Design and Development, via Prototype Testing and Multiphysics Modelling, of a Thermoelectric Generator (TEG) for Integration in Autonomous Gas Heaters

Matteo CODECASA	CNR - IENI Lecco unit	m.codecasa@ieni.cnr.it
Carlo FANCIULLI	CNR - IENI Lecco unit	
Roberto GADDI	ITALKERO S.r.l.	www.italkero.it
Francisco GOMEZ PAZ	Designer	www.gomezpaz.com
Francesca PASSARETTI	CNR - IENI Lecco unit	

COMSOL Conference 2011 Stuttgart

Stuttgart (DE) – 27 Oct 2011

SUMMARY

- Introduction
  - Wide range of gas heaters
  - TEG cogeneration targets and features
- Test case 1
  - Design options and basic specifications
  - Design features and operating layout
- **Why** multiphysics numerical modeling?
- Test case 1: results and discussion
- Conclusions

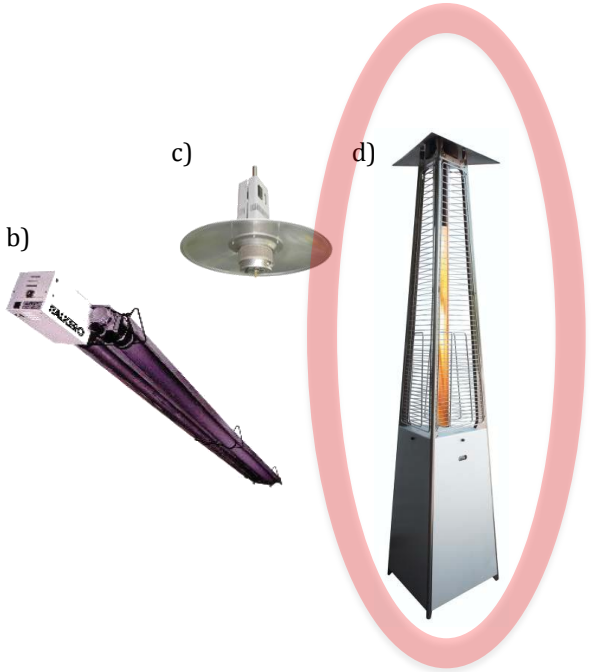
INTRO: WIDE RANGE OF GAS-HEATERS

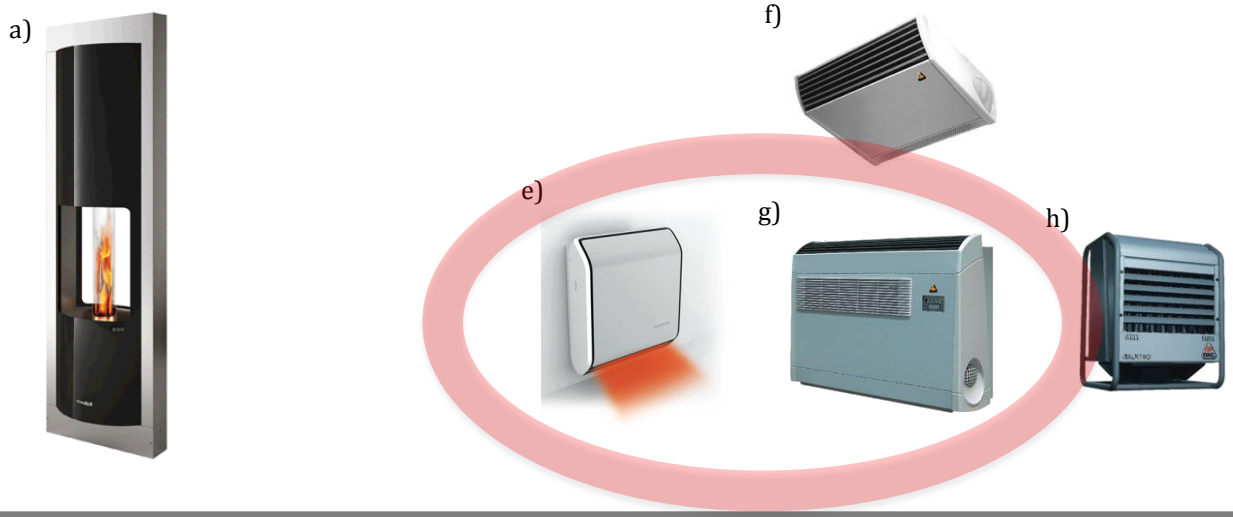
Italkero's gas heating product range

A wide range of technical solutions based on gas combustion is available for heating of both residential and industrial environment.

Most plants use central heating unit (boiler) and an intermediate fluid (e.g. water) to distribute and diffuse heat using separate radiators.

In some relevant cases, each heat-radiating unit includes the gas combustor and operates autonomously with local feed of gas and electricity.





INTRO: TEG COGENERATION TARGETS

Application of a thermoelectric device aiming to produce a small amount of cogenerated electricity for:

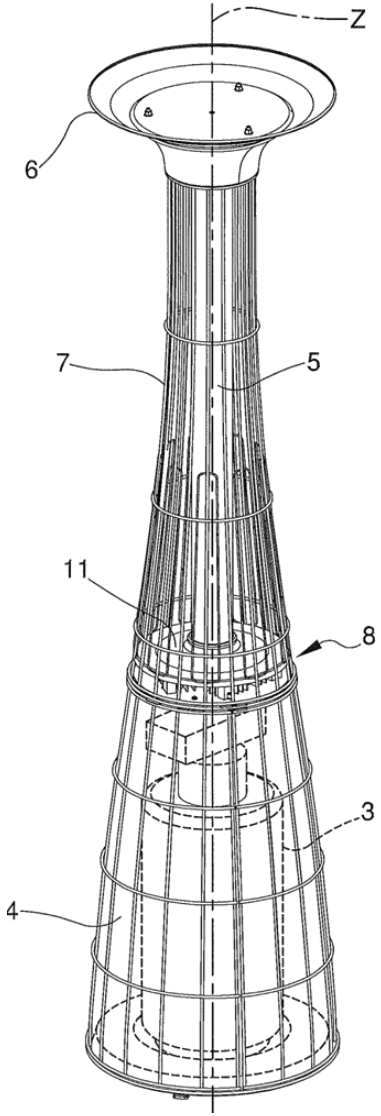
- independent installation from of the electrical network,
- cutting down the consumption of electricity for ventilation, increasing energy efficiency
- providing electricity to products that are without, for auxiliary or ancillary functions

TE direct conversion allows for **compact design**, no **complex thermodynamic cycles**, **no moving parts**, intrinsically **robust** & **reliable**, easy operation and **maintenance-free**

