Development of a New Micro CHP Pellet Stove Technology

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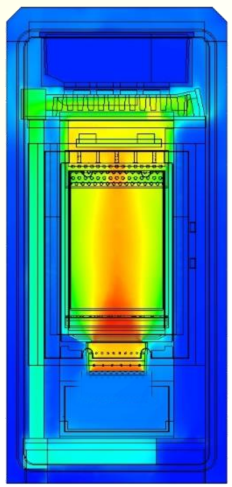

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Outline

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- Stepwise optimization of the new CHP technology for pellet stoves
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Background and objectives (I)

- Biomass based room heating systems are very common for space heating throughout Europe. In the recent 15 years pellet stoves became more and more popular due to their advantages regarding
  - automatic control,
  - user friendliness (automated ignition, easy and clean fuel handling) and
  - low emissions in comparison to logwood stoves.
- However, the need of an external electric power supply to provide electricity for ignition and stove operation is a disadvantage of pellet stoves especially with regard to fail-proof and independent heating systems.
- In order to enable the operation of a pellet stove without electric grid connection, a new micro CHP technology for a pellet stove based on a thermoelectric generator has been developed.

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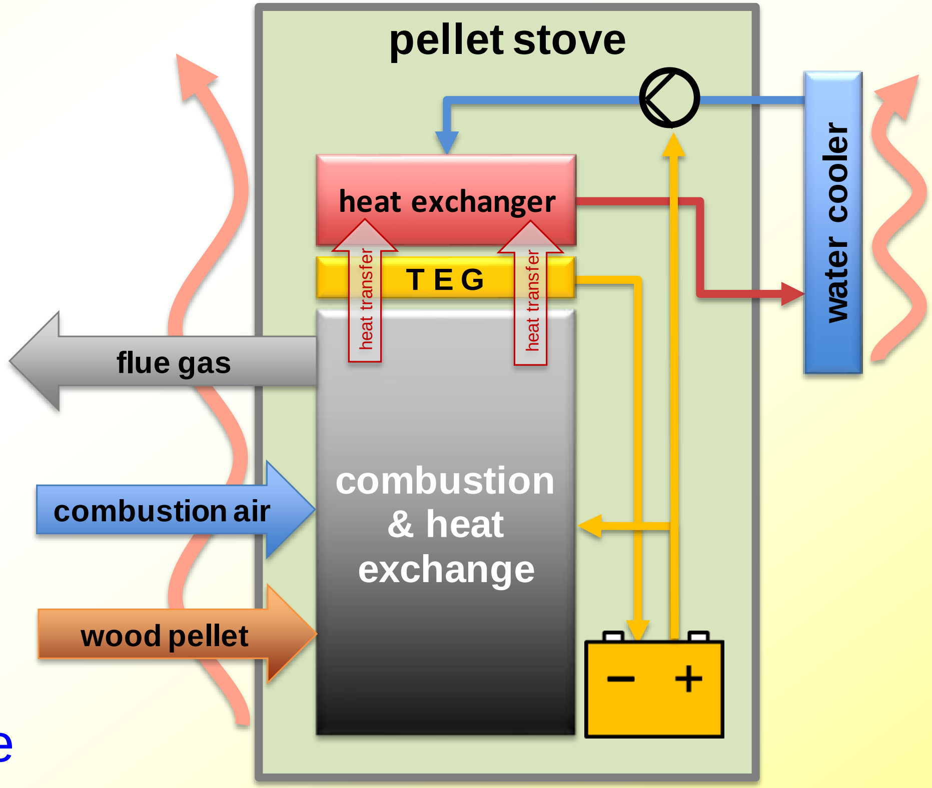
Background and objectives (II)

- With thermoelectric generators (TEG) maintenance-free electric power can be silently produced from heat. Thus, this technology is particularly suitable to realise a grid-independent operation of stoves, which are usually used in residential areas (e.g. for heating of the living room).
- Project partner RIKA has worked in former projects on the development of a TEG to cover the own-electricity consumption of a pellet stove. Thereby, the general applicability of the TEG technology for stoves has been proven and a pre-selection of thermoelectric modules (TEM, a TEG consists of several thermoelectric modules connected in series) took place.
- Remaining open questions for a commercialisation of the technology:
    - Number of TEMs needed to guarantee sufficient power production
    - Positioning of the TEMs to get high and homogenous hot side temperatures
    - Selection of an appropriate cooling system for the TEG
    - Design of the pellet stove to guarantee a complete burnout of the flue gas before it is cooled by the TEG and to implement all components needed in the casing of the stove
    - Optimisation of the power consumption of the pellet stove
    - As low as possible additional costs for the TEG integration

