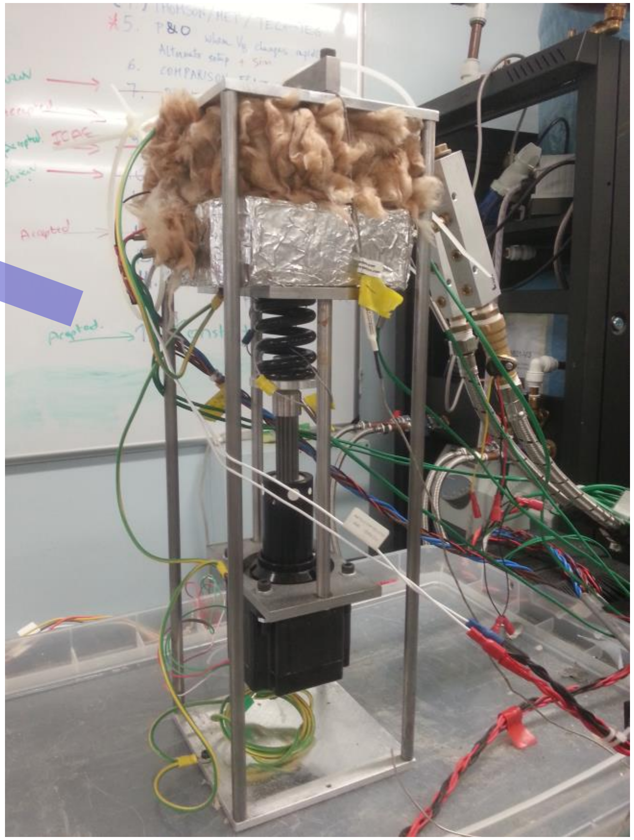
Why ? *Heat available for TEG integration is “limited” – significantly less constant temperature available for load changing conditions.*

How ? *Using a test fixture and controlling the heat flux through the TEG rather than maintaining a constant temperature gradient across the module.*

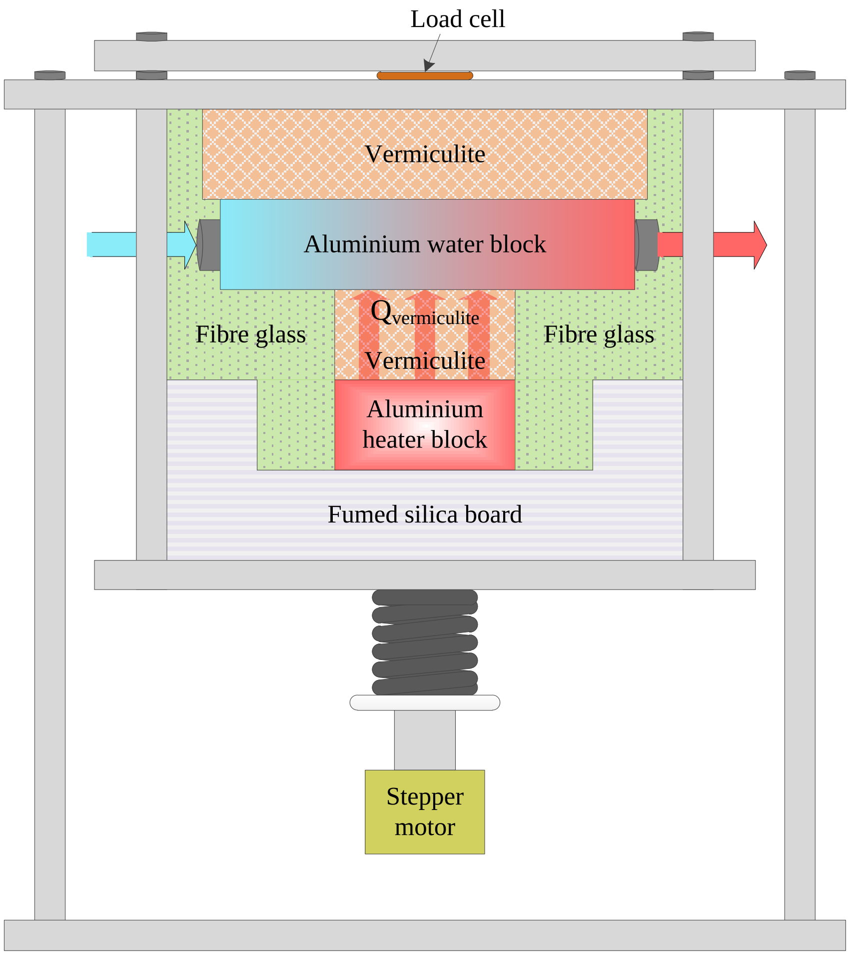
Target? *Considering the electrical and thermal interaction in the TEG system.*

TE module test fixture





Heat loss characterization



$$Q_{loss} = P_{heater} - Q_{vermiculite} = P_{heater} - \kappa_{Verm} A_{Verm} \frac{T_h - T_c}{l_{Verm}}$$

1) P_{heater} – known (set by user).

