Guidelines for low emissions and high efficiency stove concepts

Progetto Fuoco, Verona/Italy,
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for Renewable Resources (TFZ)
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The project

Development of next generation and clean wood stoves (“Wood Stoves 2020”)
Duration: 08/2014 till 07/2017

Total project costs: 960,000 €
Eranet Programme: 7th joint call for research and development proposals.

- Partners from Germany
  - Technology and Support Centre of Renewable Raw Materials, TFZ (Coordinator)
  - Kutzner+Weber GmbH
- Partners from Austria
  - BIOS Bioenergiesysteme GmbH
  - Rika Ofentechnik GmbH
- Partners from Sweden
  - RISE Research Institutes of Sweden (formerly SP)
  - Nibe AB

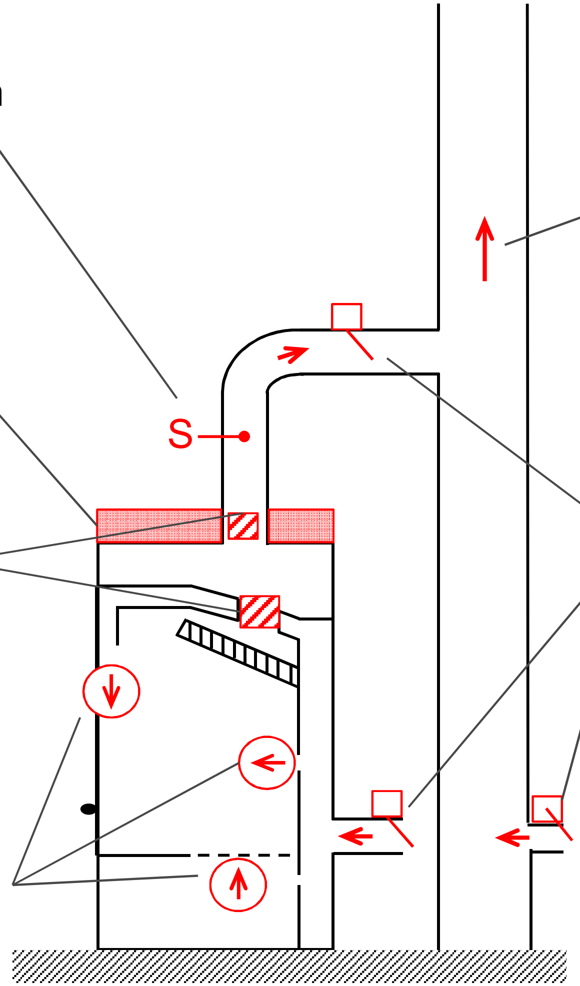
The comprehensive “Wood Stove 2020”-approach

Flue gas sensors and evaluation
RISE

Efficinency increase and
heat storage via PCM
- *BIOS*

Integrated medium or high
temperature catalysts
- *RISE*
- *BIOS*

Sensor-based integrated
combustion air control
- *BIOS*
- *NIBE AB*



Heat losses through chimney
- *TFZ*

Retrofit combustion air control
and draught stabilizers
- *TFZ*

Source: TFZ

Project webpage downloads

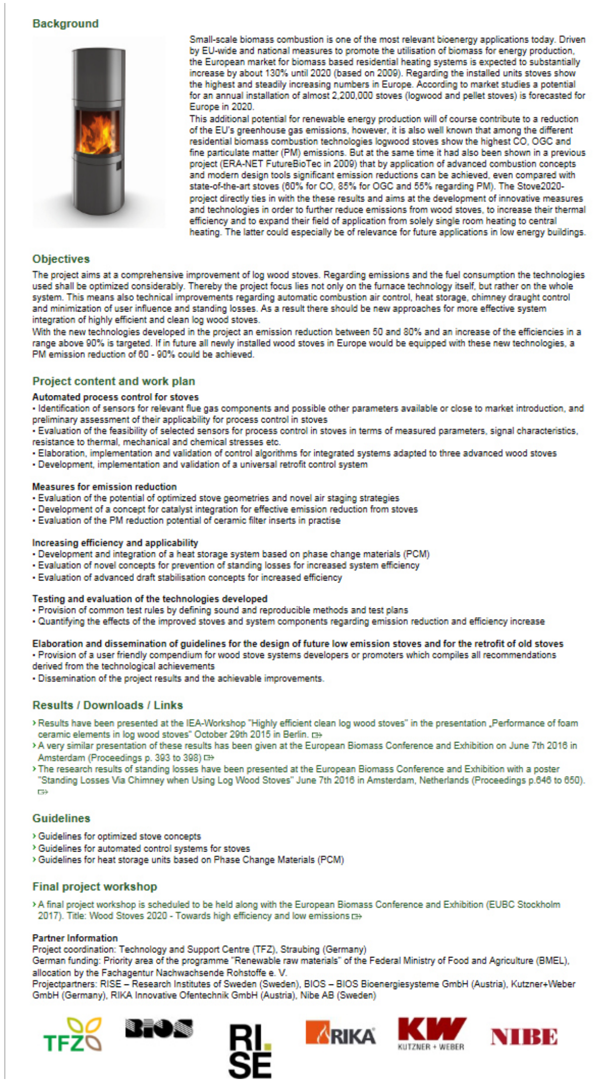
Three jointly elaborated guidelines:

- ➢ Guidelines for optimized stove concepts
- ➢ Guidelines for automated control systems for stoves
- ➢ Guidelines for heat storage units based on Phase Change Materials (PCM)

- ➢ Technical reports (in presentation format)
- ➢ Links to several publications
- ➢ Comprehensive final report
- ➢ All presentations from EUBCE-workshop

Download link at project webpage:

www.tfz.bayern.de/en/162907/index.php



Background

Small-scale biomass combustion is one of the most relevant bioenergy applications today. Driven by EU-wide and national measures to promote the utilisation of biomass for energy production, the European market for biomass based residential heating systems is expected to substantially increase by about 130% until 2020 (based on 2009). Regarding the installed units stoves show the highest and steadily increasing numbers in Europe. According to market studies a potential for an annual installation of almost 2,200,000 stoves (logwood and pellet stoves) is forecasted for Europe in 2020.

This additional potential for renewable energy production will of course contribute to a reduction of the EU's greenhouse gas emissions, however, 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. But at the same time it had also been shown in a previous project (ERA-NET FutureBioTec in 2009) that by application of advanced combustion concepts and modern design tools significant emission reductions can be achieved, even compared with state-of-the-art stoves (60% for CO, 85% for OGC and 55% regarding PM). The Stove2020-project directly ties in with the these results and aims at the development of innovative measures and technologies in order to further reduce emissions from wood stoves, to increase their thermal efficiency and to expand their field of application from solely single room heating to central heating. The latter could especially be of relevance for future applications in low energy buildings.

Objectives

The project aims at a comprehensive improvement of log wood stoves. Regarding emissions and the fuel consumption the technologies used shall be optimized considerably. Thereby the project focus lies not only on the furnace technology itself, but rather on the whole system. This means also technical improvements regarding automatic combustion air control, heat storage, chimney draught control and minimization of user influence and standing losses. As a result there should be new approaches for more effective system integration of highly efficient and clean log wood stoves.

With the new technologies developed in the project an emission reduction between 50 and 80% and an increase of the efficiencies in a range above 90% is targeted. If in future all newly installed wood stoves in Europe would be equipped with these new technologies, a PM emission reduction of 60 - 90% could be achieved.

Project content and work plan

Automated process control for stoves
- Identification of sensors for relevant flue gas components and possible other parameters available or close to market introduction, and preliminary assessment of their applicability for process control in stoves
- Evaluation of the feasibility of selected sensors for process control in stoves in terms of measured parameters, signal characteristics, resistance to thermal, mechanical and chemical stresses etc.
- Elaboration, implementation and validation of control algorithms for integrated systems adapted to three advanced wood stoves
- Development, implementation and validation of a universal retrofit control system

Measures for emission reduction
- Evaluation of the potential of optimized stove geometries and novel air staging strategies
- Development of a concept for catalyst integration for effective emission reduction from stoves
- Evaluation of the PM reduction potential of ceramic filter inserts in practise

Increasing efficiency and applicability
- Development and integration of a heat storage system based on phase change materials (PCM)
- Evaluation of novel concepts for prevention of standing losses for increased system efficiency
- Evaluation of advanced draft stabilisation concepts for increased efficiency

Testing and evaluation of the technologies developed
- Provision of common test rules by defining sound and reproducible methods and test plans
- Quantifying the effects of the improved stoves and system components regarding emission reduction and efficiency increase

Elaboration and dissemination of guidelines for the design of future low emission stoves and for the retrofit of old stoves
- Provision of a user friendly compendium for wood stove systems developers or promoters which compiles all recommendations derived from the technological achievements
- Dissemination of the project results and the achievable improvements.

Results / Downloads / Links

› Results have been presented at the IEA-Workshop "Highly efficient clean log wood stoves" in the presentation „Performance of foam ceramic elements in log wood stoves" October 29th 2015 in Berlin.
› A very similar presentation of these results has been given at the European Biomass Conference and Exhibition on June 7th 2016 in Amsterdam (Proceedings p. 393 to 398)
› The research results of standing losses have been presented at the European Biomass Conference and Exhibition with a poster "Standing Losses Via Chimney when Using Log Wood Stoves" June 7th 2016 in Amsterdam, Netherlands (Proceedings p.646 to 650).

Guidelines

› Guidelines for optimized stove concepts
› Guidelines for automated control systems for stoves
› Guidelines for heat storage units based on Phase Change Materials (PCM)

Final project workshop

› A final project workshop is scheduled to be held along with the European Biomass Conference and Exhibition (EUBC Stockholm 2017). Title: Wood Stoves 2020 - Towards high efficiency and low emissions

Partner Information
Project coordination: Technology and Support Centre (TFZ), Straubing (Germany)
German funding: Priority area of the programme "Renewable raw materials" of the Federal Ministry of Food and Agriculture (BMEL), allocation by the Fachagentur Nachwachsende Rohstoffe e. V.
Projectpartners: RISE – Research Institutes of Sweden (Sweden), BIOS – BIOS Bioenergiesysteme GmbH (Austria), Kutzner+Weber GmbH (Germany), RIKA Innovative Ofentechnik GmbH (Austria), Nibe AB (Sweden)