Description of the new CHP technology (I)

General approach:

- During operation of the pellet stove electricity is produced by the TEG to operate the stove and to charge an accumulator.
- The accumulator supplies electricity during the next start-up for the ignition and other power consumers (fan, fuel feeding, control system) until the TEG starts electricity production.
- The TEG is cooled by an appropriate water circuit supplying room heaters.



- The new CHP pellet stove technology is based on a thermal stove capacity of 10.5 kW.

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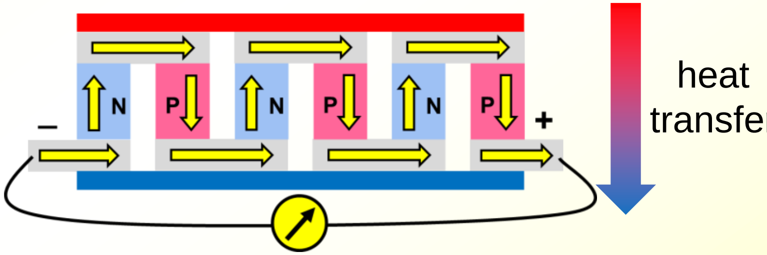
Description of the new CHP technology (II)

➢ The principle of the TEG is based on the Seebeck effect, in which heat is directly converted into electricity by two connected and differently doped semiconductors placed at different temperatures.

TEM with and without ceramic substrate



general structure of a TEM

➢ The electric output of a TEM and thus the TEG is influenced by

- the type of the TEM
- the temperature difference between the cold and hot side of the TEM
  → with rising temperature difference the electric output is increasing
- the cold side temperature of the TEM
  → with a rising cold side temperature of the TEM the efficiency is decreasing

➢ Thus, a high temperature difference and a low cold side temperature of the TEM is aimed in order to achieve a high electric output of the TEG.

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Stepwise optimization of the new CHP technology for pellet stoves

Methodology:

- Transient system calculations for
  - definition of the meaningful number of TEMs
  - evaluation of different cooling options
- Definition of optimised system components enabling high efficiency, low electricity demand and low investment costs
- CFD (Computational Fluid Dynamics) based design of a pellet stove with integrated TEG
- Construction of testing plants (2-stage approach)
- Performance of test runs, evaluation and stepwise optimisation of the technology

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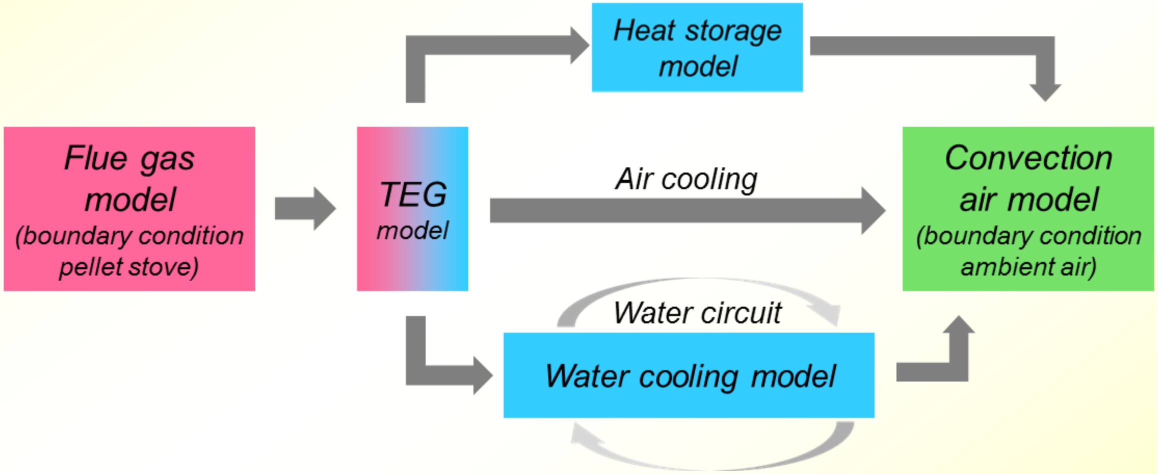
Transient system calculations

