Improved low emission and high efficiency wood stove with integrated PCM heat exchanger

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Background and objectives (I)

- Today small-scale biomass combustion is one of the most relevant bioenergy applications. Regarding the installed units, stoves show the highest and steadily increasing numbers in Europe.
- It is also well known that among the different residential biomass combustion technologies logwood stoves show the highest CO, OGC and fine particulate matter (PM) emissions.
- Furthermore, even modern stoves show clearly lower thermal efficiencies (in the range of 82% under test stand conditions) in comparison to automatically fed and controlled biomass boilers (e.g. pellet boilers).
- Appliances with integrated heat storage unit may show significantly increased efficiencies and therefore also contribute to a better economy of stove technologies.

Background and objectives (II)

- Moreover, they contribute to a better climate in the rooms as the energy released to the room can be better distributed over a rather long period in comparison to state-of-the-art wood log stoves.
- The proper selection of phase change materials (PCM) can offer energy and space efficient, innovative heat storage solutions.
- Against this background, a low emission and high efficiency stove with integrated PCM heat exchanger has been developed and tested by RIKA and BIOS.

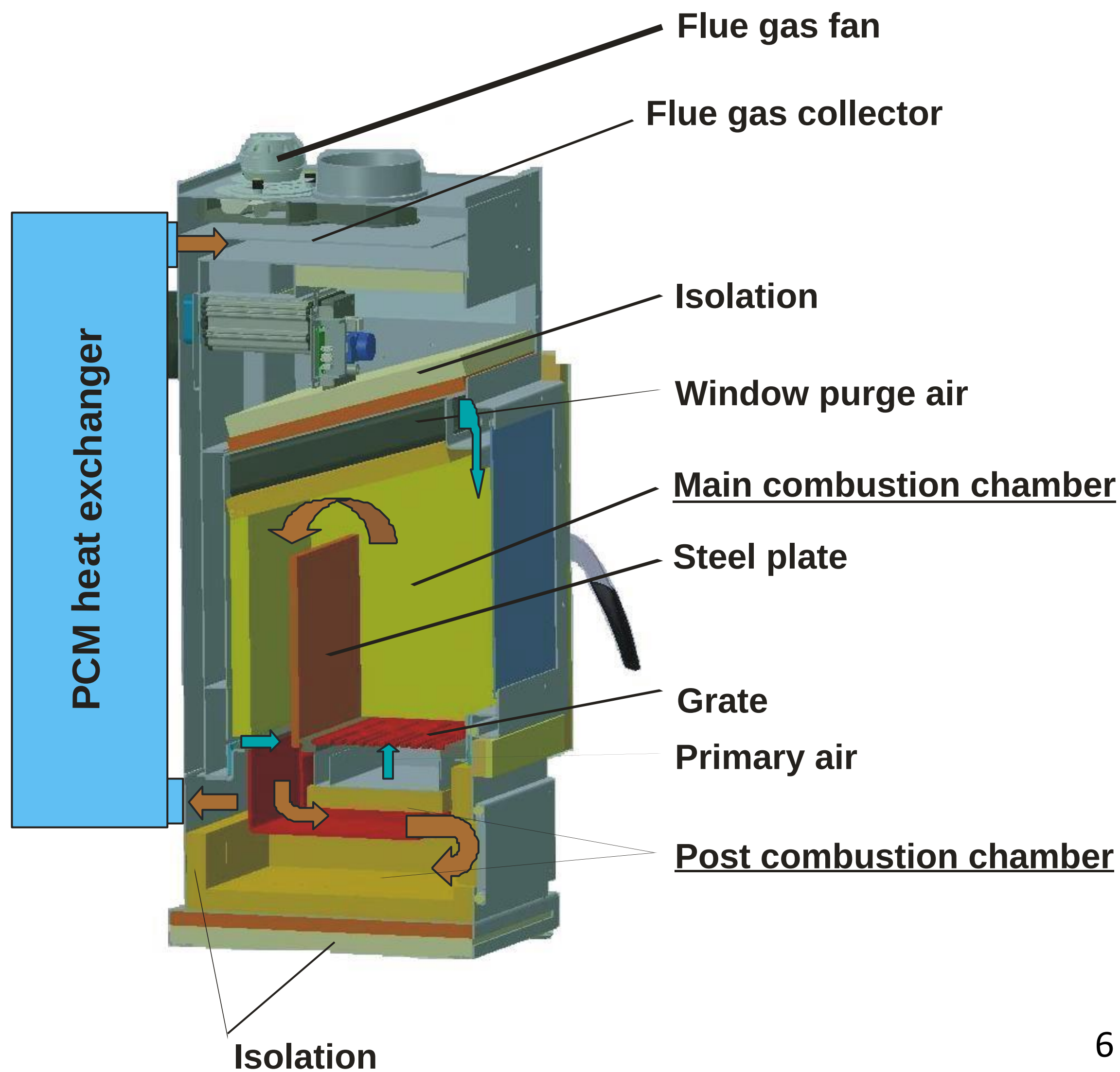
Methodology and approach (I)

General approach

- Application of a new stove concept which ensures low gaseous and particulate emissions
- Definition of constraints regarding the implementation of the heat exchanger for PCM application
- Development of the basic geometry of the new stove concept with integrated PCM heat exchanger