Content

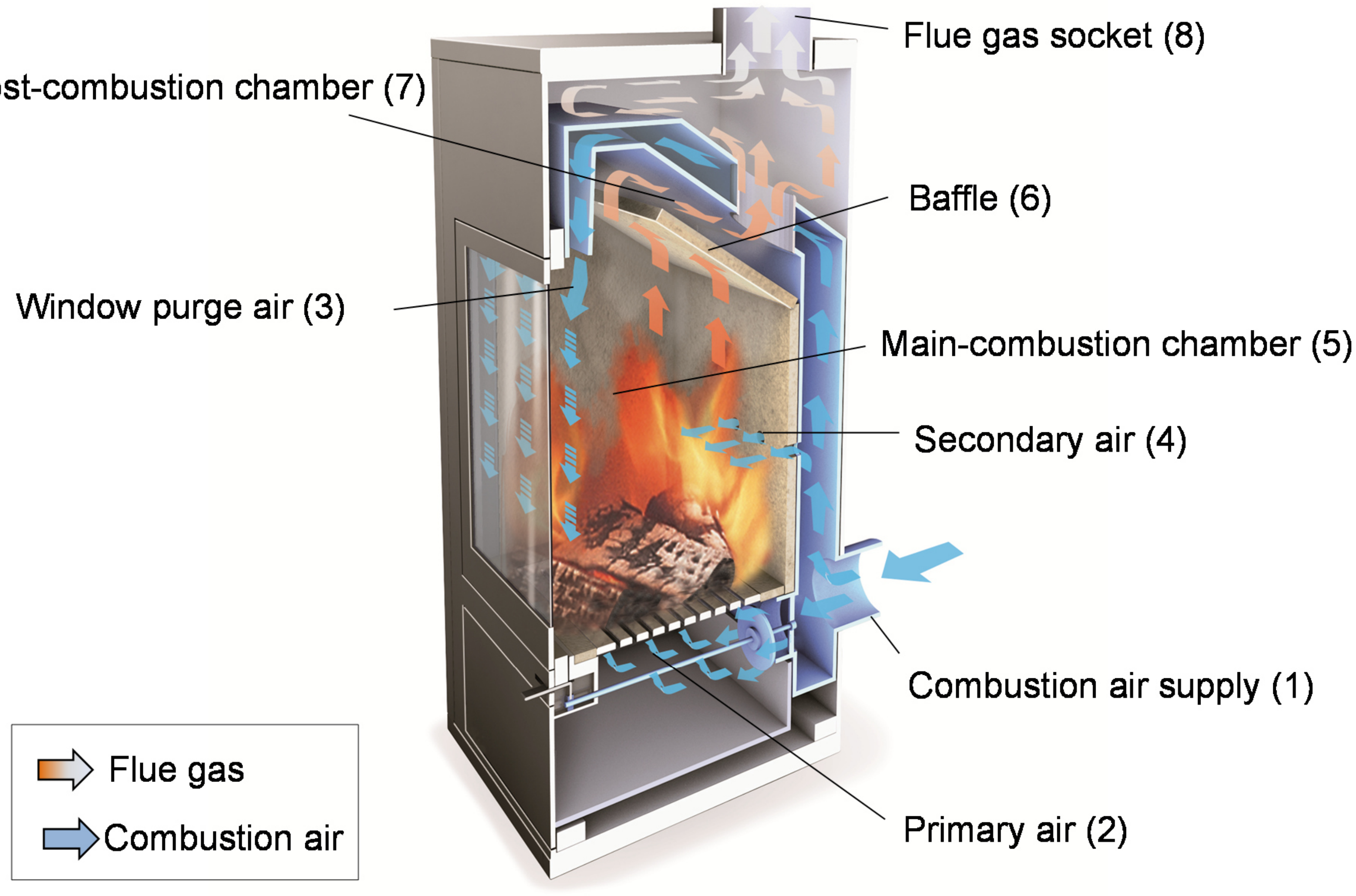
- General requirements
- Geometric design concept
- Automatic combustion control
- Avoidance of standing losses (from cold and hot chimney)
- CFD aided stove design
- Utilisation of integrated catalysts and foam ceramics
- Conclusions

General rules for combustion design

"Rule of 3-T": Time-Temperature-Turbulence

Time:	Chemical combustion reactions require sufficient time to achieve complete oxidation. ⇒ residence time >0.5 s at 800 °C
Temperature:	High temperatures speed up the combustion process. ⇒ avoid heat losses in the combustion zone (e.g. refractory lining, heat reflecting window glass)
Turbulence:	Supply of oxygen to the reactant gas molecules needs to be ensured by homogenization (mixing) ⇒ induce areas with turbulences (e.g. baffles, nozzles)