- The main target of the transient system calculations was a realistic overall dynamic system modeling based on the given boundary conditions regarding pellet stove operation, TEG and ambient.
- Thereby, 3 different cooling options have been modelled and evaluated:



- Due to the low and stable TEM/TEG cold side temperatures achievable, the water circuit is the most suitable cooling option. Furthermore, this cooling option offers the possibility to heat an additional living room.
- In addition, the calculations pointed out that 10 – 12 TEMs are required to ensure a sufficient power production during operation

CFD simulation: goals

Purpose of CFD-aided stove analysis and optimisation:

- Efficient CO burnout
- Efficient air staging
- Good flushing of the window by secondary air to ensure a clean window
- Reach high efficiency (acceptably low temperatures at stove outlet)
- Optimal positioning of TEMs
  - Regarding high and homogeneous hot side temperatures
  - Regarding allowable application temperatures
- Ensure low temperatures for the water pump and accumulator in the pellet stove casing

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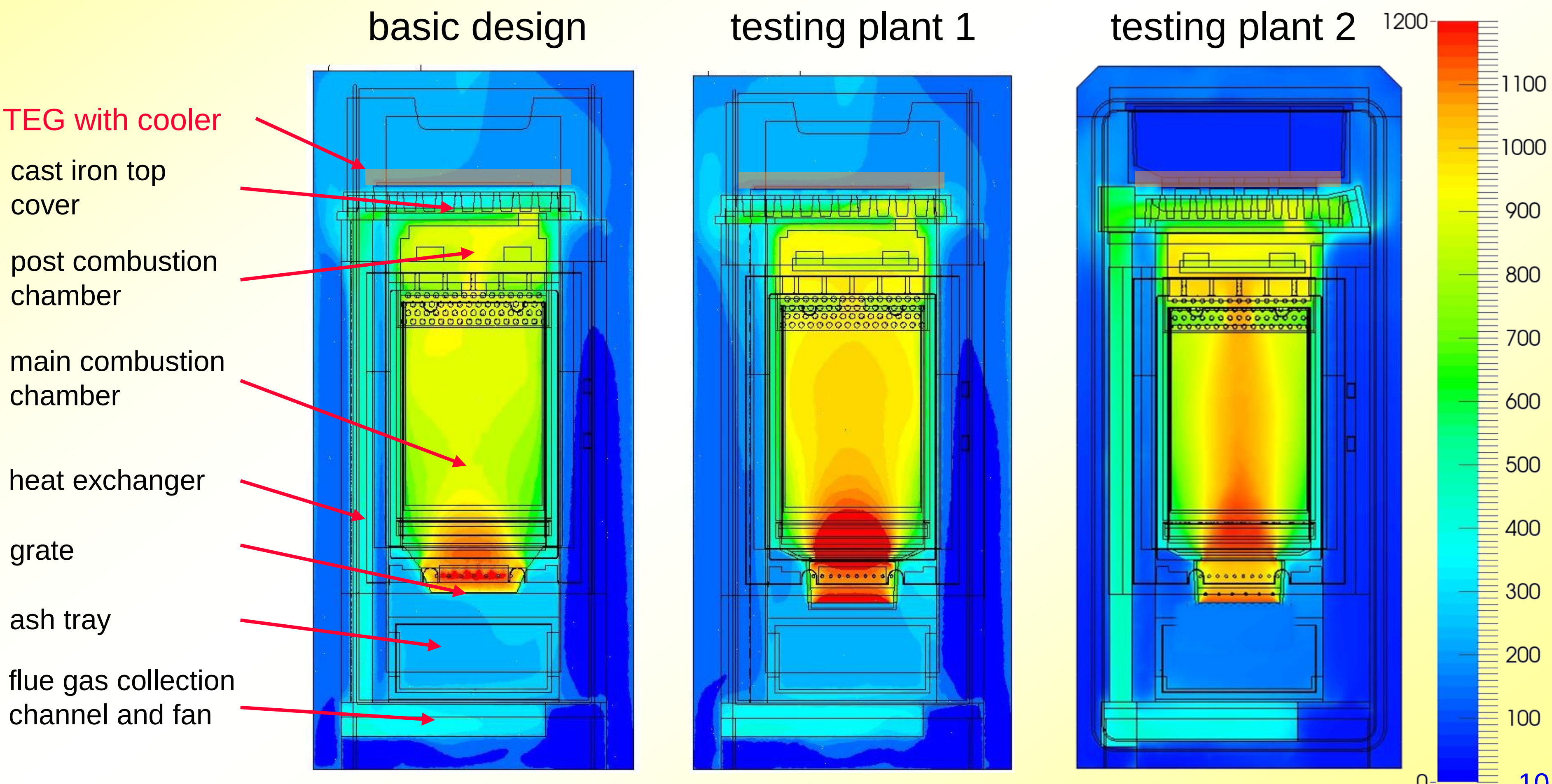
CFD simulation results - temperatures - cross sectional view