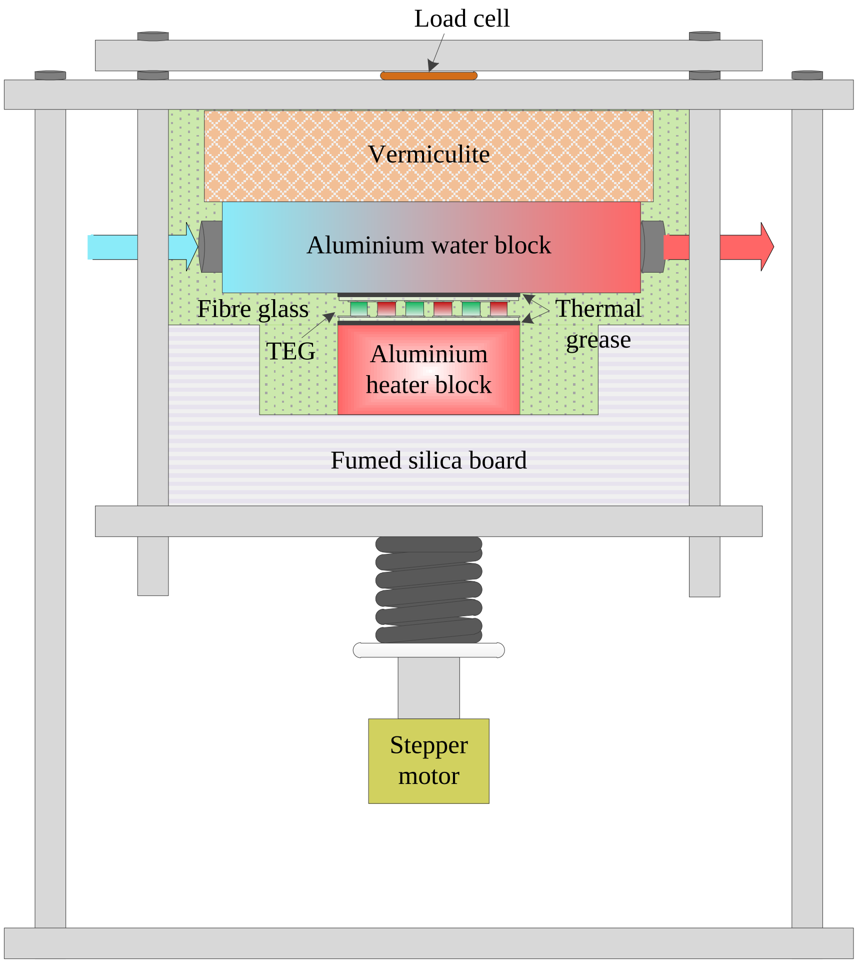
2) κ_{Verm} = 0.07W/m·K
A_{Verm} = 0.0016m^2
l_{Verm} = 0.025m
Th and Tc measured

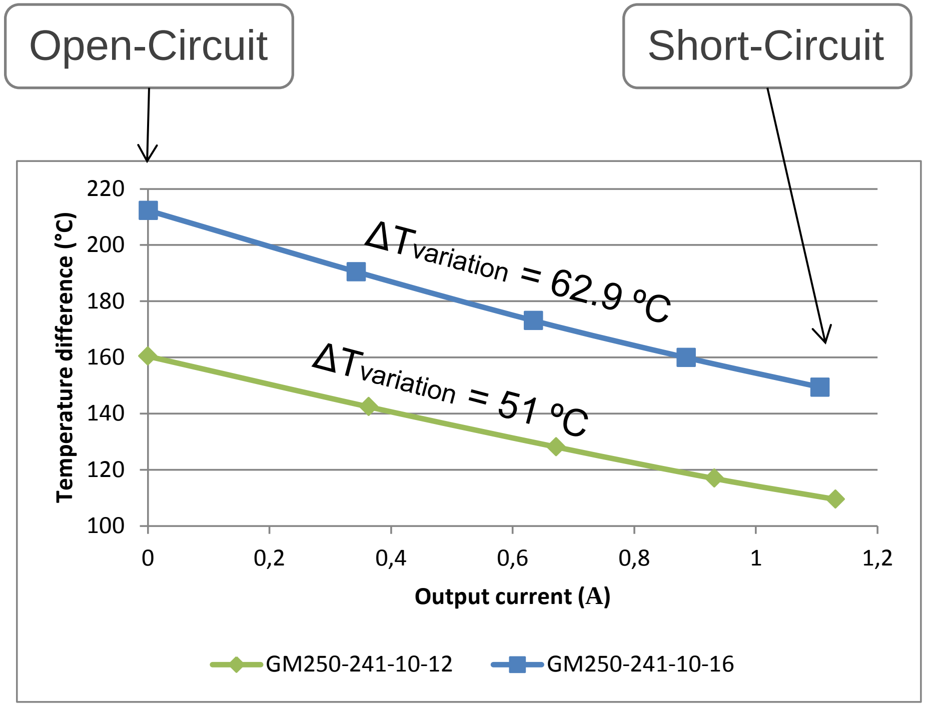
$Q_{vermiculite}$ can be calculated

$$Q_{losses\_fit} = 3 \cdot 10^{-5} \cdot T_h^2 + 0.0357 \cdot T_h$$

$$Q_{teg} = Q_{heater} - Q_{losses\_fit}$$

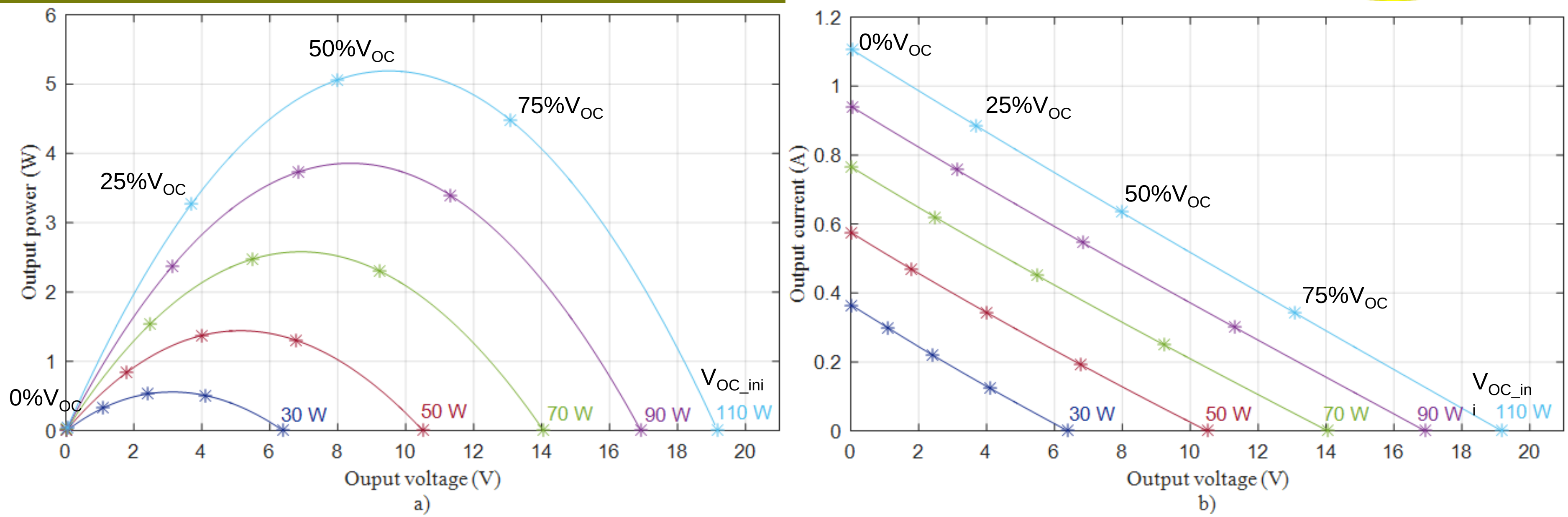
Constant heat characterization





Temperature difference variation in constant heat testing of thermoelectric module from open-circuit to short-circuit condition.