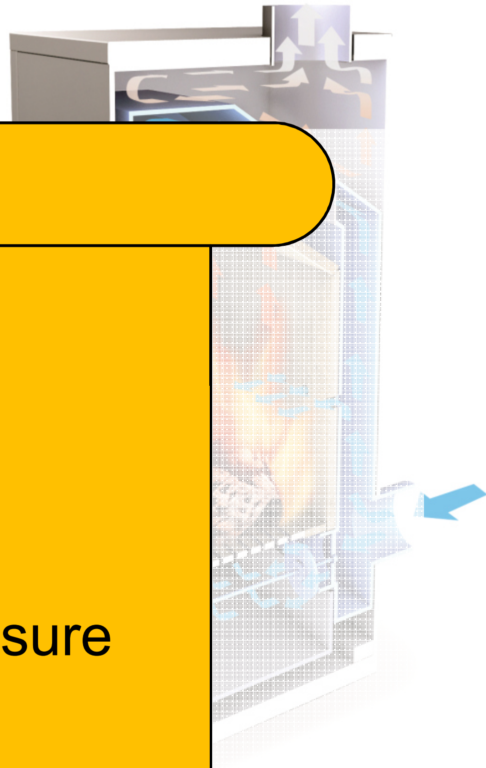
Typical design of a modern room heater for log wood



Source: TFZ-Wissen, Vol. 1, "Richtig heizen"

General rules for combustion design (2)

Impact on time-temperature-turbulence (3T)



Residence Time: - ga
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Temperature: - re
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Turbulence: - di ... ber
- di ... ozzles

Some technical conclusions are:

➢ Avoid leakage air streams by using appropriate material for the door and ensure that the door seals correctly.

➢ Avoid short-circuiting of flue gas streams within the stove.

- geometry of the main/post combustion chambers

Fundamental consequences for best suitable stove geometry:
Stove shape

Low and wide shape

High and slim shape

Source: TFZ-Wissen, Vol. 1, “Richtig heizen”

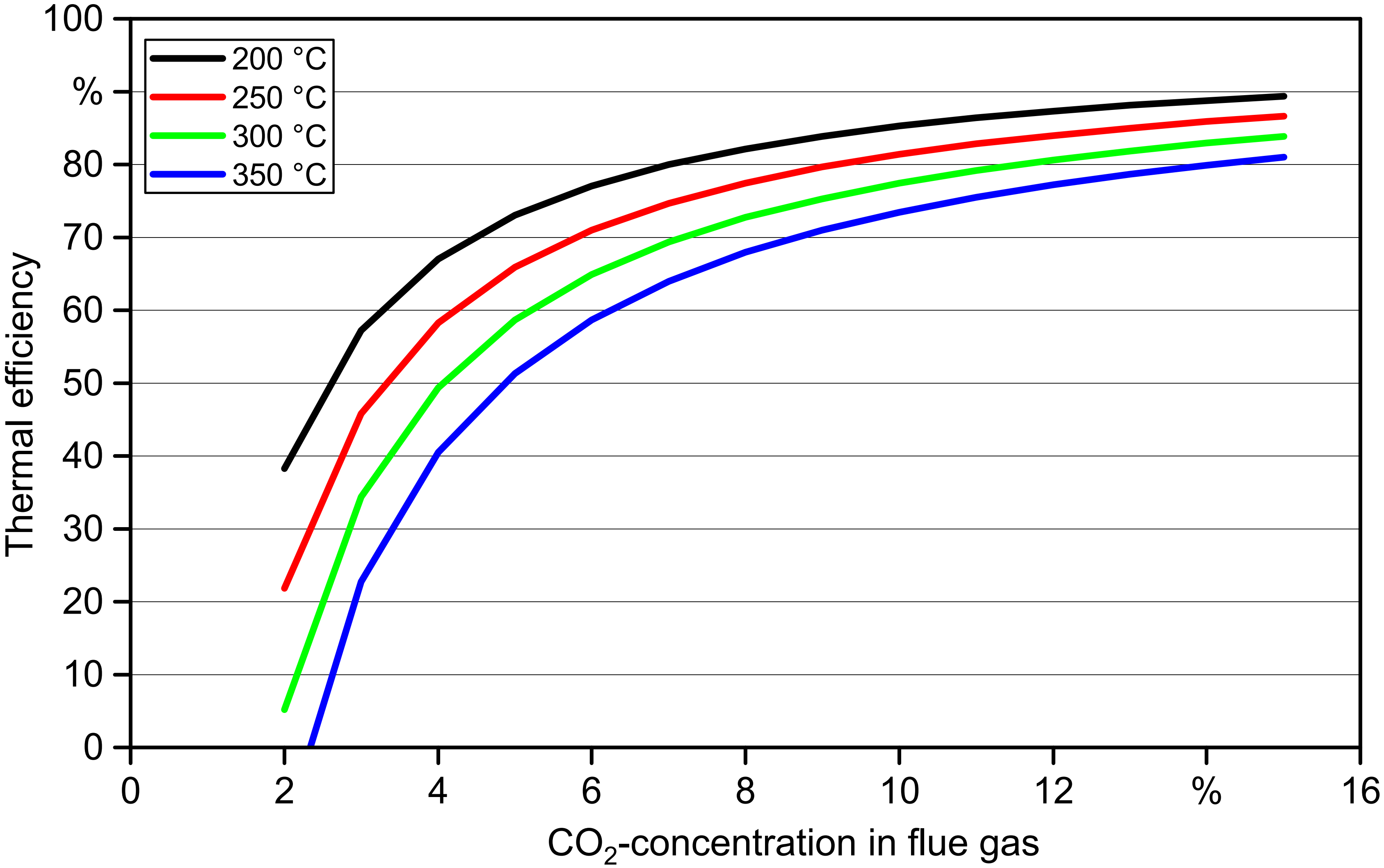
Fundamental consequences for best suitable stove geometry:
Window size