- Iso-surfaces of flue gas-, convection air- and stove temperatures [°C] (nominal load)



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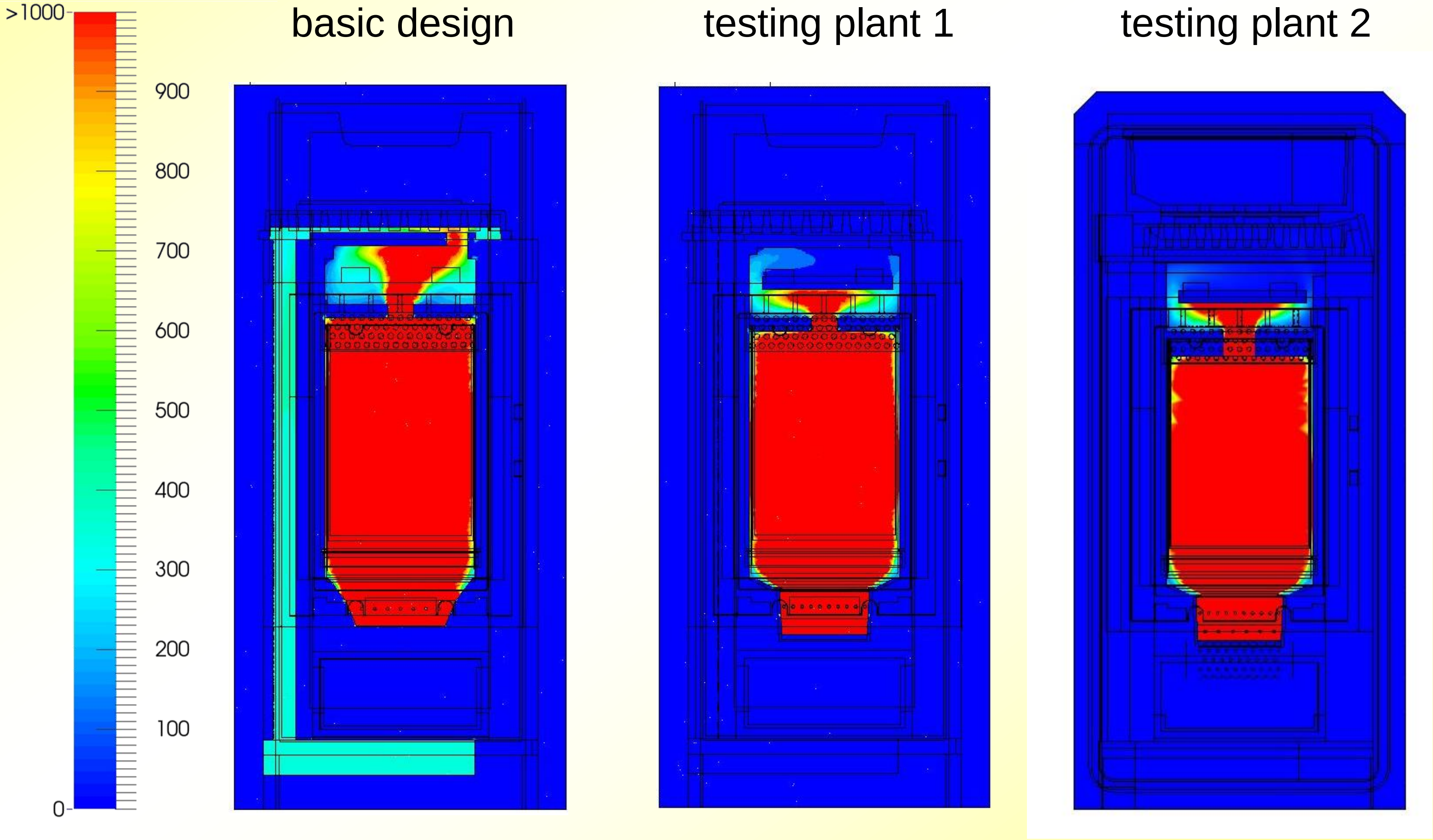
CFD simulation results - CO concentrations