INTRO: TARGET FEATURES ACCORDING TO OUTPUT POWER LEVEL

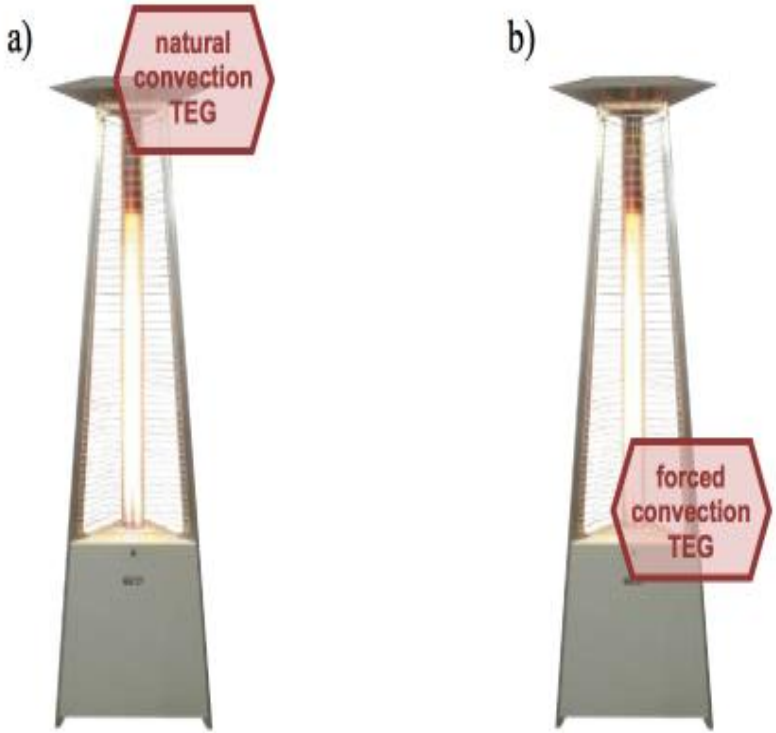
- 10 ÷ 30 W → ancillary functions such as remote control and monitoring and/or hi-efficiency LEDs illumination, indipendent from the connection to network;
- 30 ÷ 100 W → power to forced ventilation for high yield heat transfer;
- Above 100 W → cogeneration unit, if such power comes along with a conversion efficiency of at least 8%,

TC1: FIRST TEST-CASE FOR TEG DESIGN AND DEVELOPMENT



- Heat-radiating gas stove for outdoor has been used for the first test case, investigating feasibility and impact thermoelectric cogeneration
- It is a completely autonomous device, with gas cylinder incorporated, for many hours of operation and a small battery for electronic starter, controller and safety
- Adding special LED-based illumination for the unit is a major *"design"* improvement for the product, both aesthetical and functional
- Furthermore, improving the heat transfer to surrounding environment, through forced ventilation and distribution of warm air, is also very beneficial

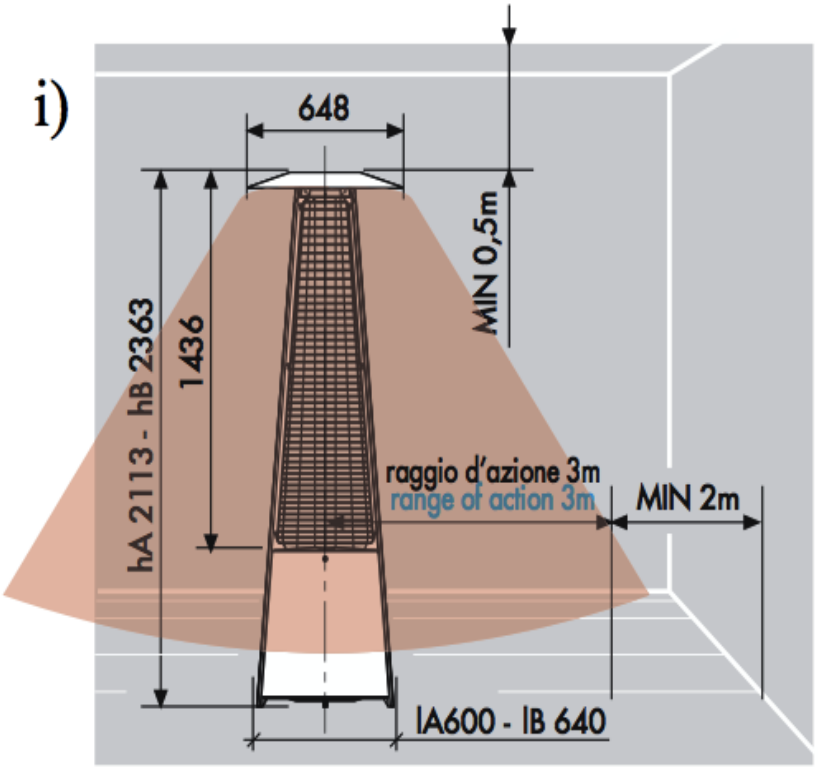
TC1: TWO STEPS / OPTIONS FOR DEVELOPMENT



- In first step (a), TEG is located at the top; cold side heat sinks exploit natural convection and radiation (simplest and most robust design); target electrical power: about qoWrequirement is about 10W
- In the second step, TEG Is at half height, right above the burner; power required is intended to grow up to 35W, for powering an auxiliary fan to spread warm air efficiently down and around to the environment

TC1: BASIC SPECIFICATIONS OF THE HEATER

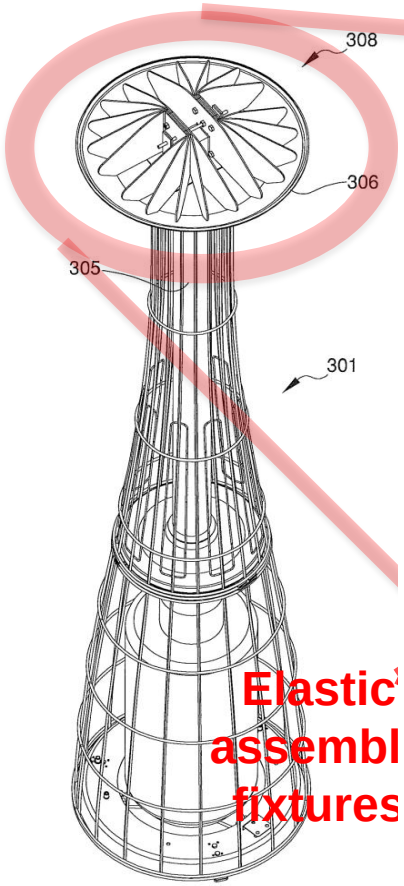
i)