Very large window surface

Moderately sized window surface

Source: TFZ-Wissen, Vol. 1, "Richtig heizen"

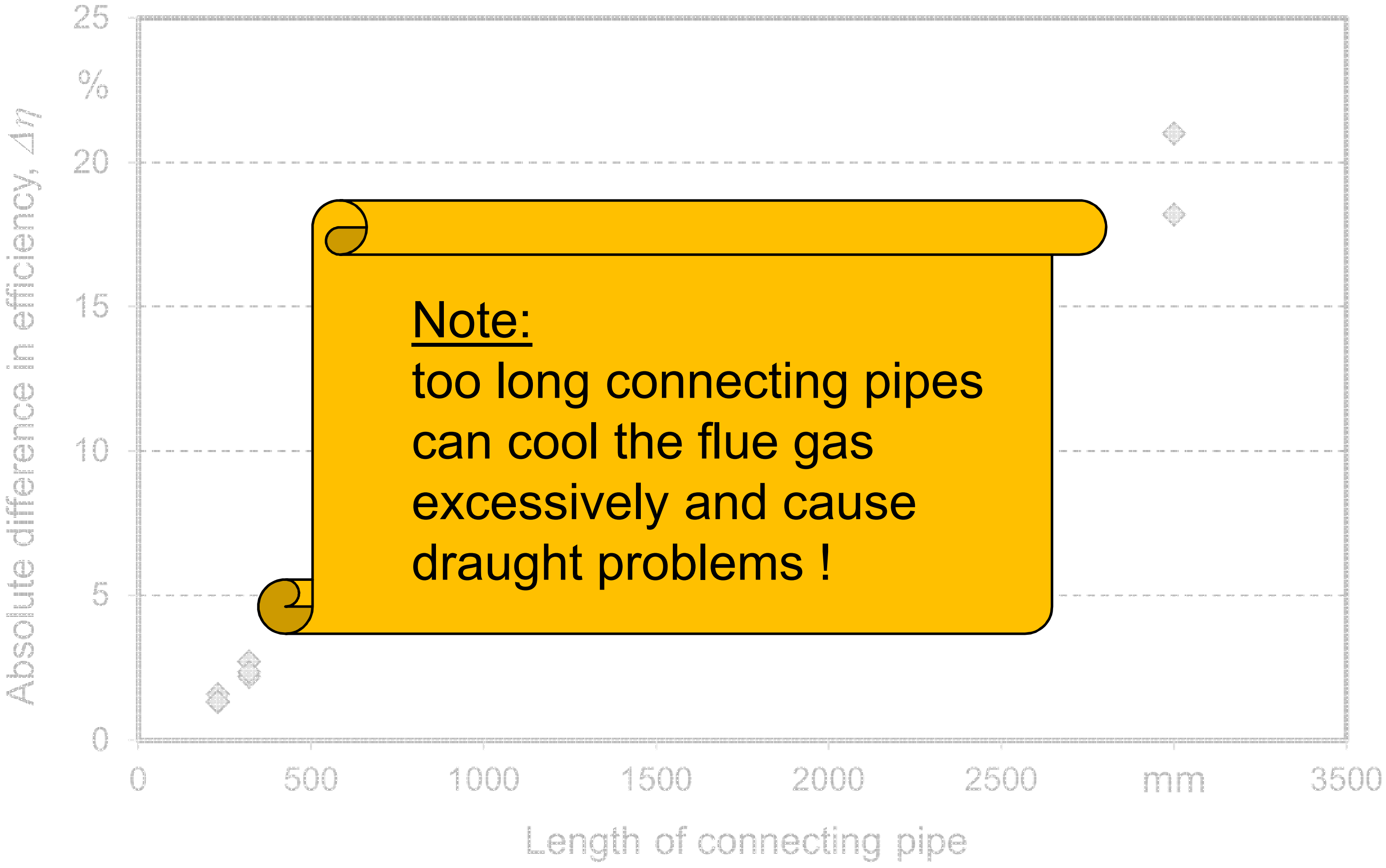
Main influencing factors on combustion efficiency: Flue gas temperature and lambda (or CO_2)



The assumptions for these calculations are:
CO: 0.15 vol-% d.b., fuel: beech wood, fuel moisture: 14 %

Source: TFZ

Thermal efficiency as a function of the length of the connecting pipe to the chimney (examples from field tests)



Results from 8 log wood stoves tested in the field during beReal-project (http://www.bereal-project.eu/)