Constant heat characterization



Output power versus output voltage and b) output current versus output voltage for GM250-241-10-16. The module was tested in constant heat starting at 30W to 110W with 20W increments.

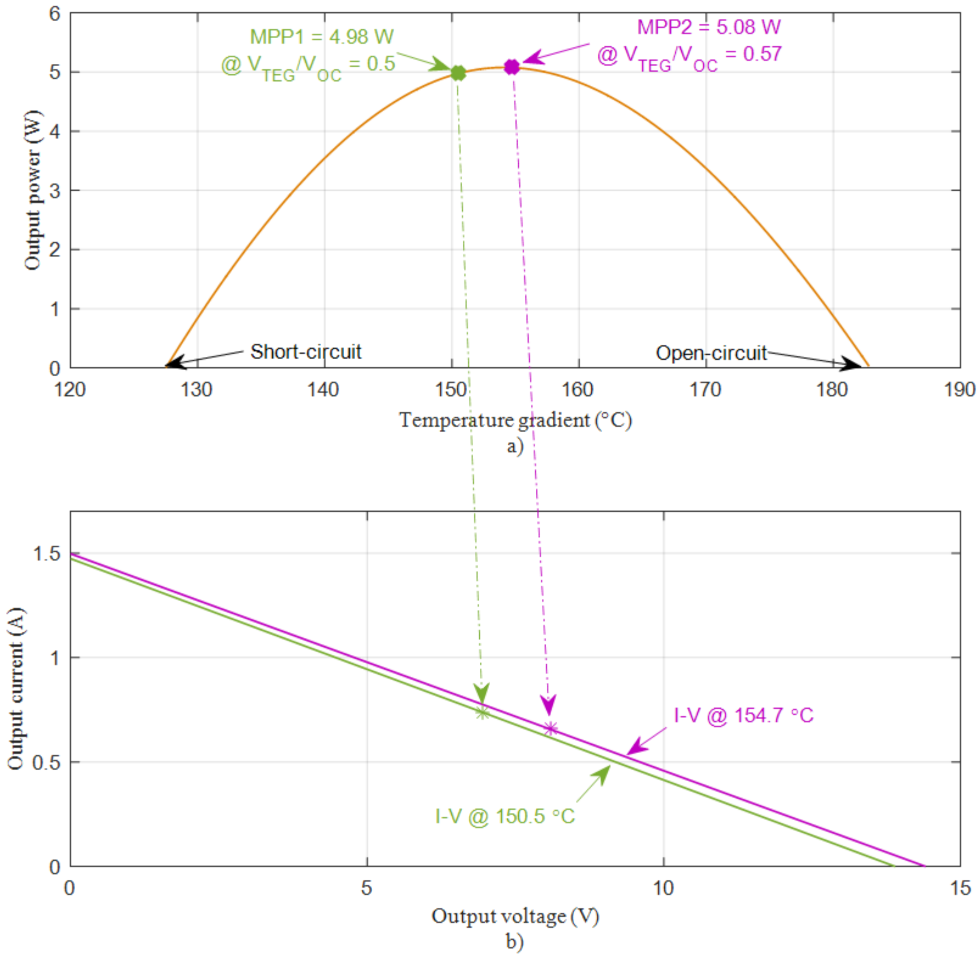
STEPS:

1. Maintain constant heat flow through module (e.g. 110W) and reach thermal equilibrium.

2. Measure V_{OC_ini} and set $V_{load} = \beta V_{OC\_ini}$ where β ={75,50,25,0}.

3. Repeat V_{OC} measurements every few seconds and set V_{load} until thermal equilibrium, then measure and log voltage and current values.

MPP in constant heat



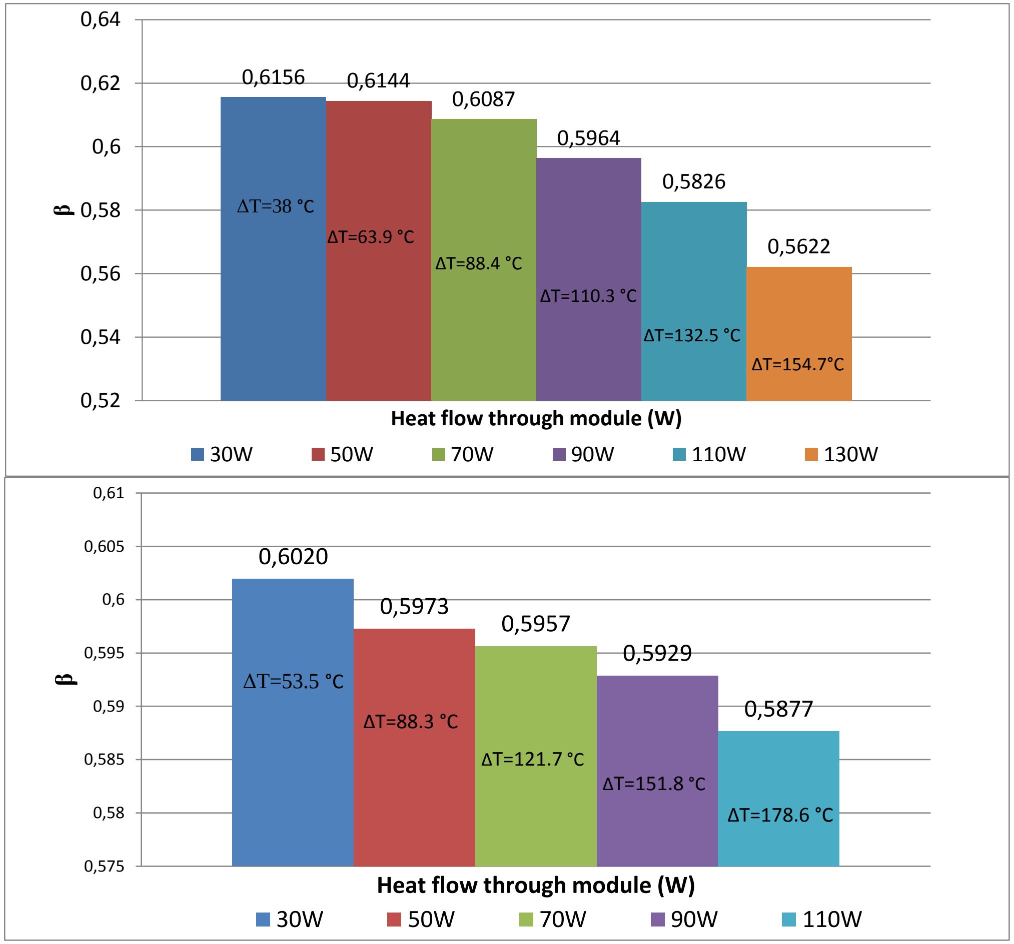
Output power versus output voltage (constant heat @ 130W)