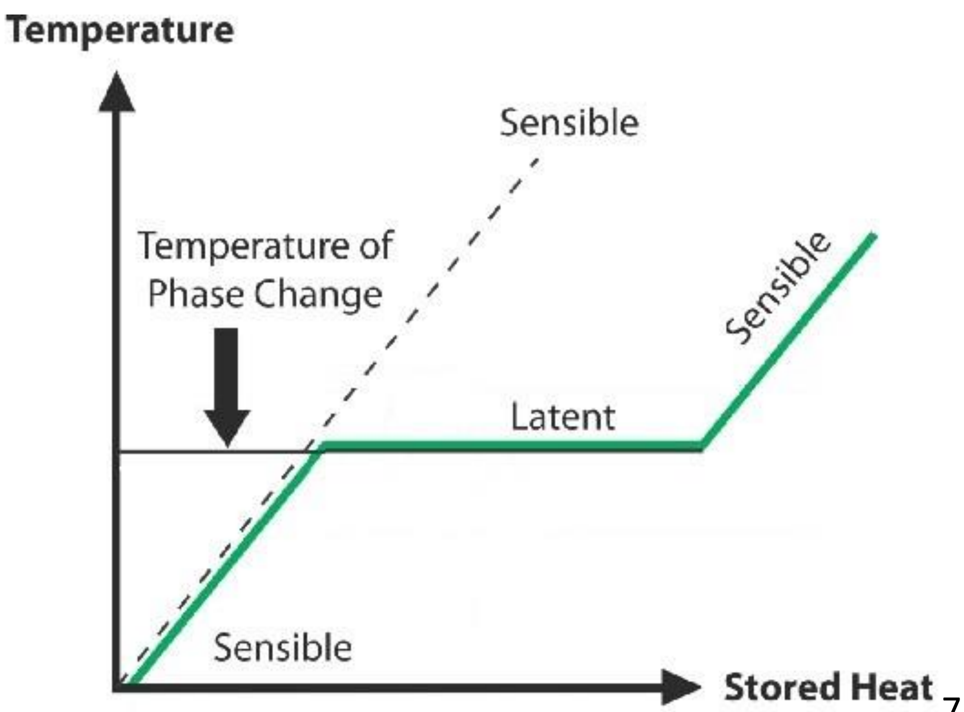
Methodology and approach (II)

- **Patented new low emission stove concept**
  - **Appropriate insulation of main combustion chamber and post combustion chamber for almost complete burnout**
  - **Efficient mixing of the flue gases with the combustion air**
  - **Application of air staging**
  - **PCM heat exchanger to maximise the efficiency**
  - **Automatic control**



Methodology and approach (III)

- PCMs (Phase Change Materials) enable a more efficient energy recovery from the flue gas as due to the melting of the material at a defined temperature the latent heat can be stored in addition to the sensible heat.
- Therefore, heat storage based on PCM can show valuable advantages and potentials:
  - **increase the thermal efficiency**
  - **make space efficient heat storage possible**
  - **supply heat at reasonably high temperatures**



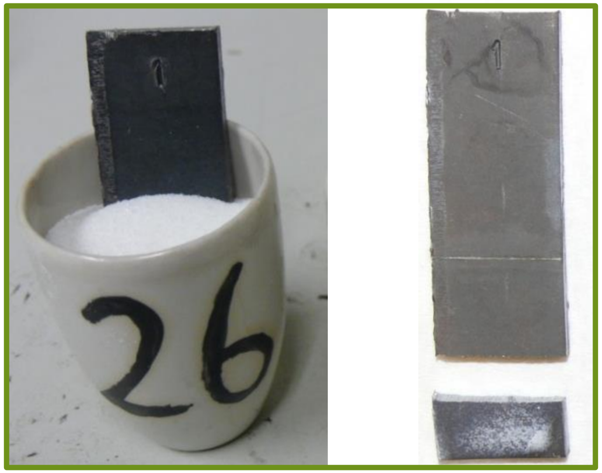
Development of the new stove technology (I)

Relevant steps

- **Evaluation of possible phase change materials (PCM)**
- **Final selection of PCM and design of an appropriate heat exchanger concept**
- **CFD (Computational Fluid Dynamics) based design of the stove with integrated PCM heat exchanger**
- **Construction of testing plants**
- **Performance of test runs, evaluation and stepwise optimisation of the technology**

Development of the new stove technology (II)

- **Detailed evaluation of PCMs available on the market based on literature reviews and data from manufacturers**
  - **A high density and heat capacity of the PCM is important as the heat storage unit should be realised in a compact way.**
  - **PCMs have to be suitable for the application in a heat storage unit (e.g. flue gas heat exchanger) of wood stoves.**
    - Melting temperature: 150 – 300 °C
    - Degradation temperature: > 600 °C
    - The price should be as low as possible in order to be economically competitive
    - The material should not be corrosive or toxic under operation conditions

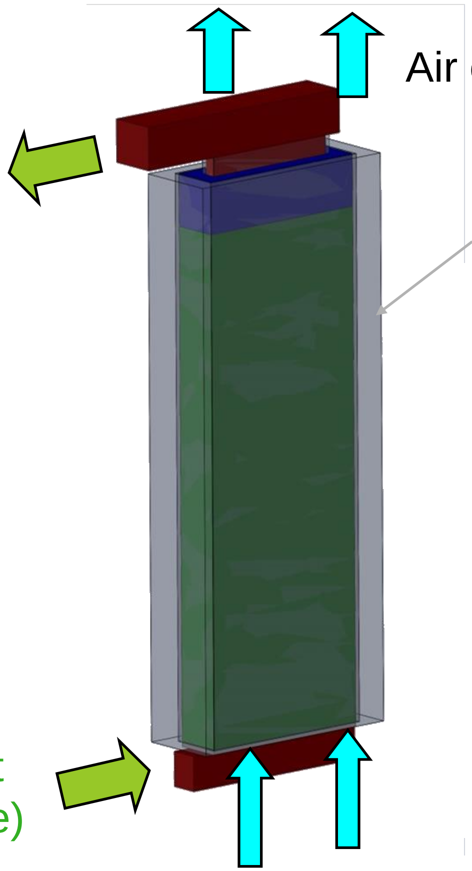


corrosion test

→ Based on the evaluation performed promising PCMs (salt mixtures) have been selected for the PCM heat exchanger

Development of the new stove technology (III)

- **The PCM heat exchanger should be integrated into the stove concept in a way that a large share of the energy produced is transferred to the PCM in order to ensure a high storage efficiency**



The release of the stored heat (unloading cycle) can be realised:

- **Via convection air channels which are opened at the end of operation of the stove. Thus, the stored heat can be distributed even to different rooms.**
- **Via slow natural convection over a larger time duration which is of advantage for the comfort of living.**