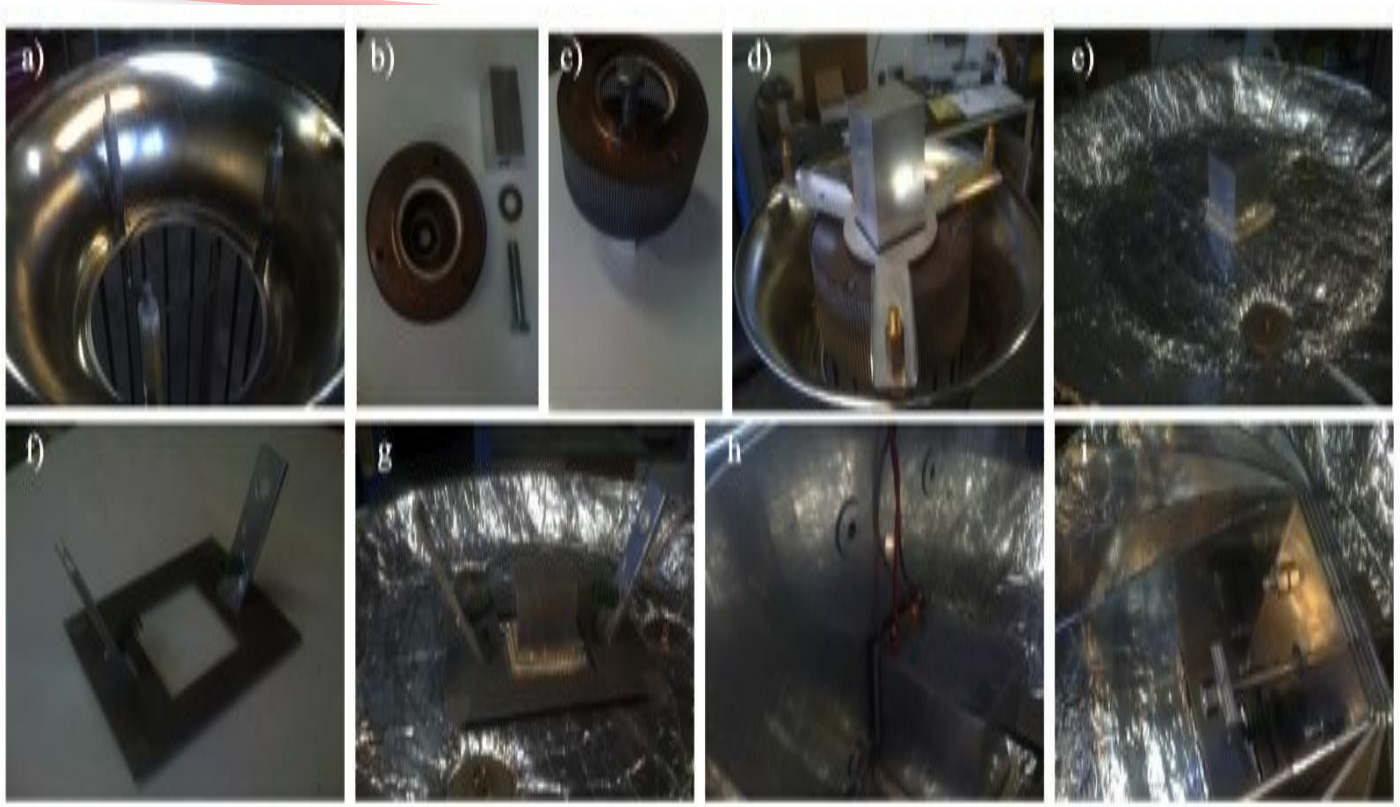
j) Specifications:

- fuel: LPG
- cylinders: 5 kg to 15 kg
- power: 8 kW
- ceramic burner
- weight: 38 kg
- dimensions: 600x600x2113 mm
- consumption: 0.59 kg/h

TC1: TEG SYSTEM DESIGN FEATURES



Elastic
assembl
fixtures



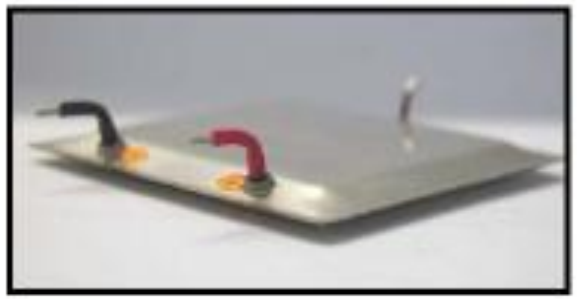
TIM - thermal interface materials / insulation / radiation shielding / sensor instrumentation…

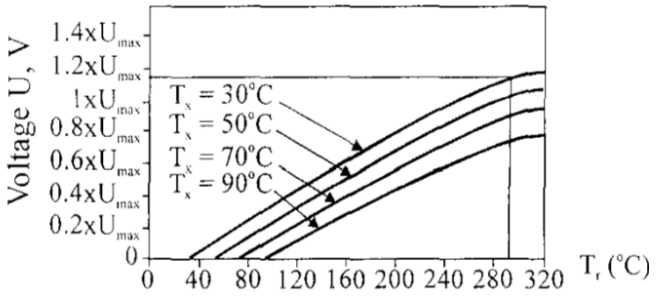
TC1: TEG MODULE SPECIFICATIONS

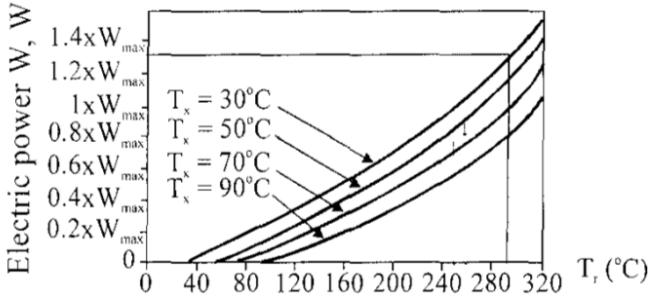
d) Altec-1060 TEGM specifications (referring to conventional *"maximum"* operating conditions: match load, hot side temperature T_h=250°C, temperature gradient DT=220K across the TEGM)

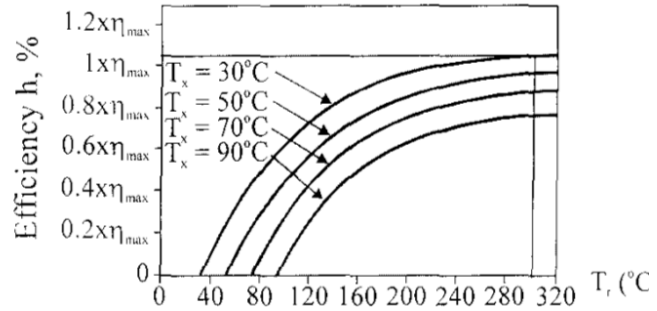
Description	Value
Dimensions	40 x 40 x 4,0 mm
Max continuous hot side temperature (short term)	Th_{max} <= 300°C (400°C)
Max continuous cold side temperature (short term)	Tc_{max} <= 100°C (120°C)
Match-load voltage and corresponding current	U_{max} = 4,8 V / I_{max} = 1,7 A
Match-load output electrical power	W_{max} = 8,0 W
Match-load thermal power	Q_{max} = 123 W
Match-load conversion efficiency	η = 6,5 %

c)