and b) output current versus output voltage (constant temperature) for GM250-241-10-12.

MPP in constant heat

The fraction between the set voltage and V_{OC} (β) that sets the conditions to achieve MPP in constant heat

$\beta = V_{load}/V_{OC}$



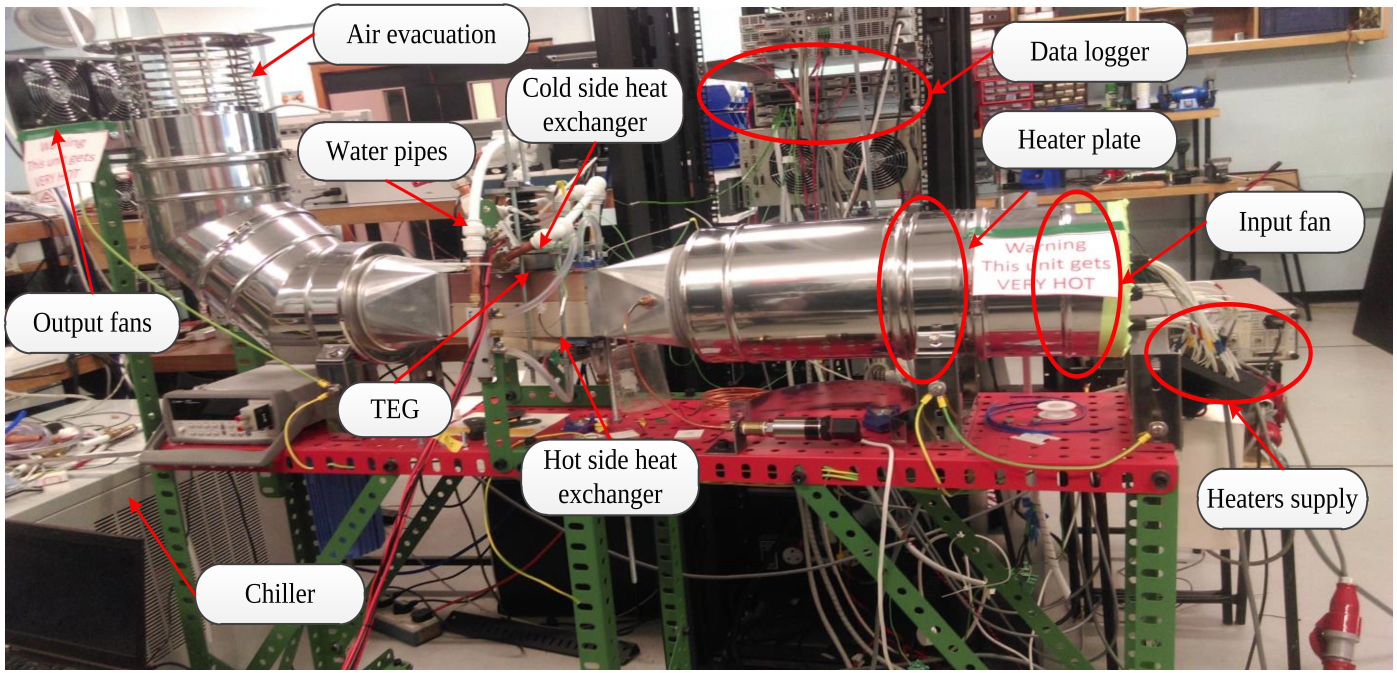
GM250-241-10-12
(40mmx40mmx1.2mm)
(short pellets)

ΔT on TEG faces

GM250-241-10-16
(40mmx40mmx1.6mm)
(longer pellets)

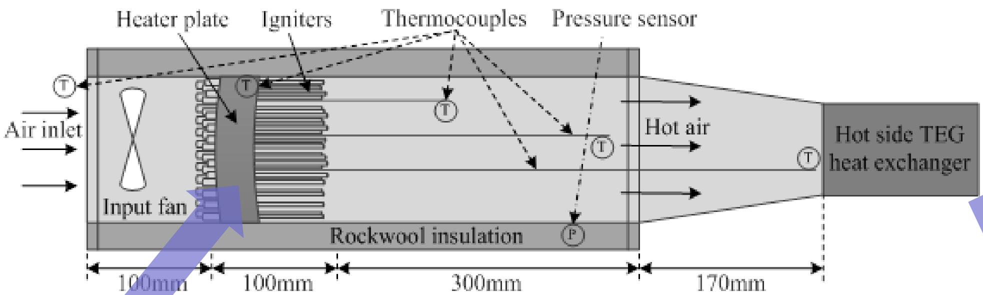
Hot gas system

Partially controllable test system to validate real MPP concept



Hot gas system

Schematic of the heater side



Heater plate

Cold heat exchanger

TEG module assembly

Hot gas system - Results

Power increase: real MPP vs theoretical MPP (maximum power transfer theorem)

GM250-241-10-16				
Q_{teg} (W)	β	$P_{MPP,\beta=0.5}$ (W)	$P_{MPP,\beta\neq0.5}$ (W)	PowerIncr. (%)
30	0.602	0.5307	0.5583	**5.20**
50	0.5973	1.3736	1.4421	**4.98**
70	0.5957	2.4766	2.5813	**4.22**
90	0.5929	3.7312	3.8584	**3.41**
110	0.5877	5.0577	5.1911	**2.63**