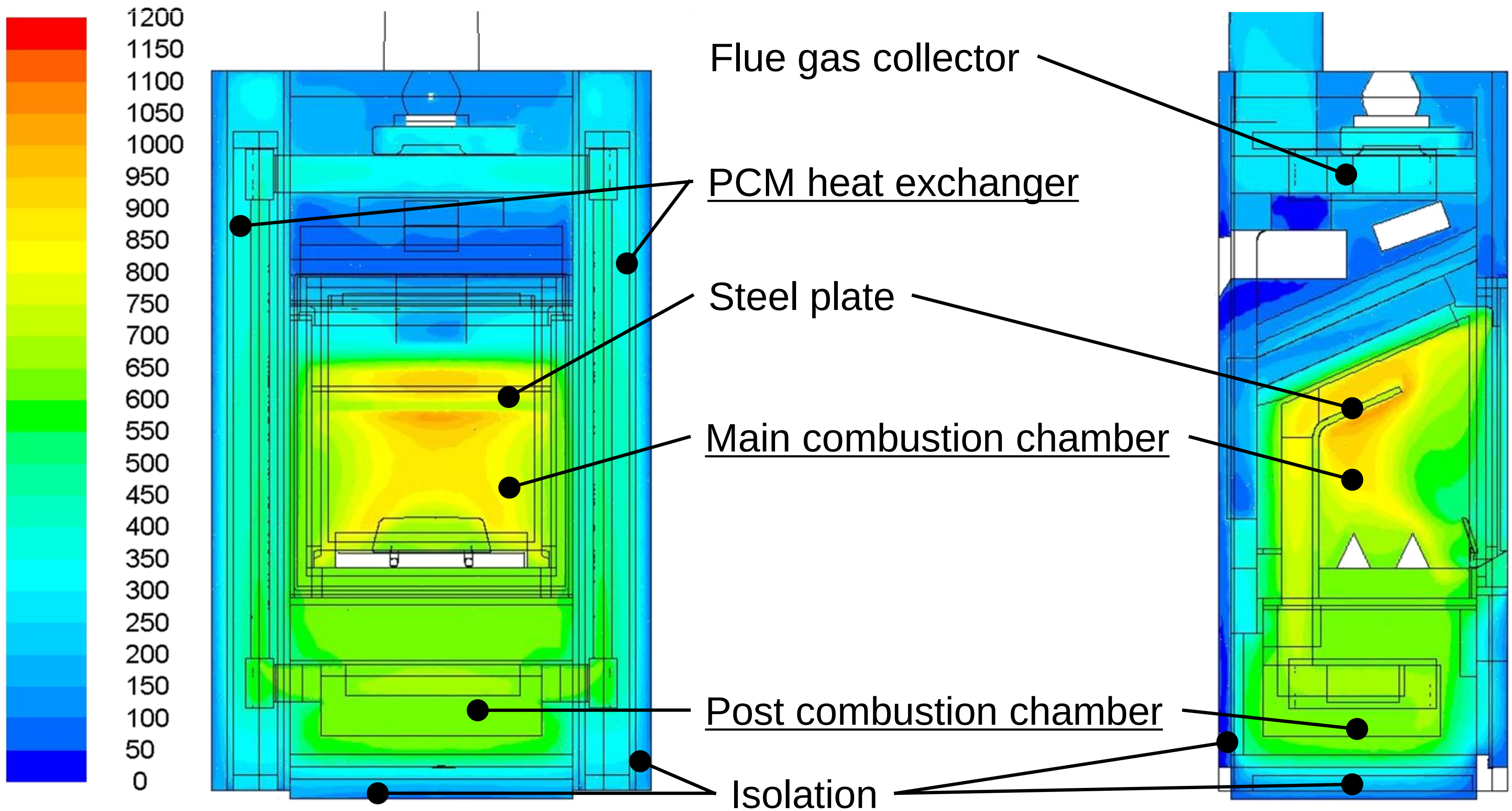
Development of the new stove technology (IV) – CFD simulations

Purpose of CFD-aided stove development and optimisation:

- **Efficient CO burnout**
- **Efficient air staging**
- **Ensure a clean window**
- **Optimal integration of the PCM heat exchanger**
  - Regarding high utilization rate
  - Regarding allowable application temperatures
- **Reach high efficiency (low flue gas temperatures at stove outlet)**

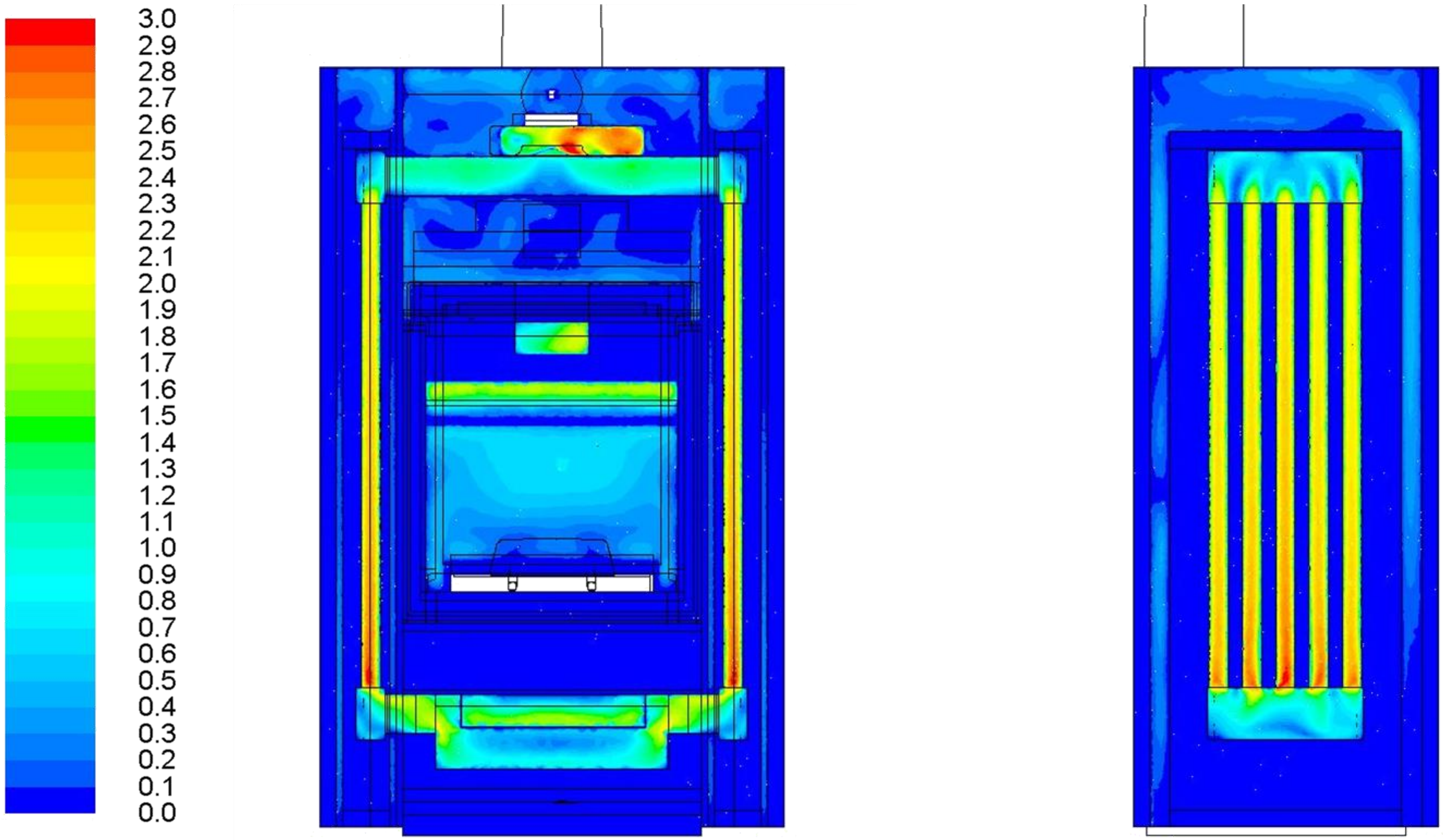
Development of the new stove technology (V) – CFD simulation results