- Iso-surfaces of CO concentrations [ppmv w. b.] in the flue gas in a vertical cross section (nominal load)



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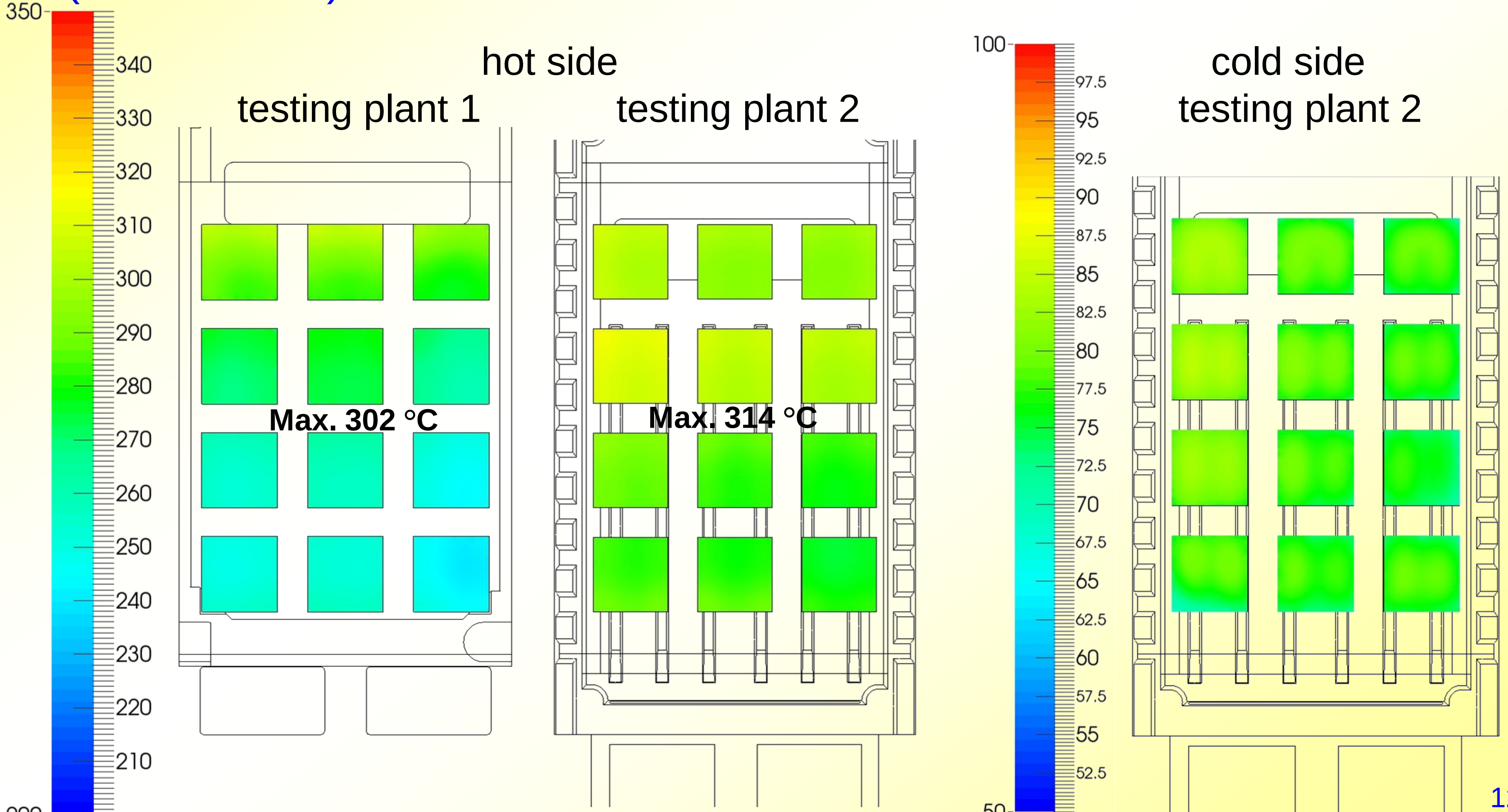
CFD simulation results - surface temperatures of TEG