*Q_{teg_max} = 145W

GM250-241-10-12				
Q_{teg} (W)	β	$P_{MPP,\beta=0.5}$ (W)	$P_{MPP,\beta\neq0.5}$ (W)	PowerIncr. (%)
30	0.6156	0.3699	0.3875	**4.75**
50	0.6144	0.9591	1.0101	**5.31**
70	0.6087	1.8138	1.9081	**5.19**
90	0.5964	2.7708	2.8827	**4.03**
110	0.5826	4.0509	4.1947	**3.54**
130	0.5622	4.9816	5.0769	**1.91**

*Q_{teg_max} = 185W

GM250-127-28-10				
Q_{teg} (W)	β	$P_{MPP,\beta=0.5}$ (W)	$P_{MPP,\beta\neq0.5}$ (W)	PowerIncr. (%)
63	0.62	1.74	1.89	**8.36**
540	0.54	23.63	24.24	**2.56**

*Q_{teg_max} = 560W

This is the increase in the maximum power obtained from the TEG

Systems comparison

Controllable TEG test system (*one-module* test fixture) vs. **Uncontrollable TEG test system (*multiple-module* hot gas system)**

Controllable TEG test system (*one-module* test fixture)

- Temperature or heat control.
- Additional parameter measurements (*i.e.* pressure, hot side temperature)
- Automatic pressure control (fixed pressure at variable temperature).
- TEG characterization (usually better performance is obtained due to improved testing conditions).
- Hot heat exchangers dimensioned to fit module (thermal short-circuit avoided).
- Small size and wight.
- Slight influenced by changing atmospheric conditions (good test repeatability).
- Low total heat flux.

Uncontrollable TEG test system (*multiple-module* hot gas system)

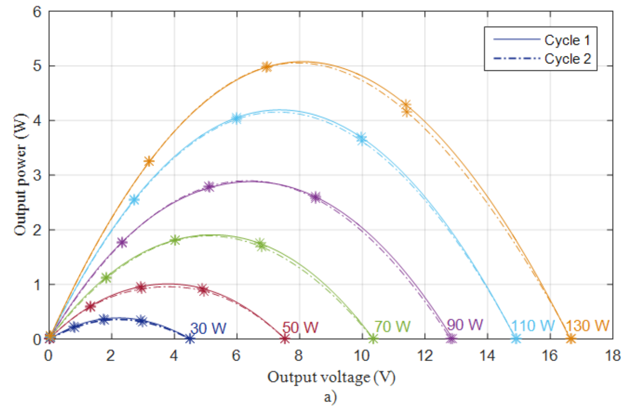
- Partial heat control.
- Fixed pressure upon assembly.
- Precise module characterization equivalent to its performance in TEG applications.
- Oversized hot heat exchanger (higher heat losses).
- Larger size and weight.
- Highly influenced by changing atmospheric conditions (more difficult to achieve test repeatability).
- High total heat flux.

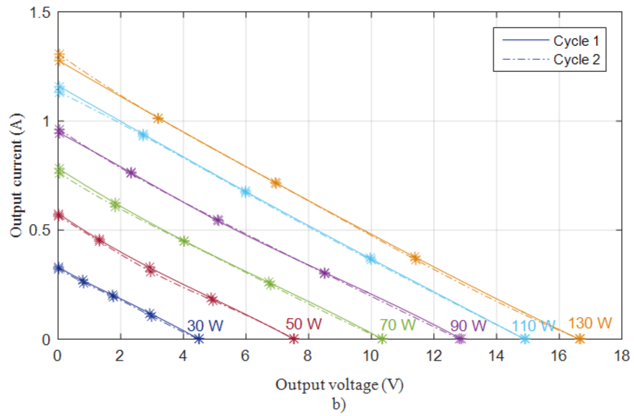
Systems results – different atmospheric conditions

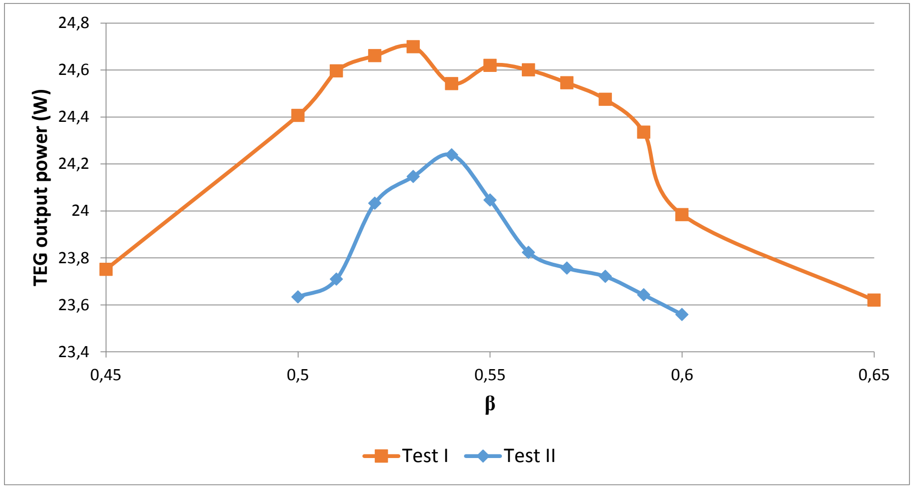
Controllable TEG test system (one-module test fixture)

vs.