- Iso-surfaces of air, flue gas and stove temperatures [°C]



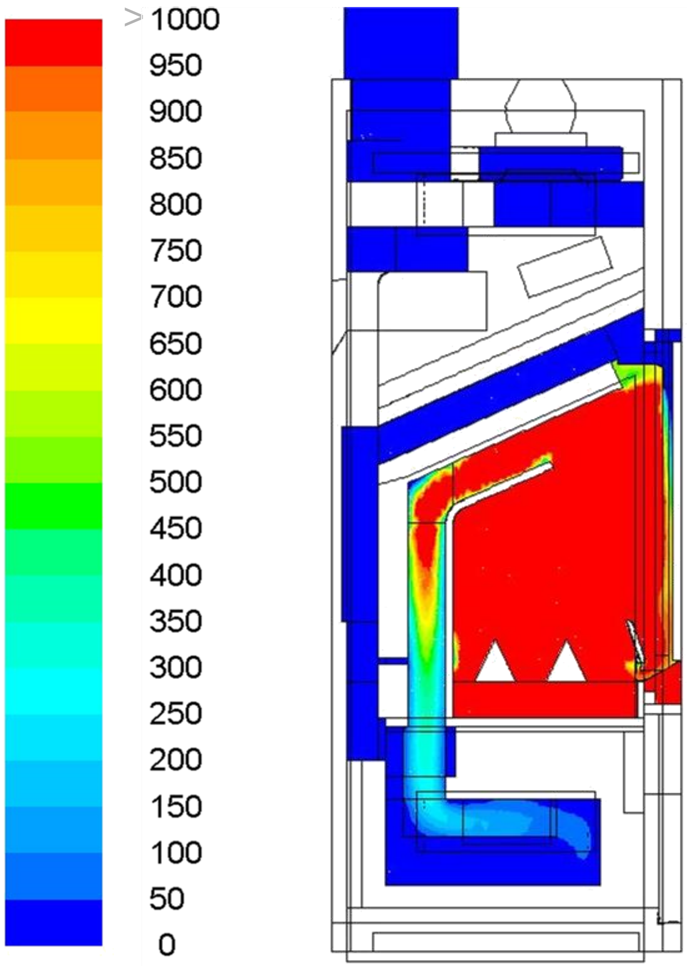
Development of the new stove technology (VI) – CFD simulation results

- **Iso-surfaces of air and flue gas velocities [m/s]**

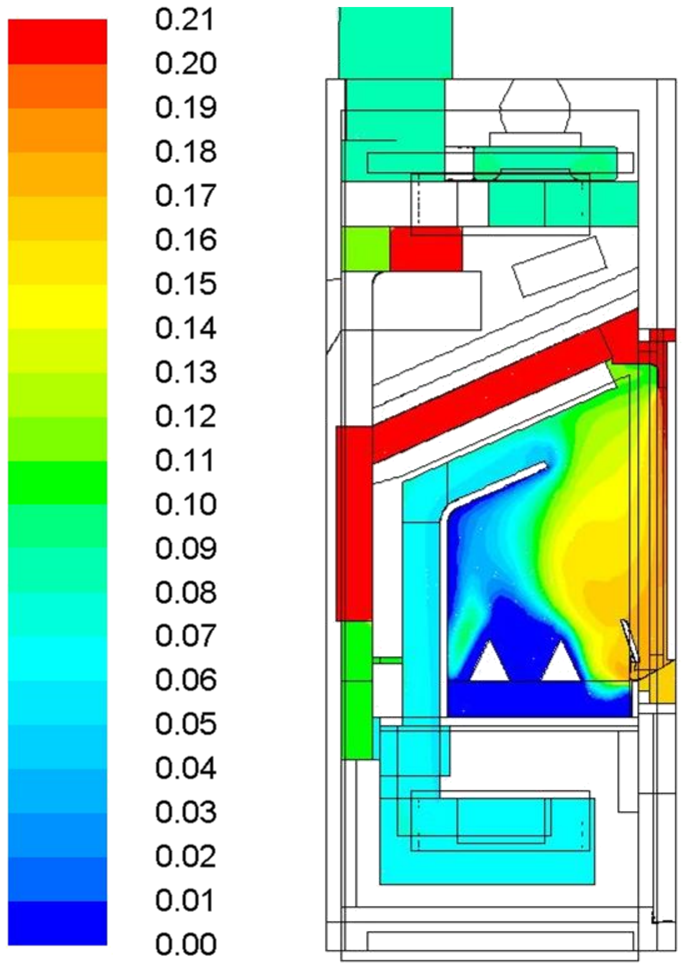


Development of the new stove technology (VII) – CFD simulation results

- Iso-surfaces of CO concentrations [ppmv]