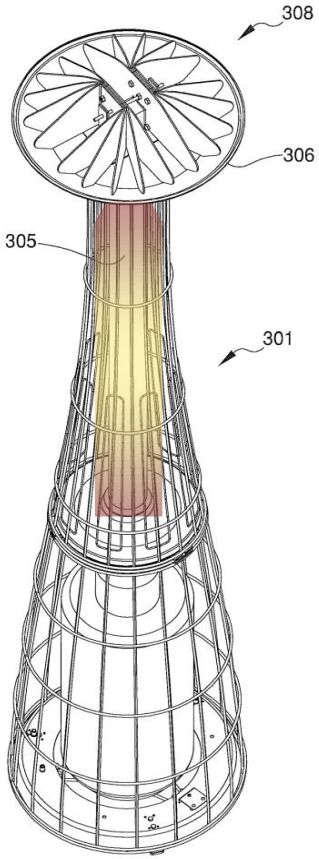


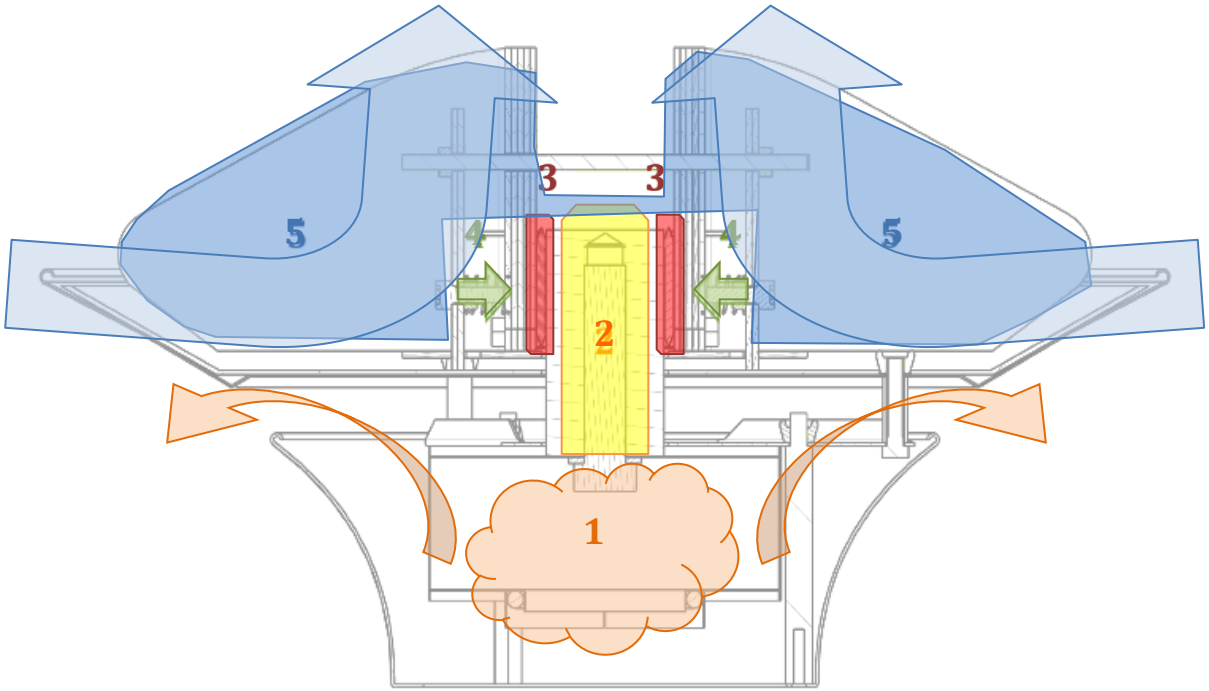




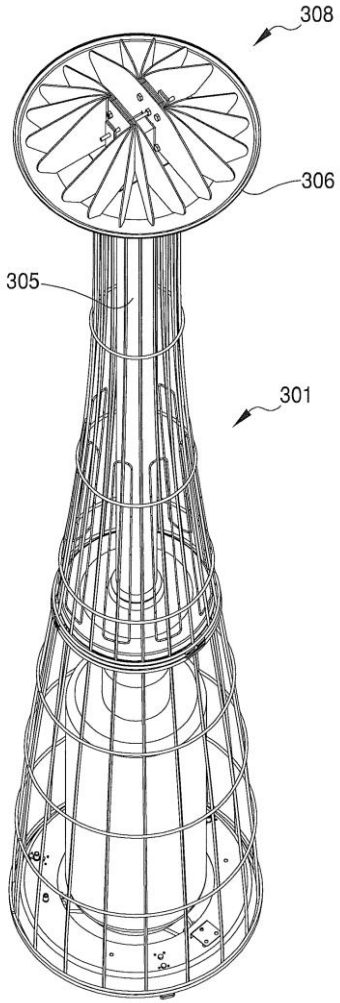


TC1: TEG SYSTEM OPERATING LAYOUT



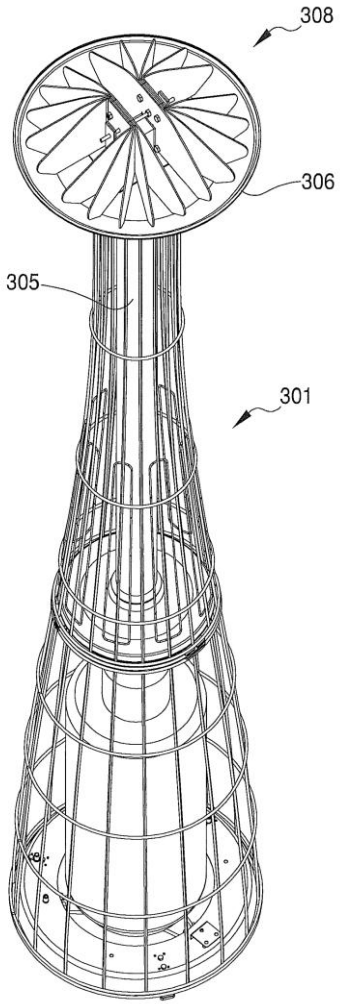


MP: MULTI-PHYSICS MODELLING: WHY?



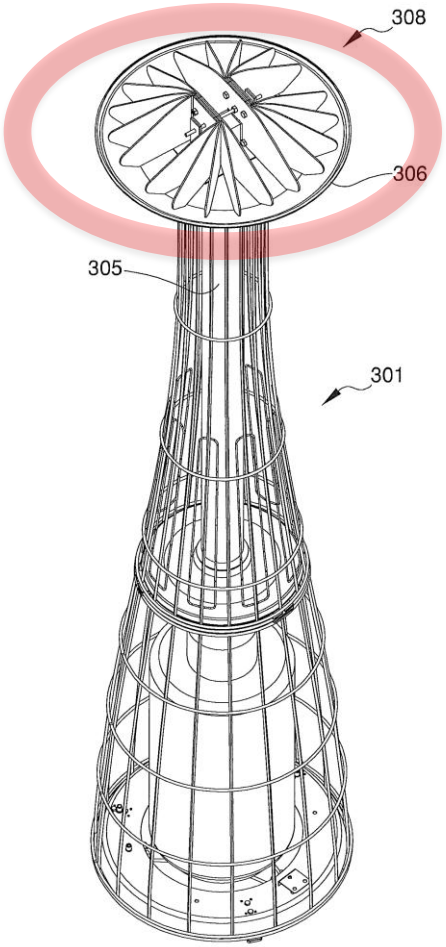
- Incremental design based on existing products
- the INPUT (what is needed and consumed) and OUTPUT (how it benefits the user) is well known
- Limited knowledge on “inner complexity” and energy balances within different macro-components:
  - natural draft burner,
  - glass tube “combustion chamber”
  - “throught-glass”-radiating flame
  - hot gas exhaust (iron cover)
- Relevant “hidden” interactions, increasingly important when approaching complex integration of new features (ventilation fan, TEG cogenerator, etc.)