Uncontrollable TEG test system (multiple-module hot gas system)



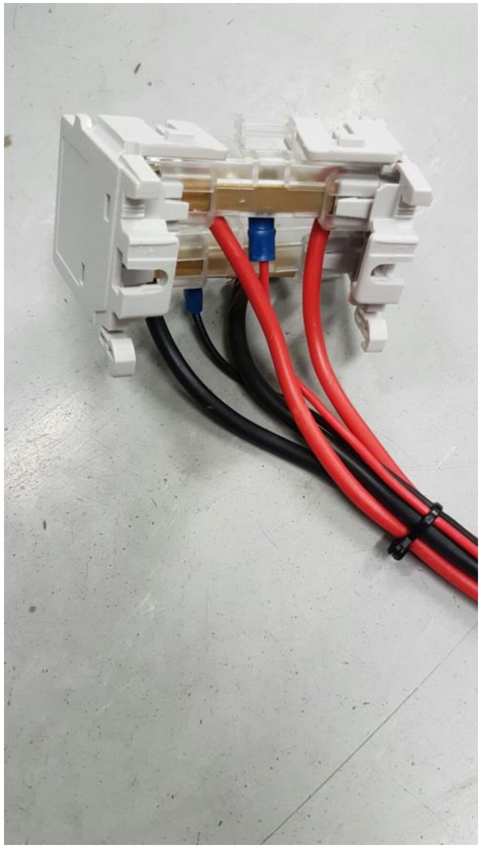




Other system issues

TE module design

- ❖ Large pellets => high current => thick cables => wire losses (~2W losses @ 10A, 24W MPP – 4-wire sense, ~2m wire length).
- ❖ High current => high losses in converters, need of large heat sink for semiconductor devices => increased volume and weight.
- ❖ Low current => failure to start-up converters and difficulties in THP control.