- Iso-surfaces of surface temperatures [°C] on the TEMs in the TEG (nominal load)



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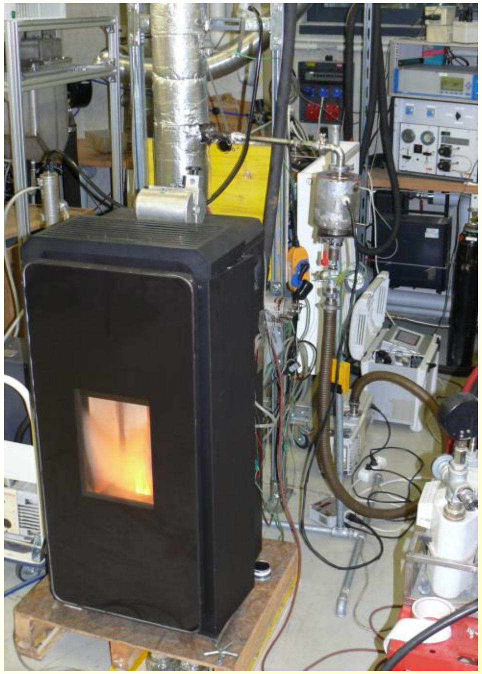
Testing plants of the new CHP technology

- Based on the development work a pre-optimised prototype of the micro CHP system was constructed (testing plant 1) and comprehensive test runs have been performed to evaluate the performance of the pellet stove, the TEG as well as the cooling system.
- Based on the data and experiences gained from the test runs, the system has been optimized and a second - close-to-the-product - testing plant was constructed and tested.
- In addition to the pellet stove a cooling system (water circuit) was designed, constructed and tested.



testing plant 2

TEG cooling system

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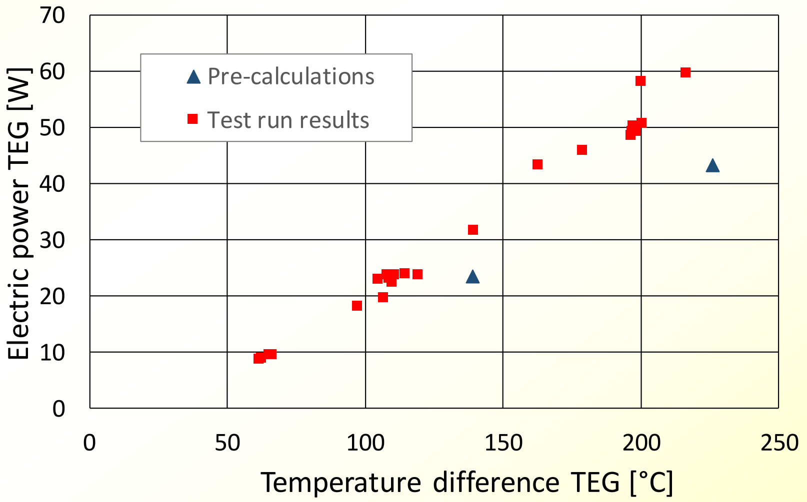
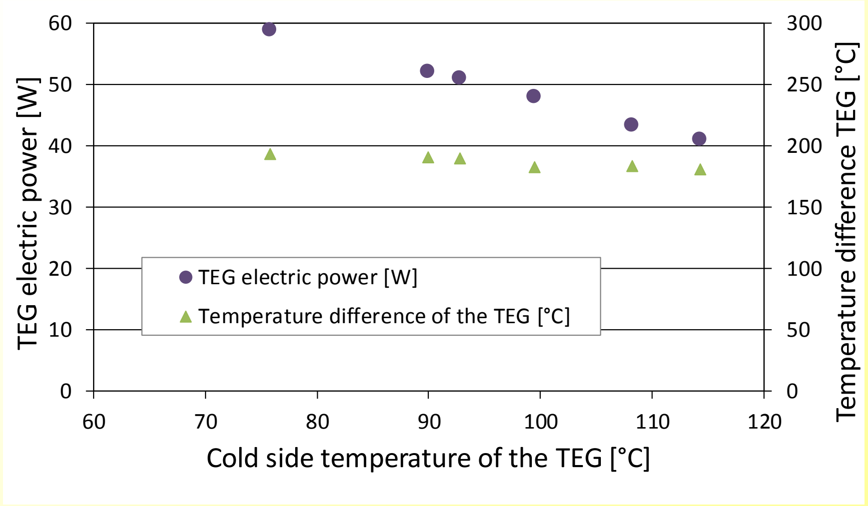
Evaluation of test runs with the new CHP technology (I)