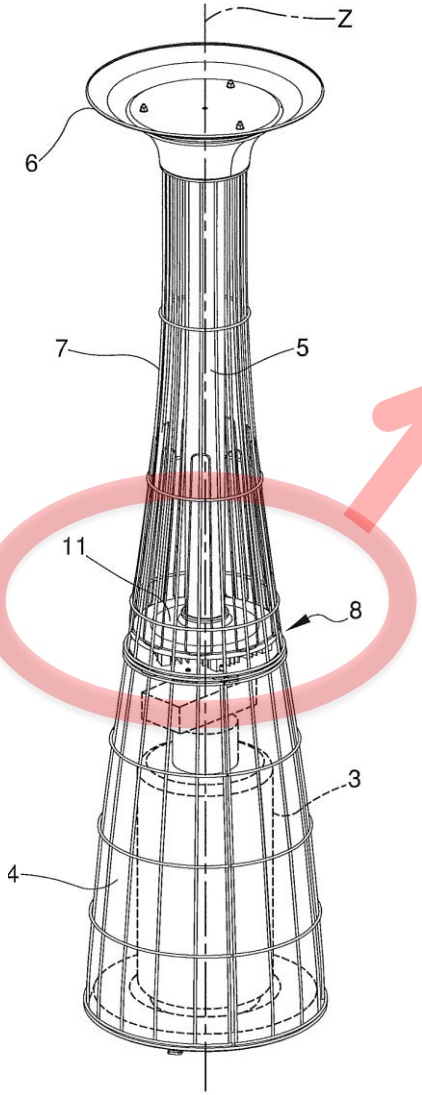
MP: MULTI-PHYSICS MODELLING: WHY?



- Relatively easy-to-model single problems, when studyed one-by-one as isolated sub-systems with known boundary conditions
- A strategy for modeling of operation of the whole complex system is needed to analyze and optimize interactions of sub-systems
- COMSOL multi-physics modularity suits this purpose
- Moreover, we aim to build parametric sub-models to be customized and combined, in new design analysis, for modeling different configurations involving same physics, similar problems and objectives BUT different size and ways of operations… different products

NEW DESIGN (AT HALF HEIGHT)





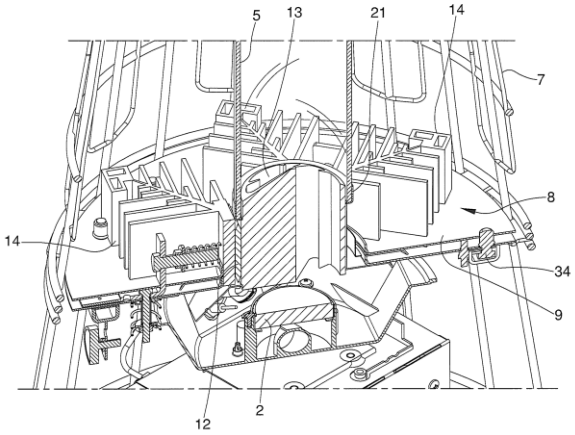
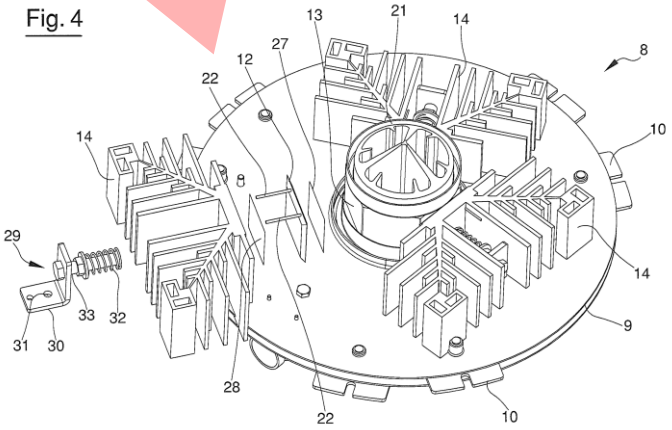
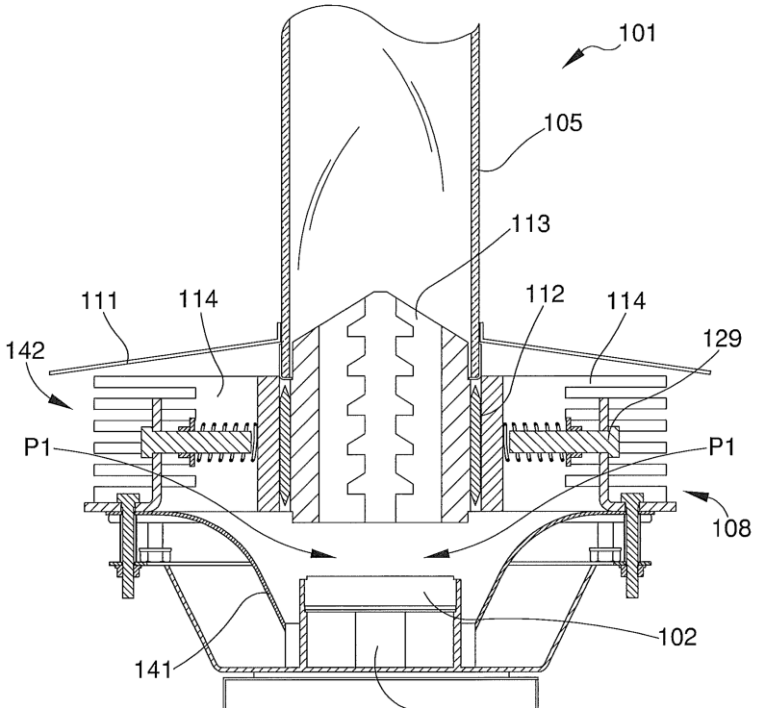