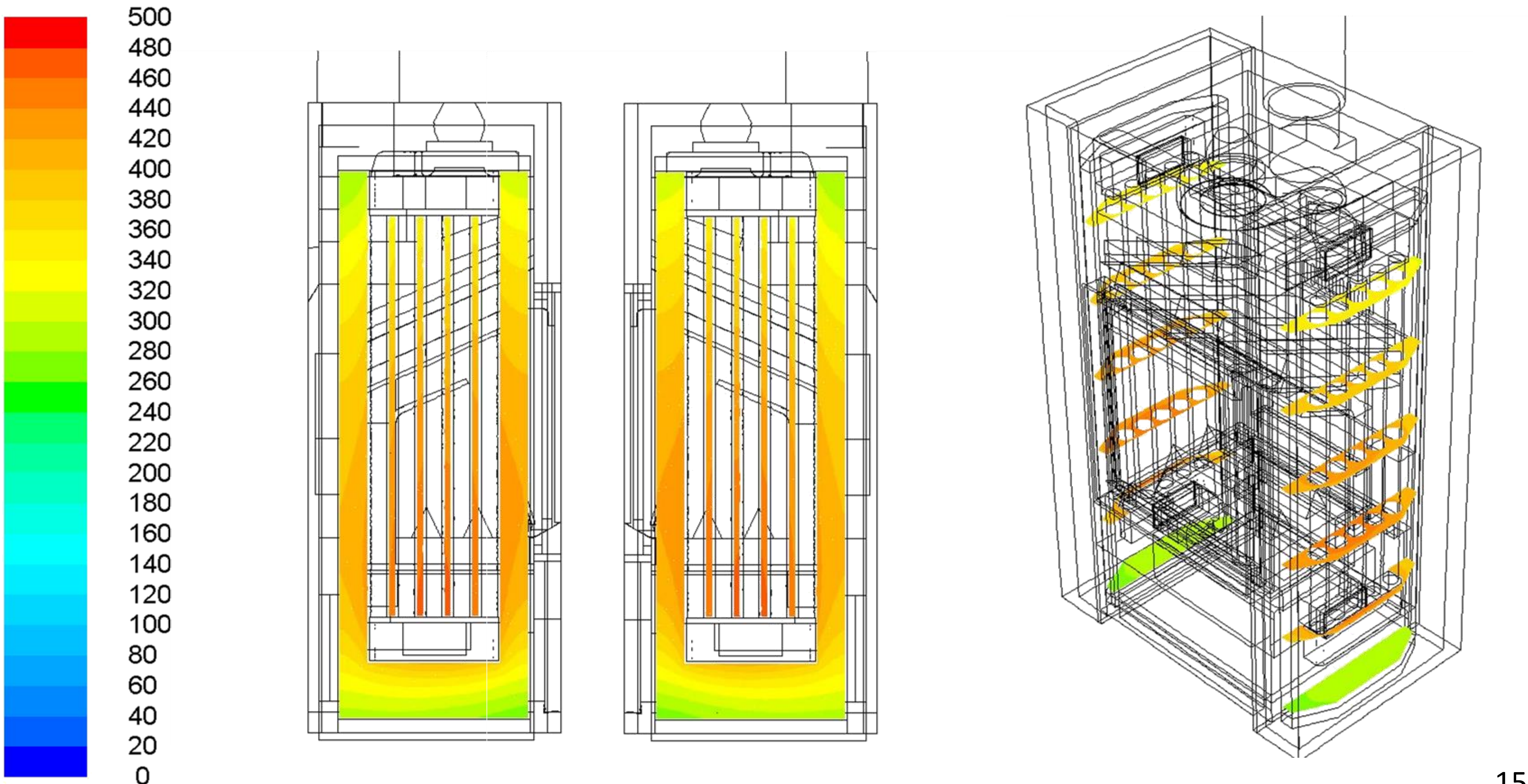


- Iso-surfaces of O_2 concentrations [m^3 O_2/ m^3 flue gas w.b]



Development of the new stove technology (VIII) – CFD simulation results

- Iso-surfaces of temperatures of the PCM material [°C]



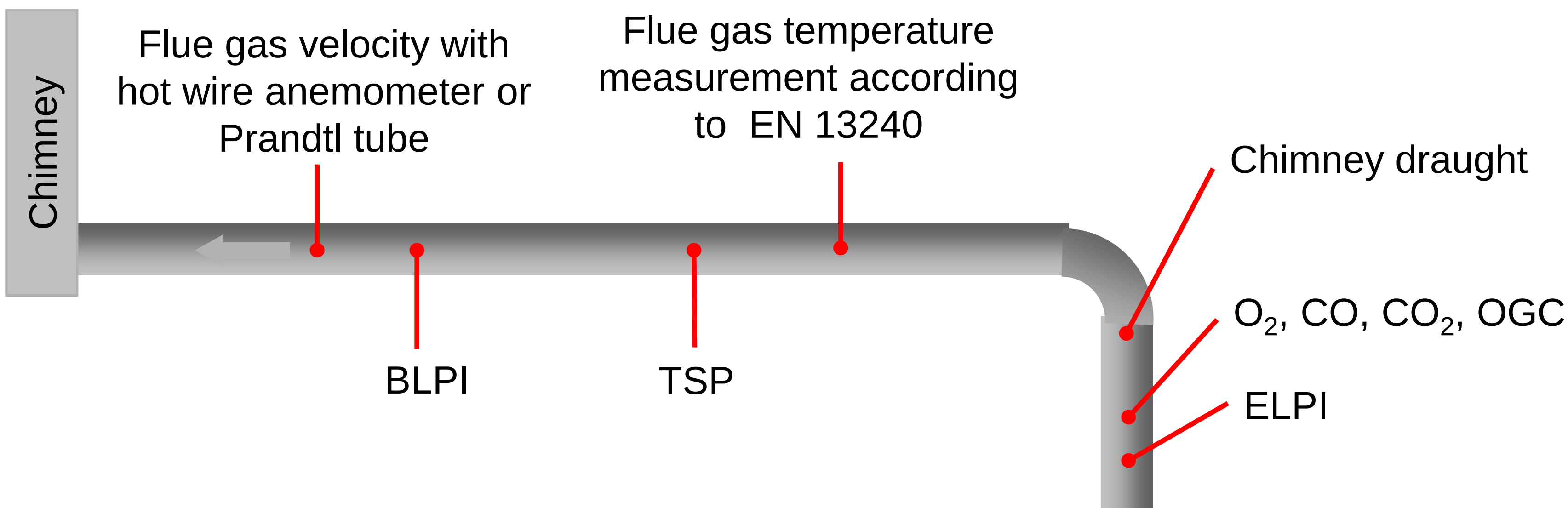
Development of the new stove technology (IX) – CFD simulation results

- Air staging and window flushing has been optimized to ensure a clean window and low O_2 contents in the flue gas.
- Good mixing of the flue gas with the combustion air indicated by even distributions of O_2 and CO at stove outlet.
- Due to the high temperatures in the combustion chamber and the efficient mixing of the flue gas with the combustion air a very good gas phase burnout quality can be achieved, indicated by very low CO emissions.
- Due to the optimised positioning and improved insulation of the PCM heat exchanger a complete melting of the PCM can be achieved:
  - **Minimum temperature of the PCM is in the steady state 263 °C → above the melting temperature of the selected PCM**
  - **Maximum temperature of the PCM is in the steady state 477 °C → lower than the degradation temperature of the selected PCM**

Evaluation of test runs performed with the new stove technology (I)

- Based on the development work a prototype of the stove with integrated PCM heat exchanger was constructed.