- According to the calculations performed 12 TEMs have been implemented in the testing plants.
- Depending on the temperature difference between cold and hot side of the TEMs/TEG (which is directly correlated to the power of the pellet stove) the potential electric output is 10 to 60 W.
- In addition the cold side temperature of the TEMs/TEG has a strong influence on the efficiency and the electric output. Thus, an efficient cooling is essential.

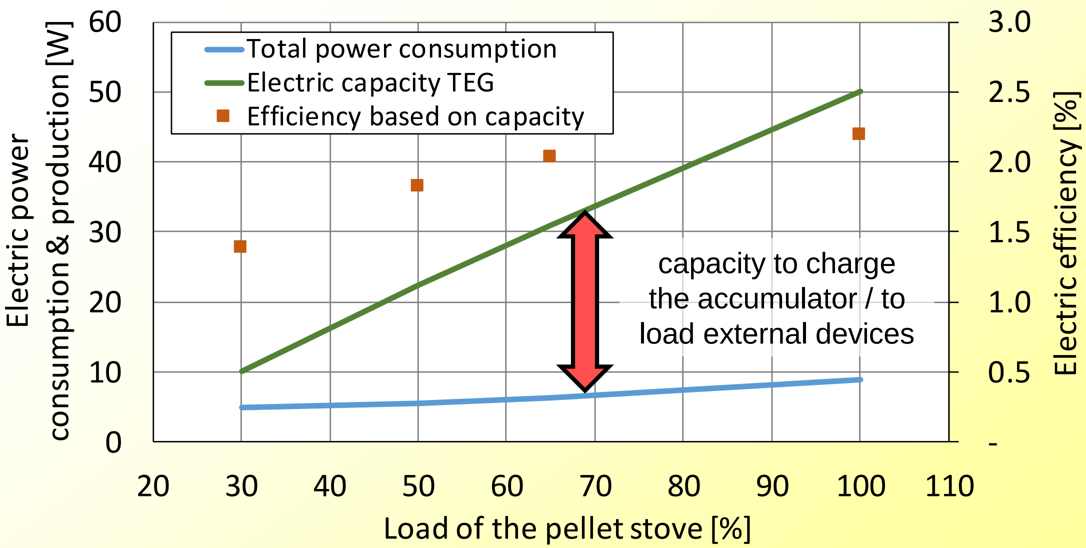




Evaluation of test runs with the new CHP technology (II)

Electricity own consumption & electricity production:

- RIKA selected appropriate low voltage components (e.g. flue gas fan, ignitor) and optimised the control system to reduce the electricity consumption.
- Based on the already very low electricity consumption of testing plant 1, for testing plant 2 a further reduction down to 9 W at nominal load and 5.5 W at part load (including the water pump for the TEG cooling circuit) could be achieved.
- The electricity production of the TEG strongly rises from 10 W at 30% part load to 50 W at nominal load.
- The electric efficiency of the TEG based on the thermal input is in the range of 1.4 to 2.2% (related to the thermal power input).



Evaluation of test runs with the new CHP technology (III)

Energy balance:

- The biomass fuel input at nominal load is 2.4 kg/h or 11.8 kW (NCV).
- Based on the test run results, the thermal efficiency at nominal load is 91% and rises at 30% part load up to 97%.
- At nominal load 8.4 kW of the useful heat is released by the pellet stove and about 2.3 kW by the two radiators of the water cooling system to heat a second living room.