Fig. 4



NEW DESIGN WITH FORCED VENTILATION



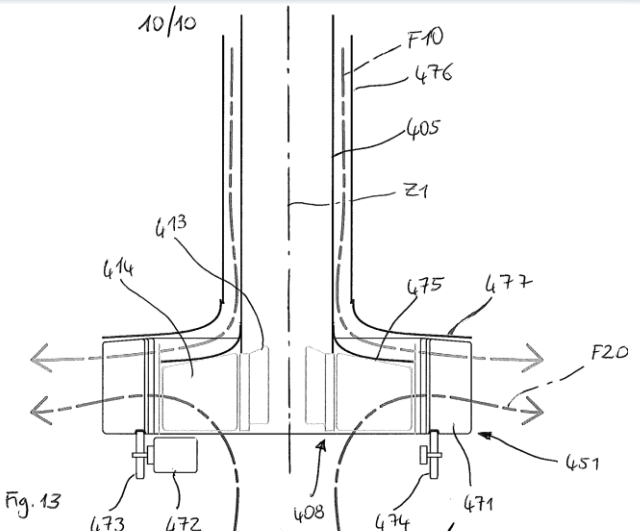


Fig. 13

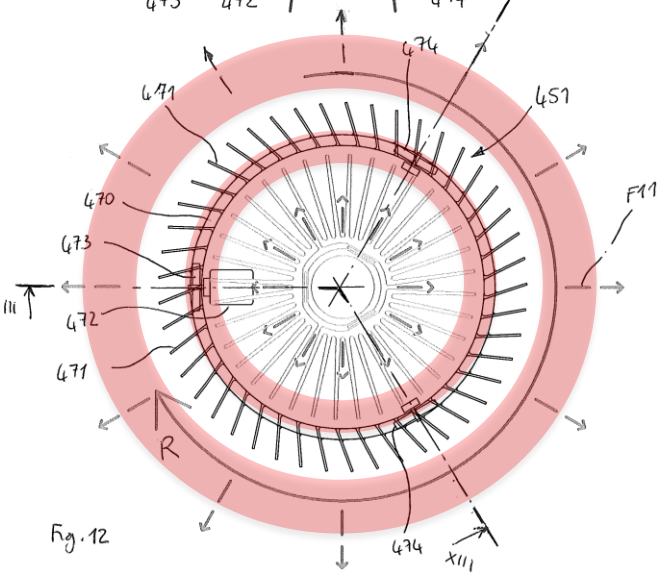


Fig. 12

NEXT PRODUCT…

Fig. 8

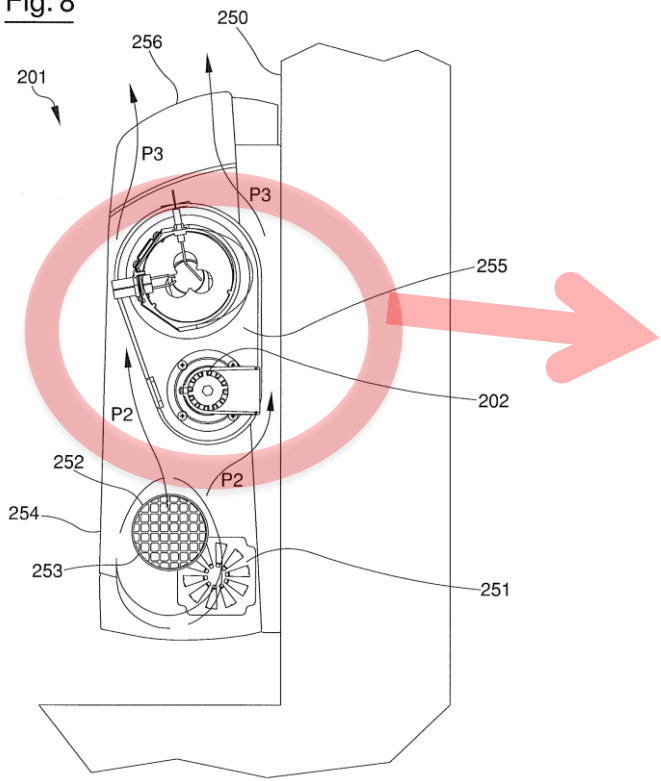
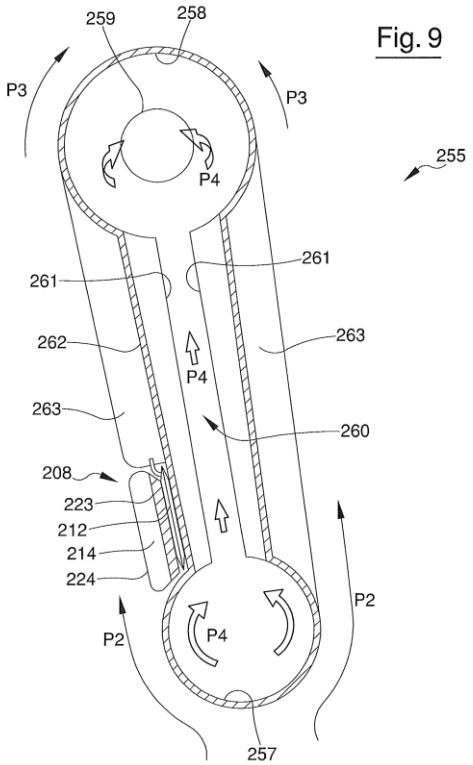
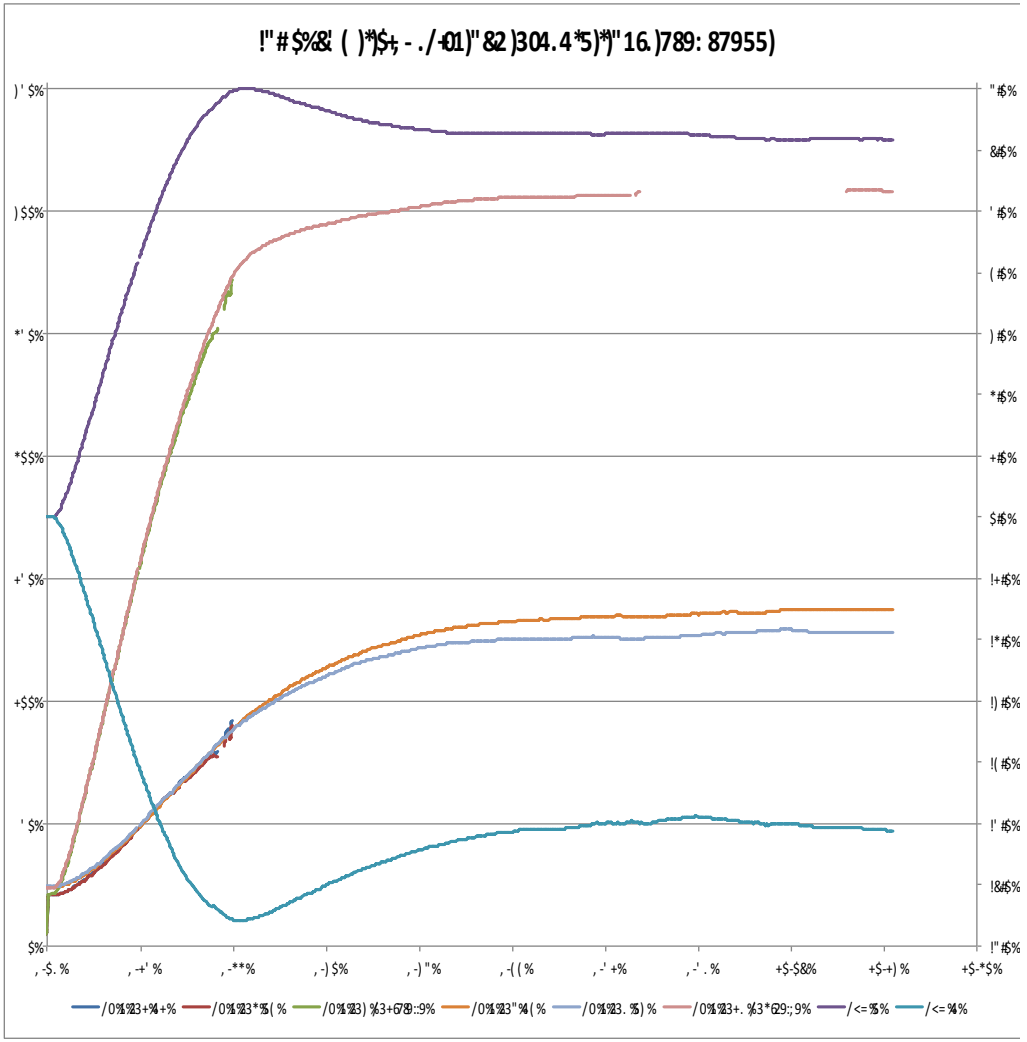