Evaluation of test runs performed with the new stove technology (II)



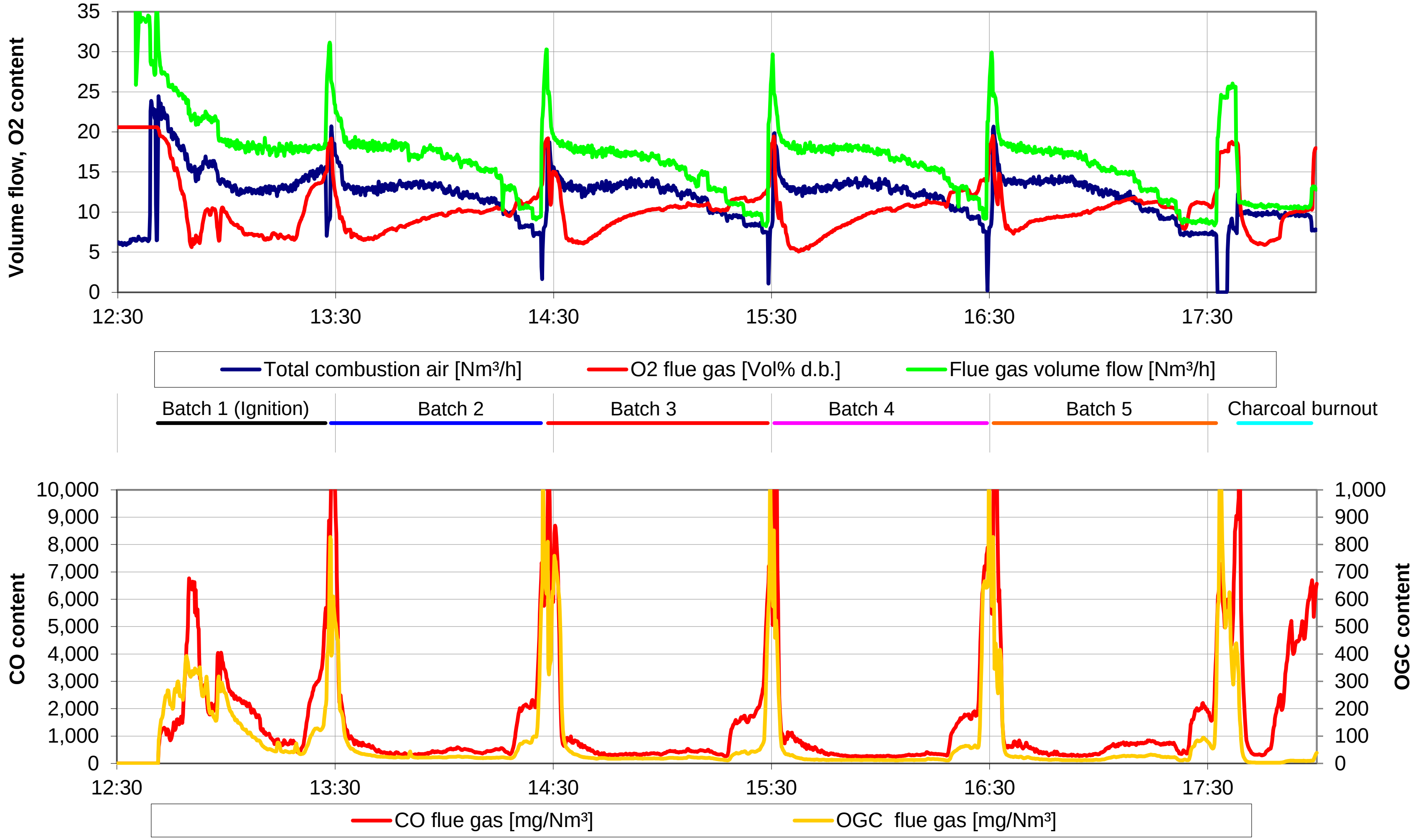
- **Determination of the total fly ash (TSP) concentration in the flue gas downstream the stove according to VDI 2066**
- **BLPI: Berner-type low pressure impactor**
- **ELPI: Electrical low-pressure impactor**

Evaluation of test runs performed with the new stove technology (III)

- **Performance of test runs with the new low emission and high efficiency stove with integrated PCM heat exchanger**
  - **Performance of test runs with automated control of the stove including emission measurements:**
    - Test run cycle: ignition batch, 4 full load batches, charcoal burnout batch
  - **Evaluation of the performance of the stove in terms of gaseous and particulate emissions**
  - **Evaluation of the performance of the PCM heat exchanger**
- **Based on the evaluation of test runs performed the new stove technology has been further developed and stepwise optimised**

Evaluation of test runs performed with the new stove technology (IV)