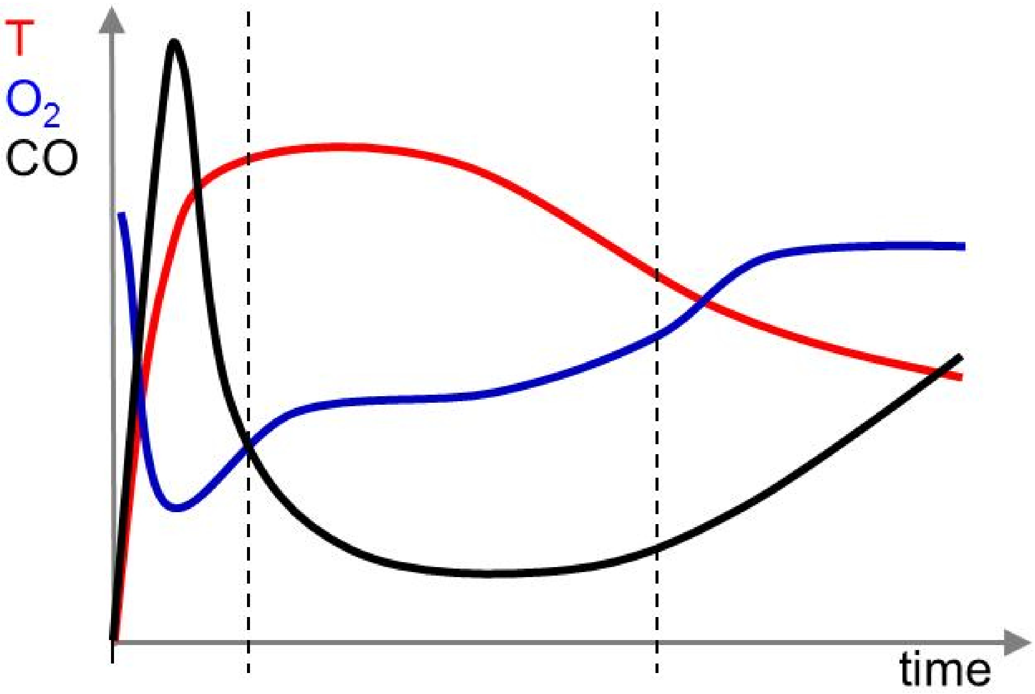
Remark: No differentiation for flue gas temperature was here be made, but it would be required for sound estimations.

Integrated automatic air control: Advantages

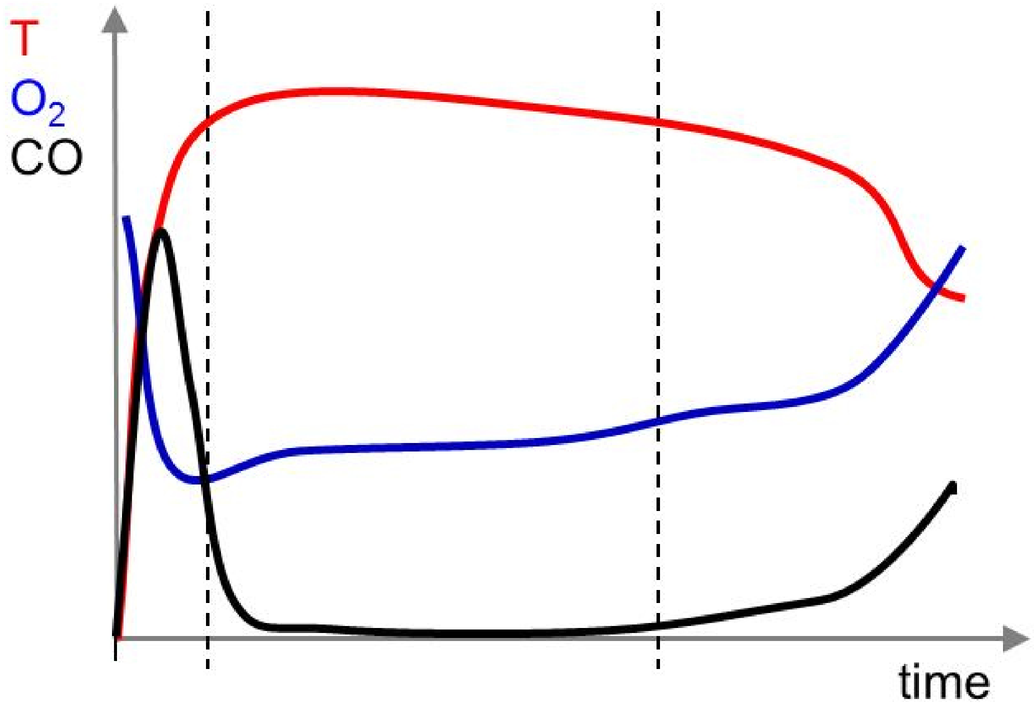
- reduce user influences (operating errors)
- provide the possibility to react on the changing process conditions throughout the entire batch
- reduce emissions
- increase thermal efficiency
- increase operational comfort
- reduce standing losses (by closing air flaps)