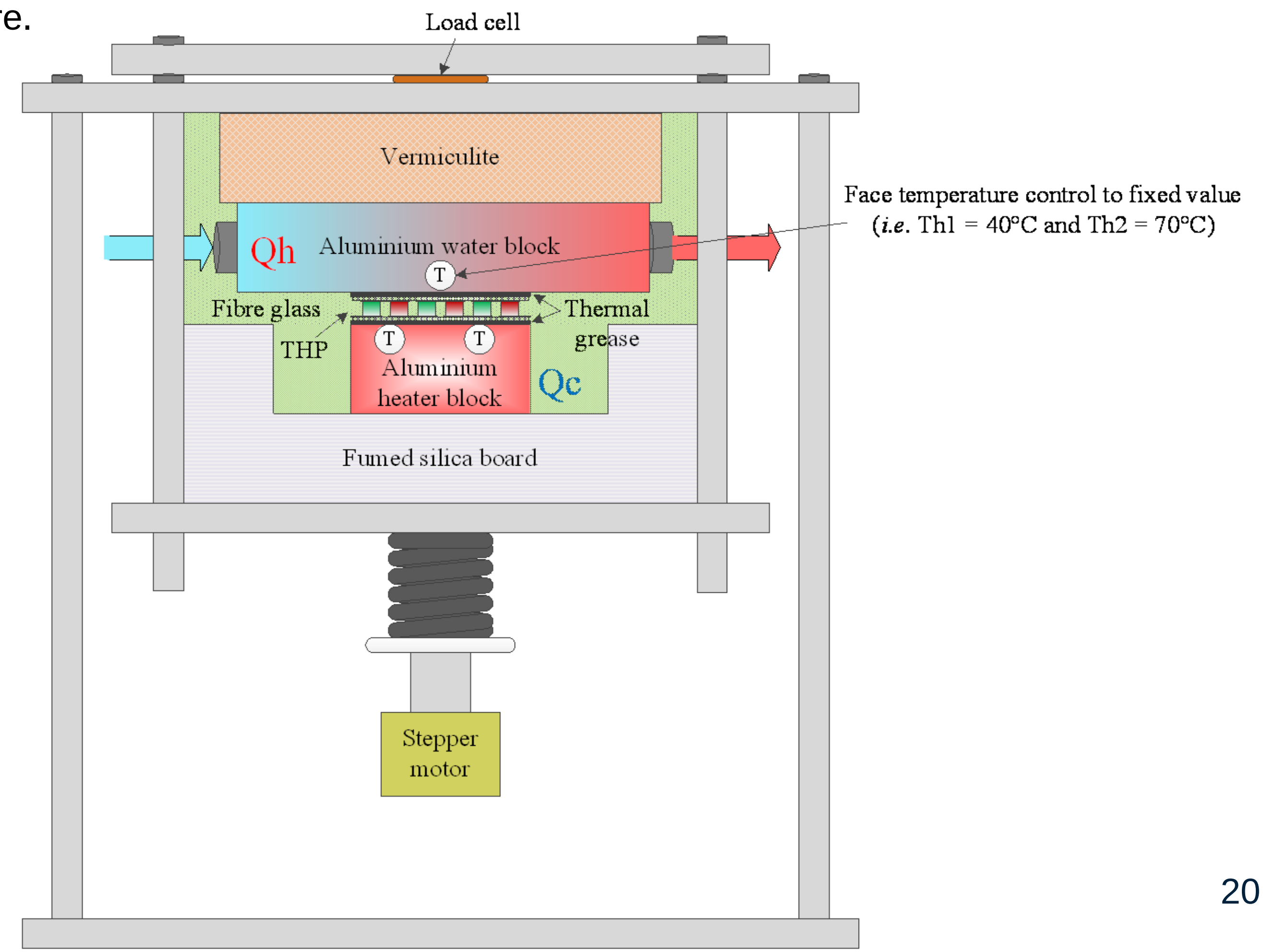


PART II

THERMOELECTRIC COOLING

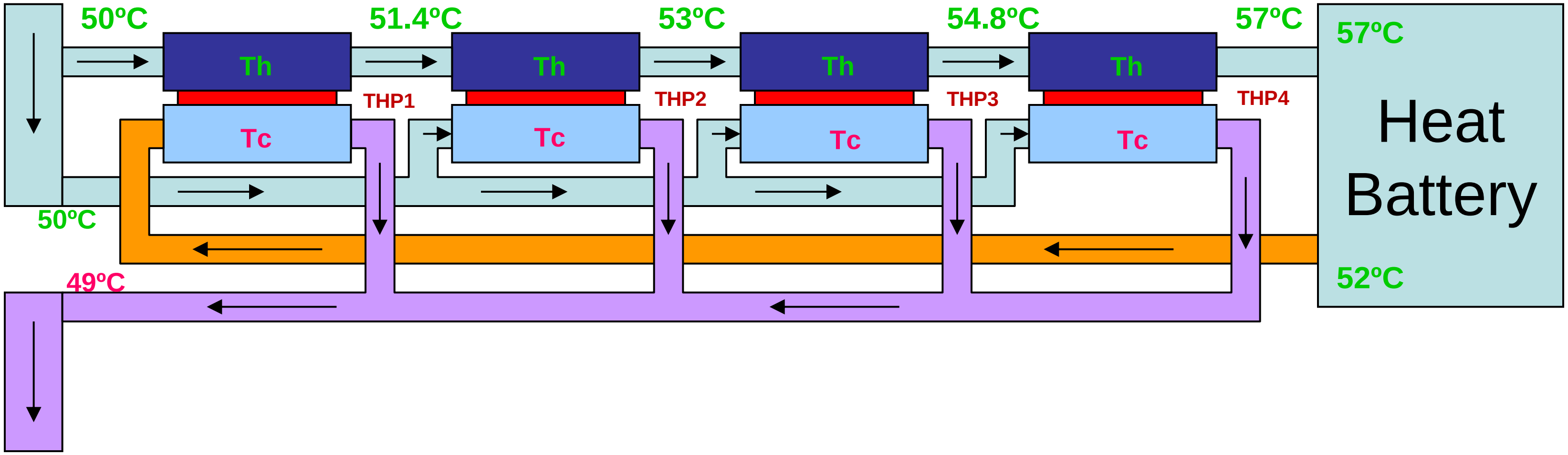
THP characterization

THP selected is a Thermonamic TEHP11256-0.3, 55x55mm module. Parameter characterization is performed using test fixture.



Heat amplifier system

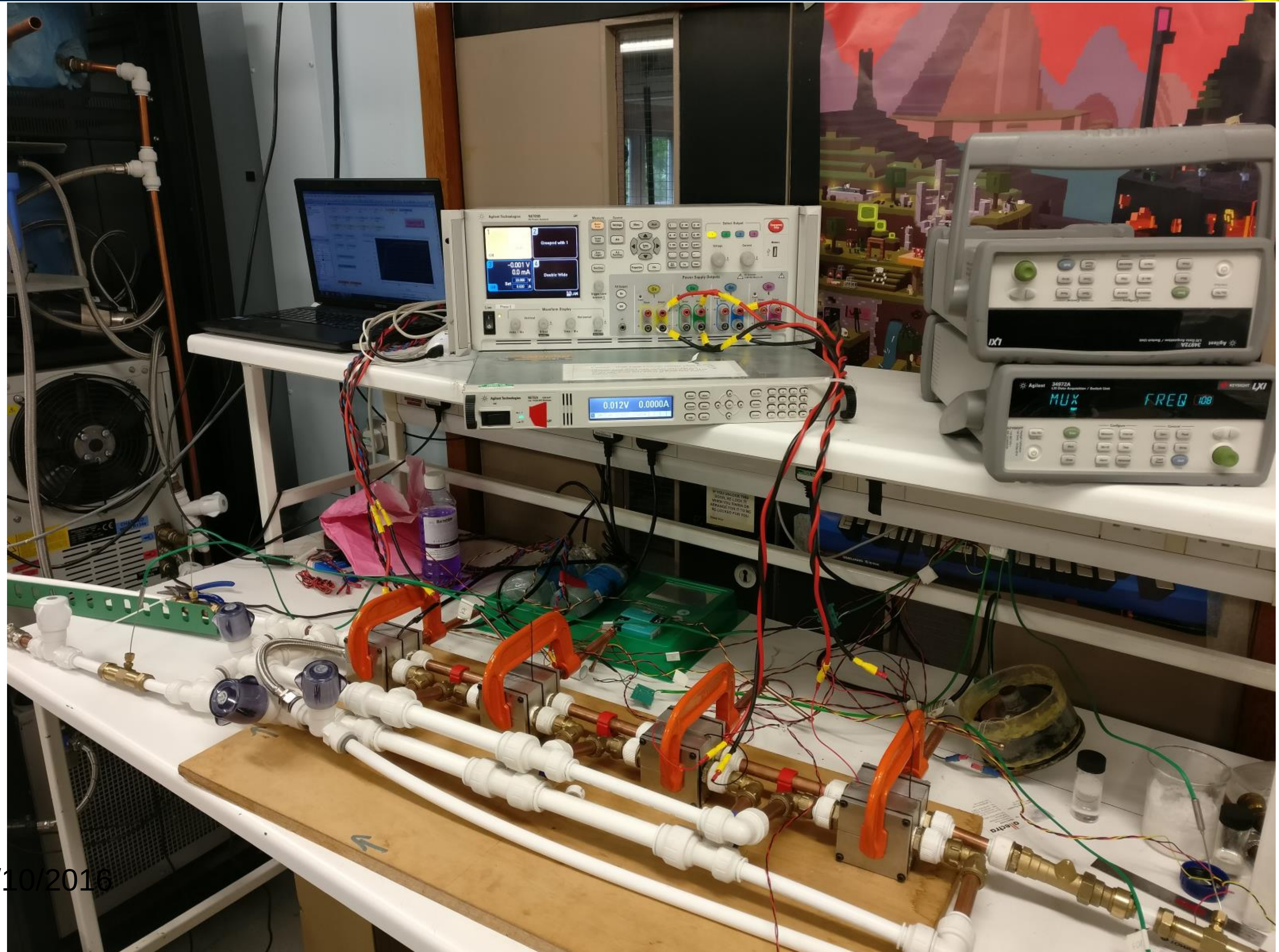
A series of cascaded heat pumps allows for water temperature to be controlled. The purpose is to boost the temperature and thermal energy to a phase change material based heat battery. Application: The input water of the heat amplifier system is previously used to cool PV panels.



This particular arrangement of pipework allows for the optimum ΔT and high COP across each stage.