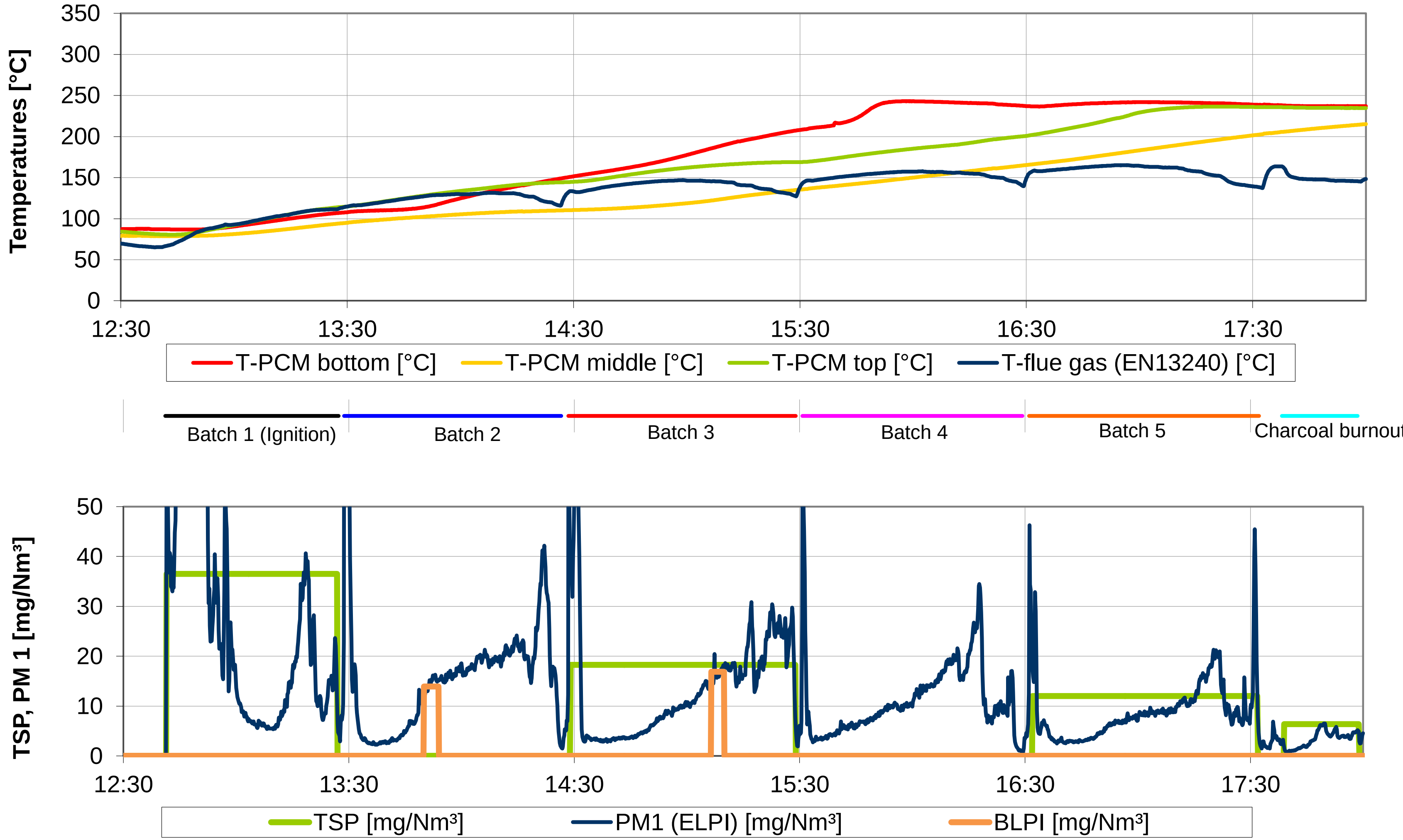
■ Test run – stove performance



Explanations: Emissions related to dry flue gas and 13 vol.% O_2

Evaluation of test runs performed with the new stove technology (V)

■ Test run – PCM heat exchanger loading and PM emissions



Explanations: Emissions related to dry flue gas and 13 vol.% O_2

Evaluation of test runs performed with the new stove technology (VI)

■ Energy balance for a complete test run

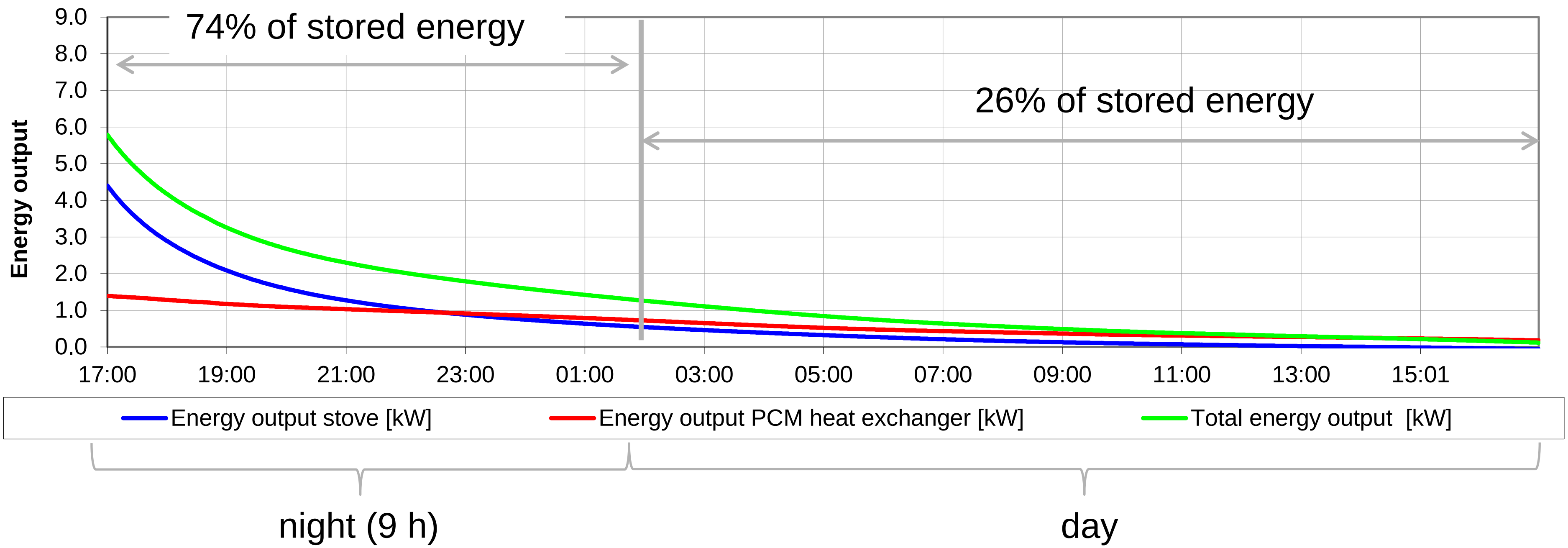
	Energy balance		
	kW	kWh	%
Fuel power input	10.6	53.5	100.0%
Energy storage char coal	1.2	5.9	11.0%
Thermal output (radiation + convection)	3.9	19.9	37.1%
Energy storage stove	2.5	12.5	23.4%
Energy storage PCM heat exchanger	2.2	11.0	20.5%
Heat losses flue gas	0.7	3.7	6.9%
Total energy storage		**23.5**	**44.0%**
Thermal efficiency incl. charcoal combustion		**93.1%**	
Thermal efficiency (EN13240)		**92.6%**	
Duration of test run		5.07 h	