Integrated automatic air control: Potential

Conventional uncontrolled stove



Automatically controlled stove



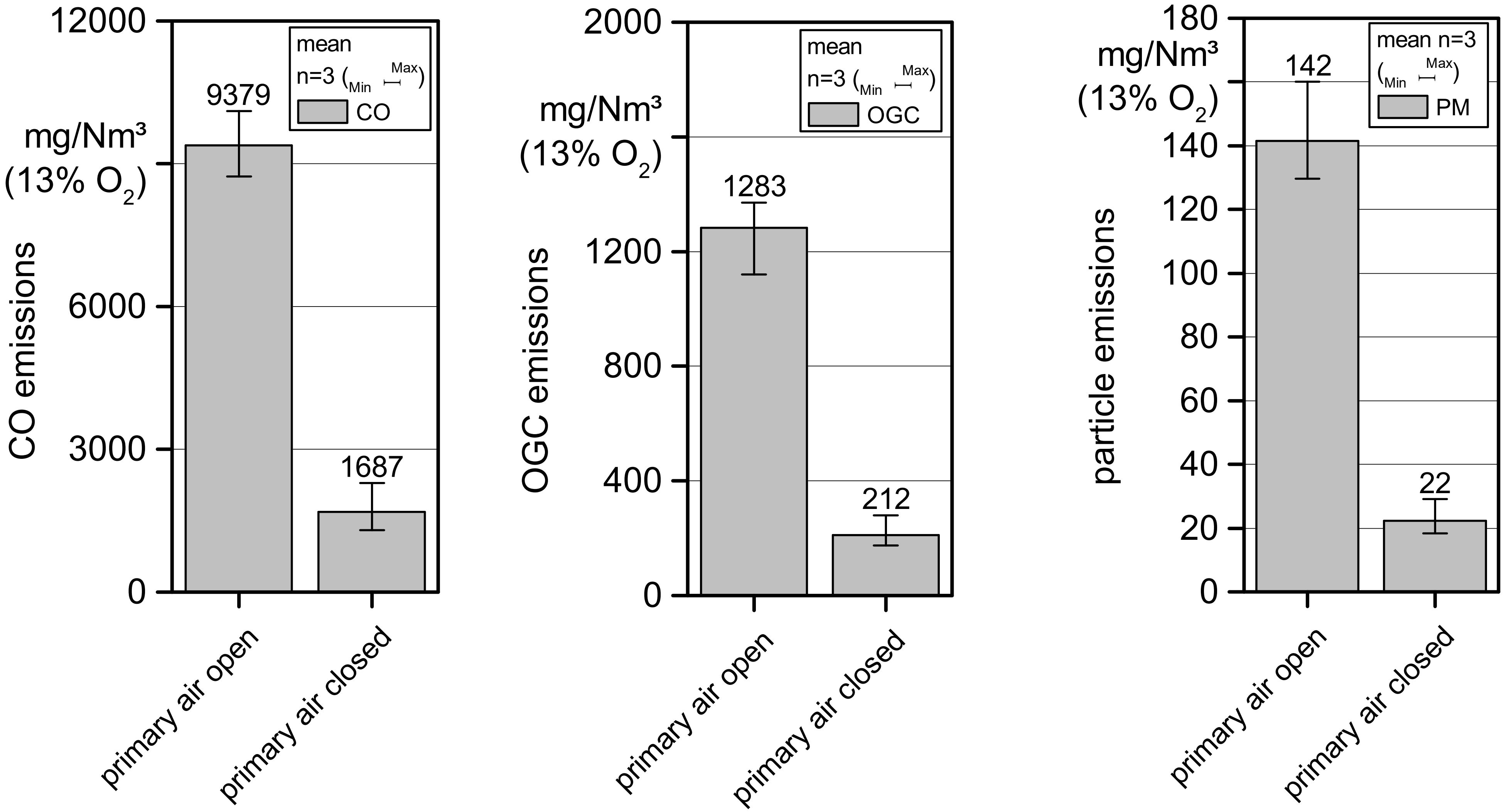
Source: BIOS Bioenergiesysteme GmbH

<u>Effects of automatic control:</u>

- Shorter ignition phase
- Stove combustion chamber temperature *T* is kept contantly on higher level.
- O_2 level is more even and lower during the main combustion and burnout (i.e.the reason for higher combustion chamber temperatures),
- therefore CO/OGC emissions are lower with only one peak (during batch ignition)

Automatic control: Potential to avoid false operation by user

Example: during 3rd batch the primary air valve is left open by user



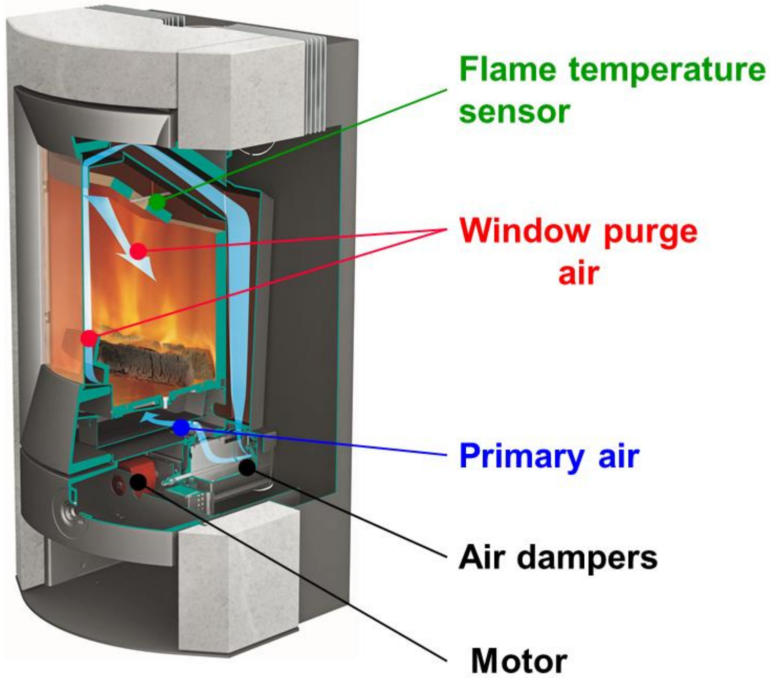
8 kW modern and air-tight log wood stove (2017), tests performed at natural draught.
Results are given only for (full) 3rd batch as mean value of 3 replications.