Fig. 9



EXPERIMENTAL TESTS



SUMMARY RESULTS AND DISCUSSION

TABLE 1. TEG converter measured performance with thermal power set to about 8 kW, working as close as possible to match-load operating conditions for maximum electrical output

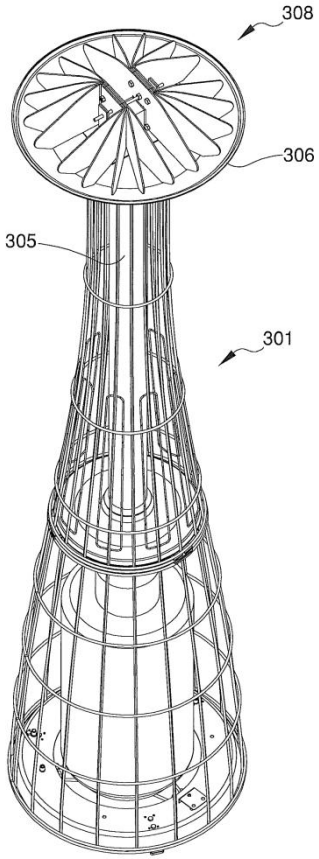
Description	Nomeclature	Unit	Value
Number of TEGMs (connected in series)	N	#	2
Hot side heat capturer temperature @ 8kW power	Th	°C	305
Cold side temperature, with T_{env}=15°C	Tc	°C	125
Open circuit voltage of TEG	V_V	V	12,8
Voltage of TEG under electrical load RL=5,5 Ω	V_L	V	6,35
Load-match current	I_L	A	1,23
Electrical power output with electrical load RL	W_{EL}	W	7,81