Energy balance		nominal load	50% part load	30% part load
Biomass fuel input	[kg/h]	2,40	1,20	0,72
Biomass fuel power input (NCV)	[kW]	11,78	5,89	3,54
Thermal power combustion air	[kW]	- 0,05	- 0,03	- 0,01
Heat losses flue gas	[kW]	1,11	0,29	0,10
Thermal power cooling system (water circuit)	[kW]	2,26	1,21	0,72
Thermal power pellet stove (radiation & convection air)	[kW]	8,41	4,40	2,72
Total thermal power pellet stove	[kW]	10,67	5,61	3,44
Share of the heat released by the water system	[%]	21%	21%	21%
Thermal efficiency (related to NCV)	**[%]**	**91%**	**95%**	**97%**
Electric capacity TEG	[W]	50,0	22,5	10,0
Electric efficiency (based on thermal input)	**[%]**	**2,2%**	**1,9%**	**1,4%**

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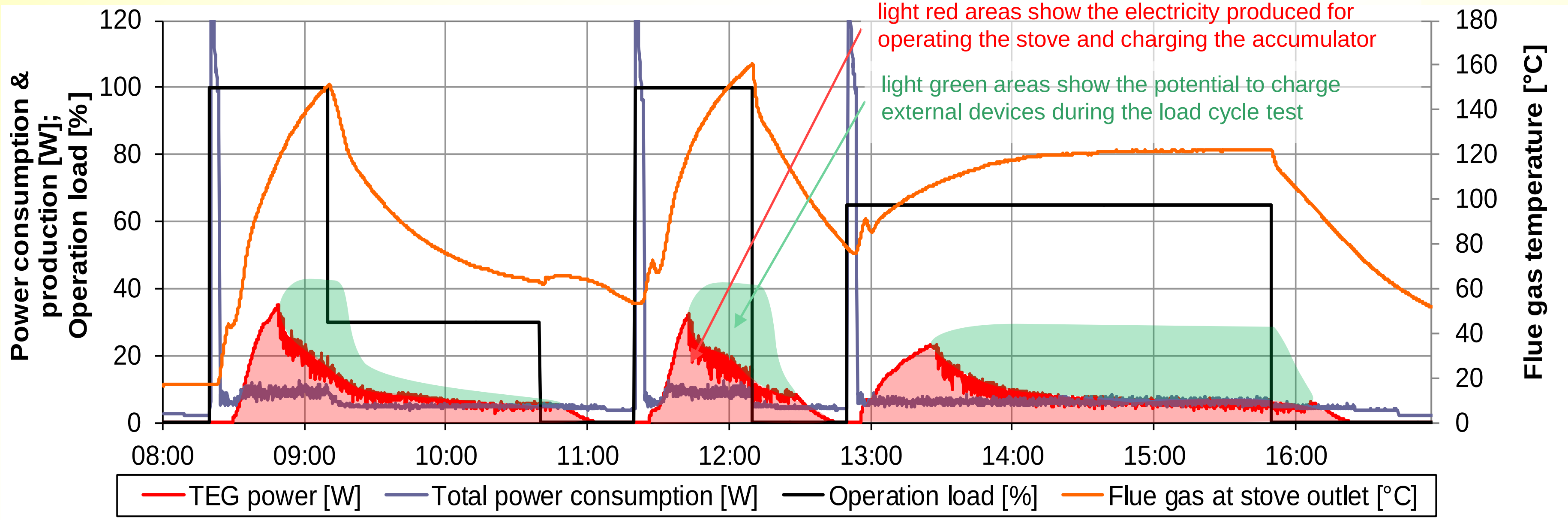
Evaluation of test runs with the new CHP technology (VI)

- Since in real life pellet stoves are operating at different loads and most of the time not at stable conditions, the practical suitability of the new micro CHP technology has been evaluated based on a load cycle test developed for pellet stoves.
- The load cycle includes four different load phases and three starts of the pellet stove and takes 8 h as a whole.



Load cycle test according to the project bereal (www.bereal-project.eu)

- At the end of the load cycle test run the accumulator is again fully charged.
- In addition a potential of about 50 Wh to charge external devices is given during the load cycle test (although only short full load operation phases occur).

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Conclusions

- With the new micro CHP technology based on a pellet stove and a TEG system, a renewable CO_2-neutral room heating technology which can operate off-grid has been developed.
- The TEG system is a wear- and maintenance-free as well as noiseless technology and thus ideally suitable for applications in living rooms.
- The electricity produced by the TEG system covers the energy demand for operation and start-up of the pellet stove. The surplus electricity produced can be used to charge mobile phones or other small consumers.
- In addition, due to the water cooling system, a second living room can be heated by the new technology.
- The final design of the new micro CHP technology and long-term testing of the new components is currently ongoing. Its market introduction is planned by RIKA within 2018.

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Thank you for your attention

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