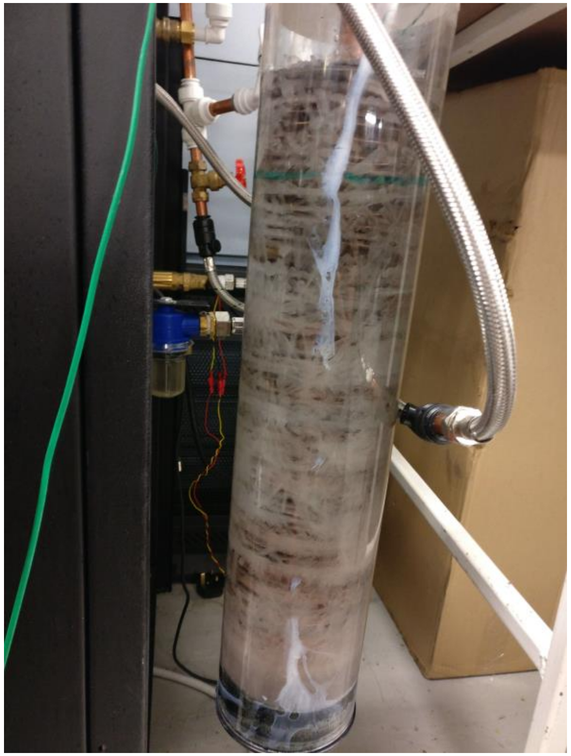
21

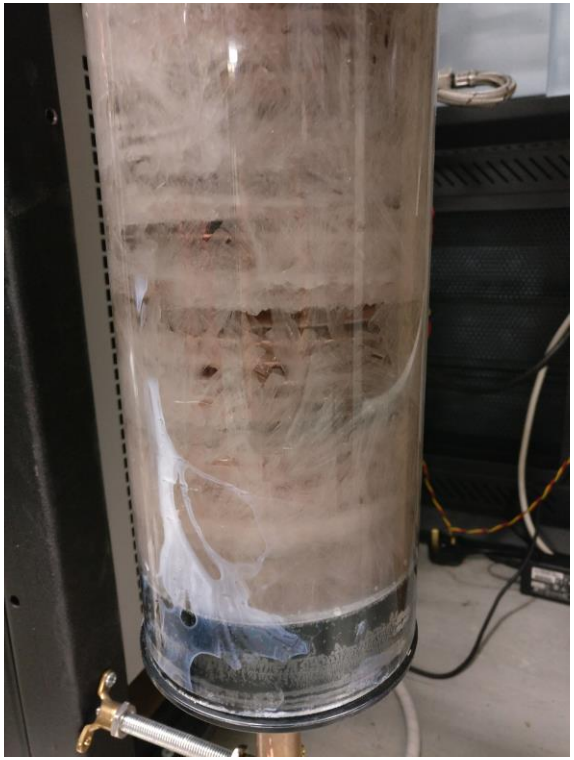
Heat amplifier system



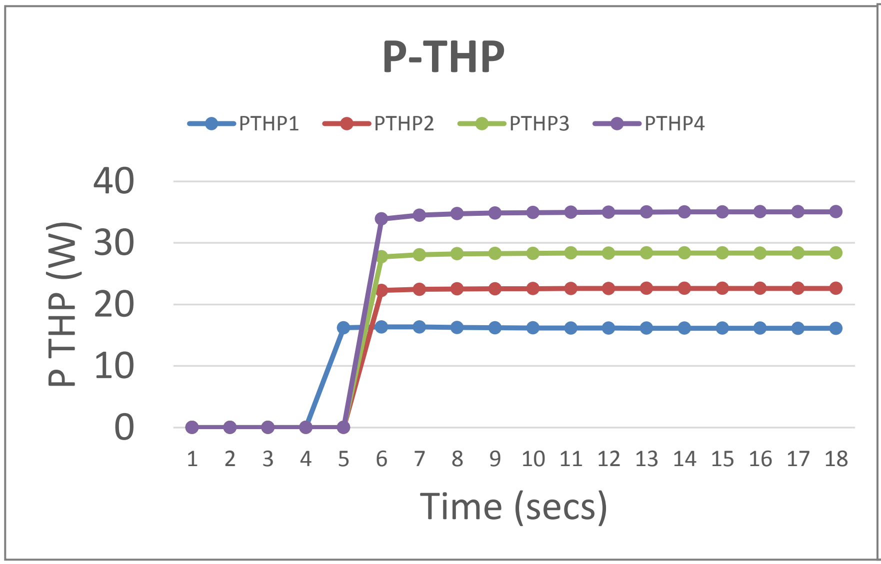
Heat battery

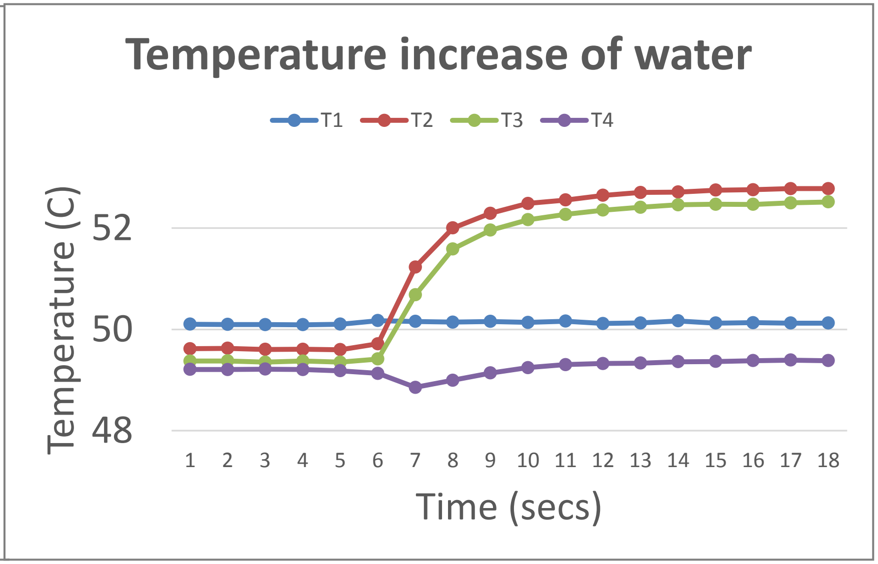
Calcium Chloride Hexahydrate





Heat amplifier system - Results





THP	1	2	3	4
COP	2.71	2.33	2.00	1.76

Heat amplifier system - Issues

- Parameters of the heat pumps for system operating at assumed fixed T_h = 50ºC were extrapolated from characterizations at T_h = 40ºC and T_h = 70ºC.
- Heat pump limited at 29A due to thickness of module wires (no datasheet).
- Initial system designed for 0.5 L/min.
- Flow meter specifications: 1 – 60 L/min.
- No flow control (chiller).
- High heat losses – difficult to insulate => experimentally measured temperature difference across the composite heat pump was half of that expected from calculations.

Thank you! Any Questions?