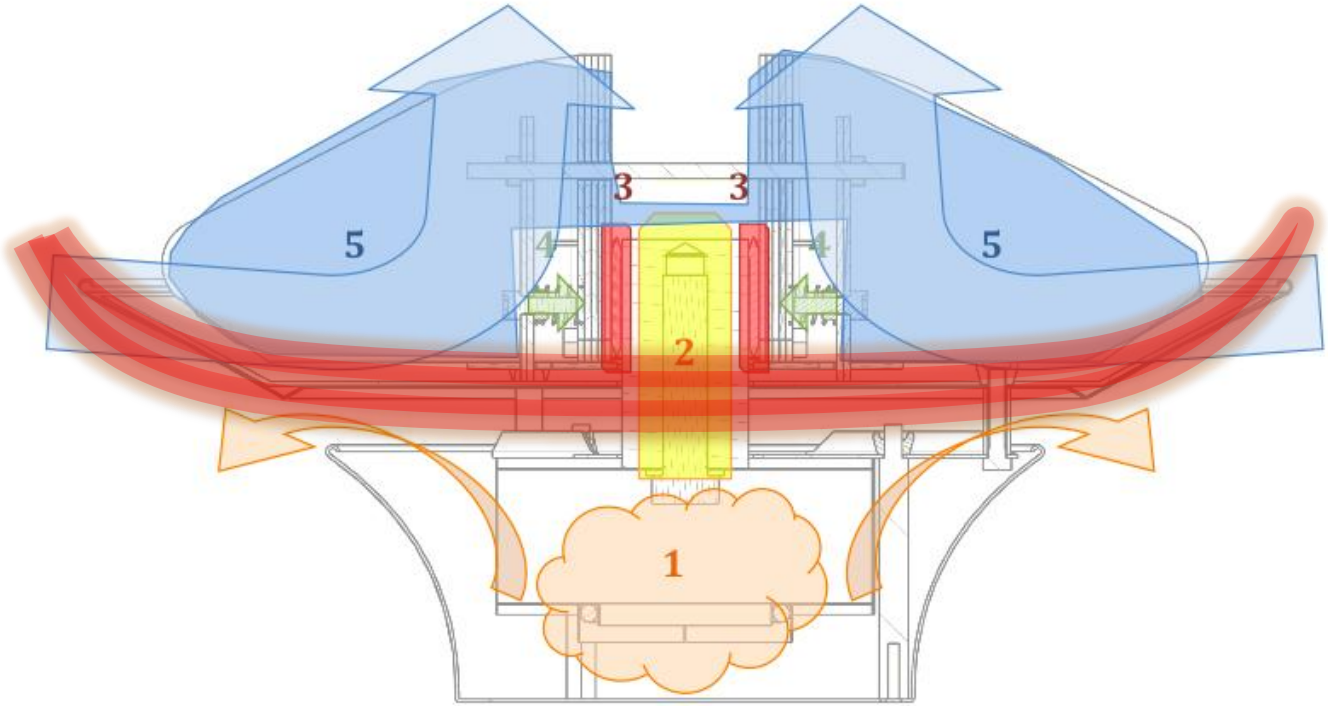
DT.sys = 180 K

DT.mod = 145 K

DT.i = 35 K

RESULTS: OPEN ISSUE





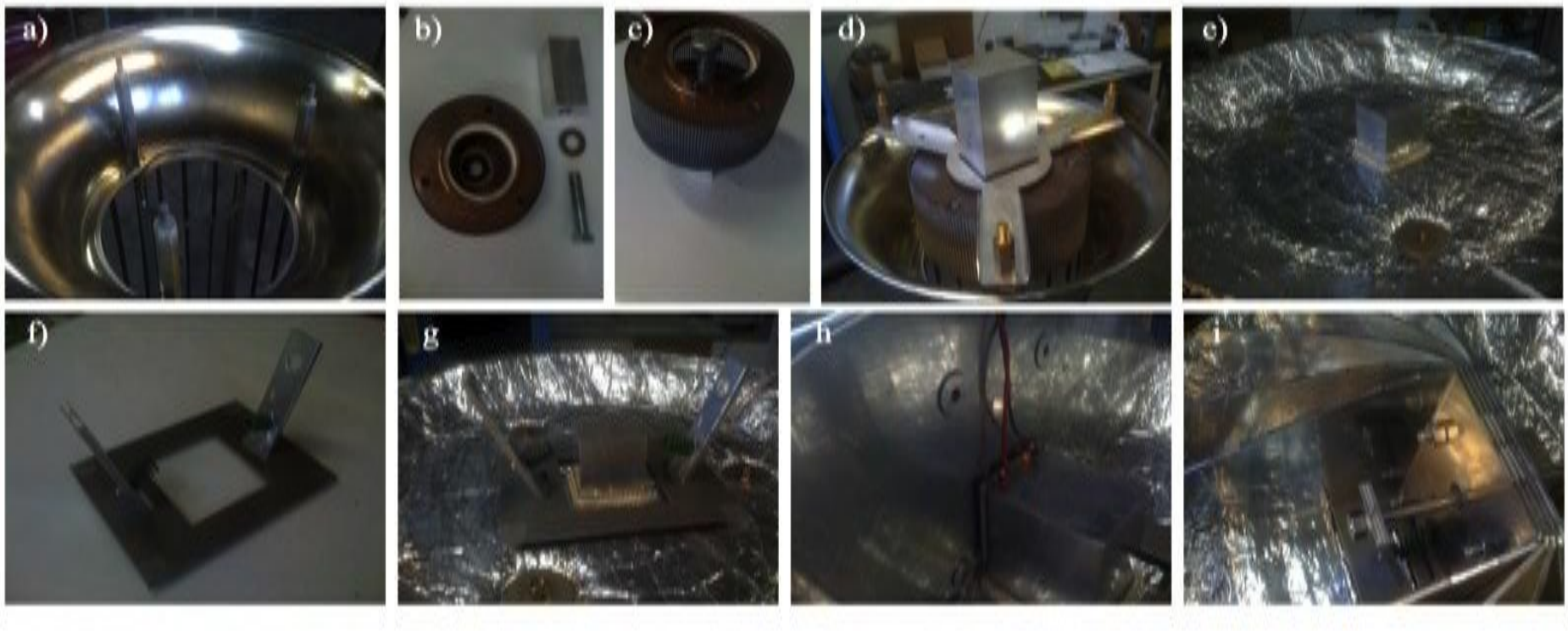
CONCLUSIONS

- Integration of TEG systems for cogeneration within gas heaters and gas stoves has been introduced
- Different steps have been planned, involving growing amount of electrical power output according to different configuration of TEG and different product involved
- Application test cases have been prototyped and tested

- Numerical modelling using COMSOL multiphysics is introduced for studying sub-systems (combustion, heat transfer, thermoelectric generation) and complex joint operation → work in progress
- Objectives: better understanding of interactions, speed up the design optimization, extrapolation of results from one configuration to other similar ones

- *Patent pending on special new design configurations*

MOUNTING SEQUENCE



1) Compressive Loading
2) Thermal Expansion
3) Uniform Load
4) Overhang
5) Thermal Spreader
6) Flatness & Thermal Transfer Compound
7) Thermal Bypass
8) The hot side of the module is the side showing dots

Issue: thermal expansion
➔ Elastic compression

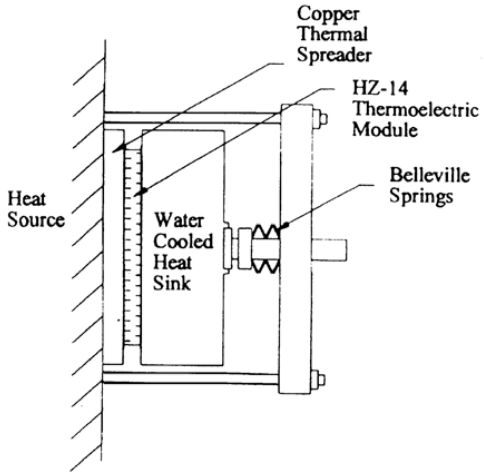


Figure 2. Module Pressure System

Issue: temperature drops and hot spots
➔ Thermal compounds, pressure

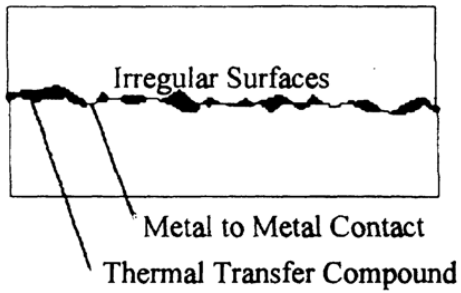


Figure 4. Interface with Irregular Surface

Issue: fragility (solid-to-solid interfaces)
➔ Uniform mechanical load

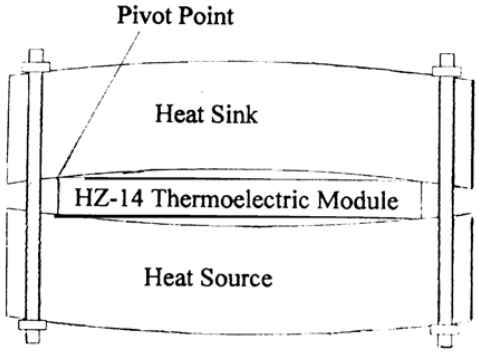


Figure 3. Bowing of Heat Sink/Source

1) Compressive Loading
2) Thermal Expansion
3) Uniform Load
4) Overhang
5) Thermal Spreader
6) Flatness & Thermal Transfer Compound
7) Thermal Bypass
8) The hot side of the module is the side showing dots

Issue: thermal bridge
➔ Increased thermal path

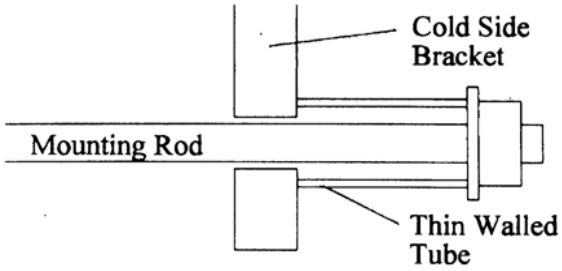


Figure 5. Increased Thermal Path

Issue: thermal bypass
➔ Special configurations

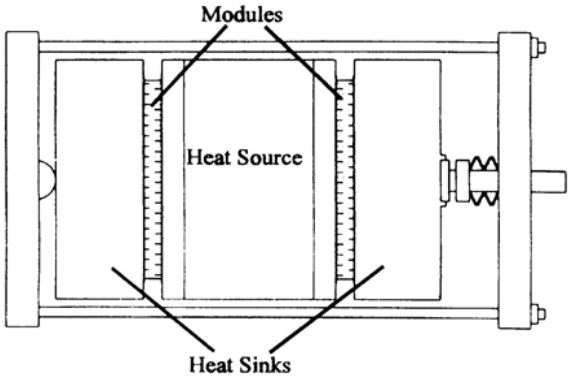


Figure 6. Double Sided Arrangement