→ **Efficiencies over 90% are possible**

→ **More than 40 % related to the energy input with the fuel and more than 50 % related to the useful heat can be stored**

Evaluation of test runs performed with the new stove technology (VII)

■ Typical unloading cycle of the PCM heat exchanger

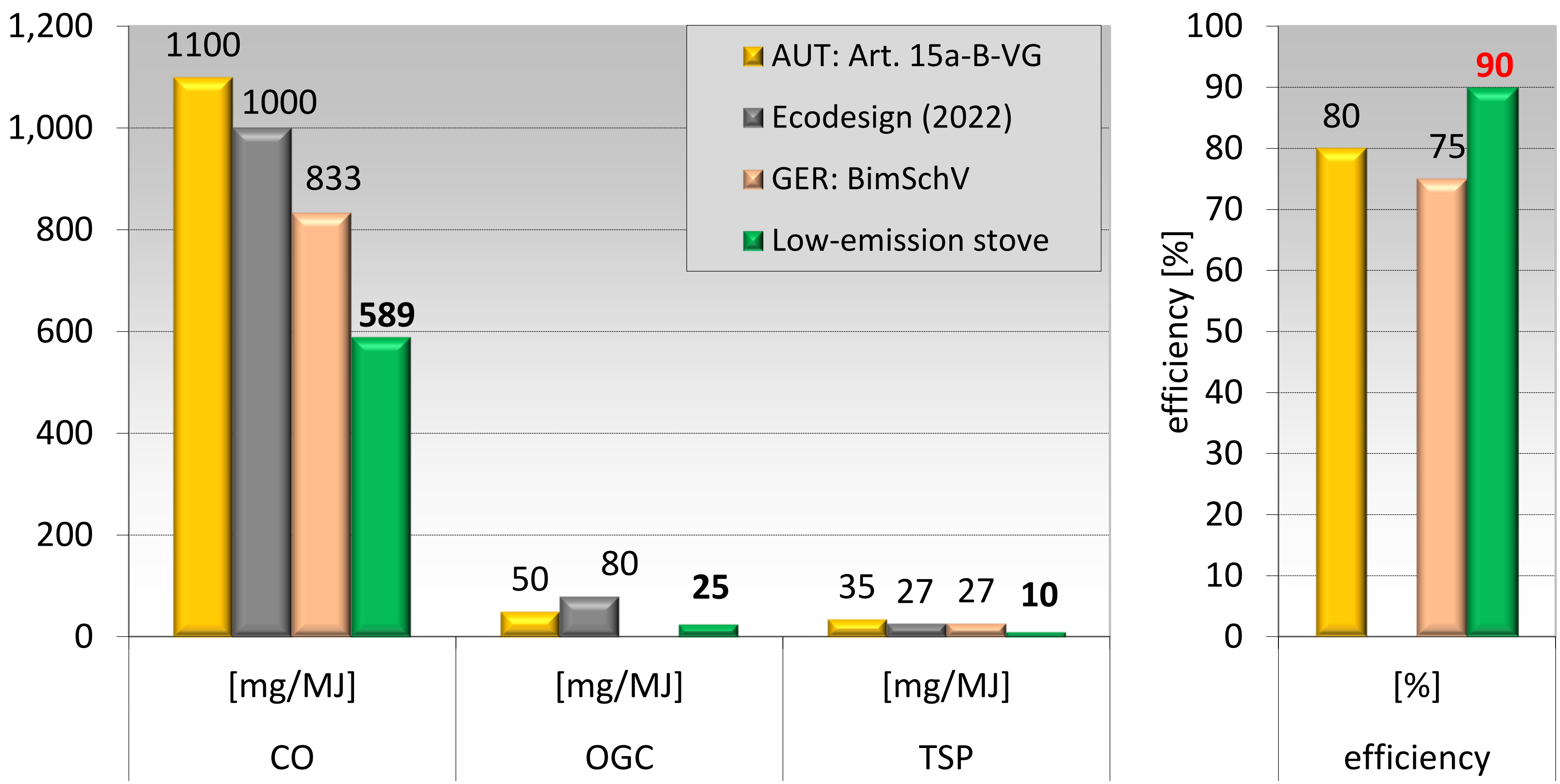


→ Slow heat release over a larger time duration which is of advantage for the comfort of living

<u>Explanations:</u> Air flaps have been closed at the end of the test run; calculation performed based on energy balances and measurements of surface temperatures during unloading

Evaluation of test runs performed with the new stove technology (VIII)

Efficiency and emissions in comparison to relevant limits



Explanations: mean values of averaged emissions over entire batches 3 to 5 (from closing the door until opening the door again for re-charging) according to prEN 16510 / DIN EN 13240

Summary and conclusions

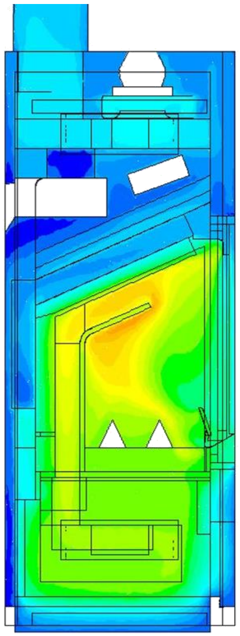
- With the new stove concept with integrated PCM heat exchanger, a renewable CO_2-neutral room heating technology which shows low emissions and significantly increased efficiencies (> 90%) has been developed.

- The gaseous and especially the particulate emissions of the new stove are on a very low level compared to state-of-the-art chimney stoves.

- The integrated PCM heat exchanger developed shows a good heat storage capacity, a compact design and contributes to a better room climate due to its slow heat release.

  → **A new technological milestone regarding stove technology has been achieved**

- The final design of the new technology is currently ongoing. The market introduction of the new stove technology with integrated PCM heat exchanger is expected for 2018.



Thank you for your attention

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