Source: TFZ 2018 (yet unpublished)

TFZ

Integrated air control strategy: Based on temperature

- Temperature measurement in the combustion chamber
- Separate control of air dampers is required
- A door switch or a manual ignition trigger is required

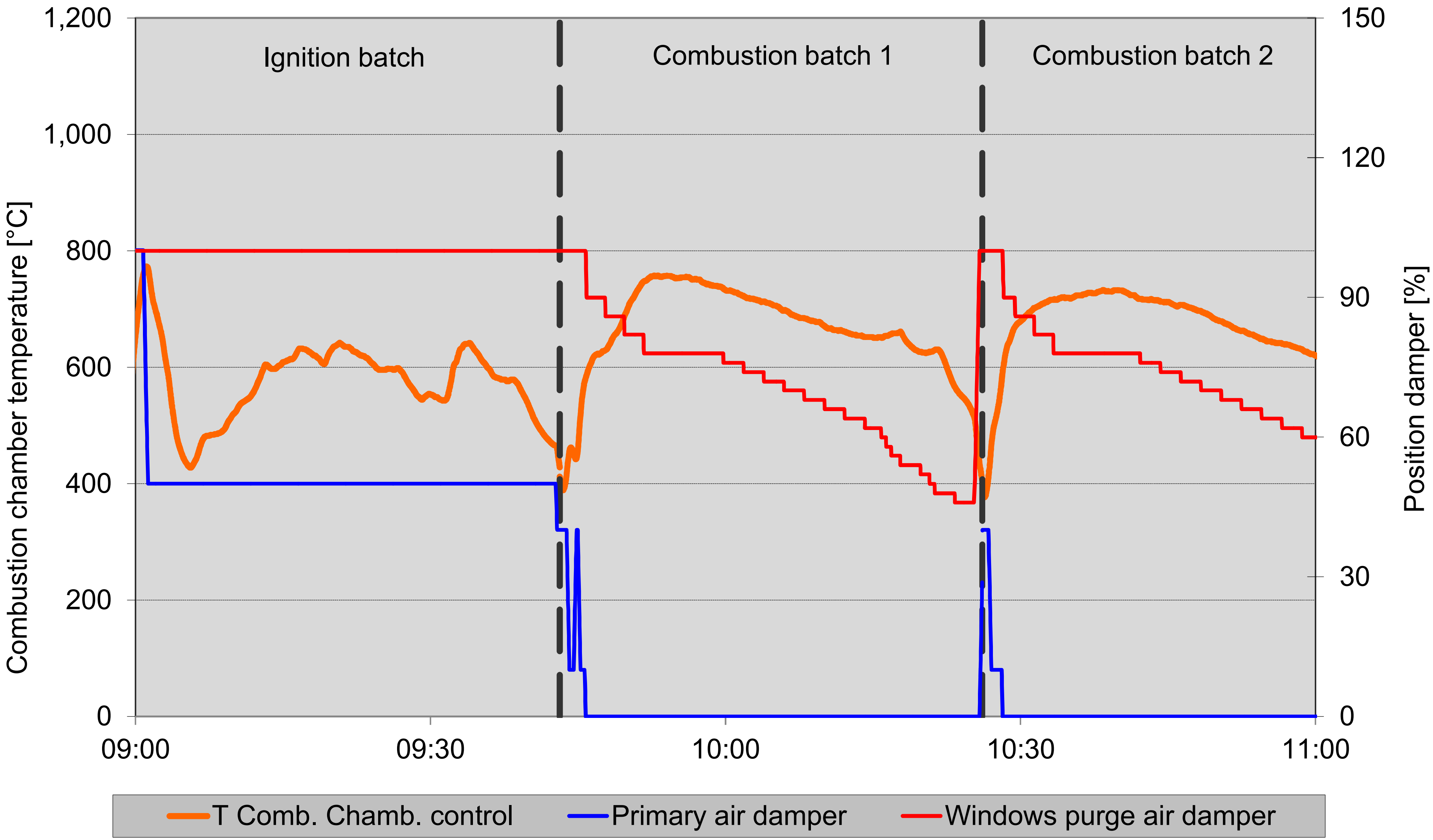


Source: RIKA

Control strategy

- **Ignition phase:** Mainly primary air and a low amount of window purge air is supplied.
- **Main combustion phase:** When temperature exceeds a certain level the primary air damper is closed and secondary air and window purge air can flow. During the main combustion phase the secondary and window purge air flow are kept rather constant (Air ratios depend on furnace design).
- **Charcoal burnout phase:** When the furnace temperature drops below certain value, the secondary and window purge air are reduced until the end of the batch. Recharging at flame extinktion.
- **Shutdown:** Closure of air flaps at the end of stove operation

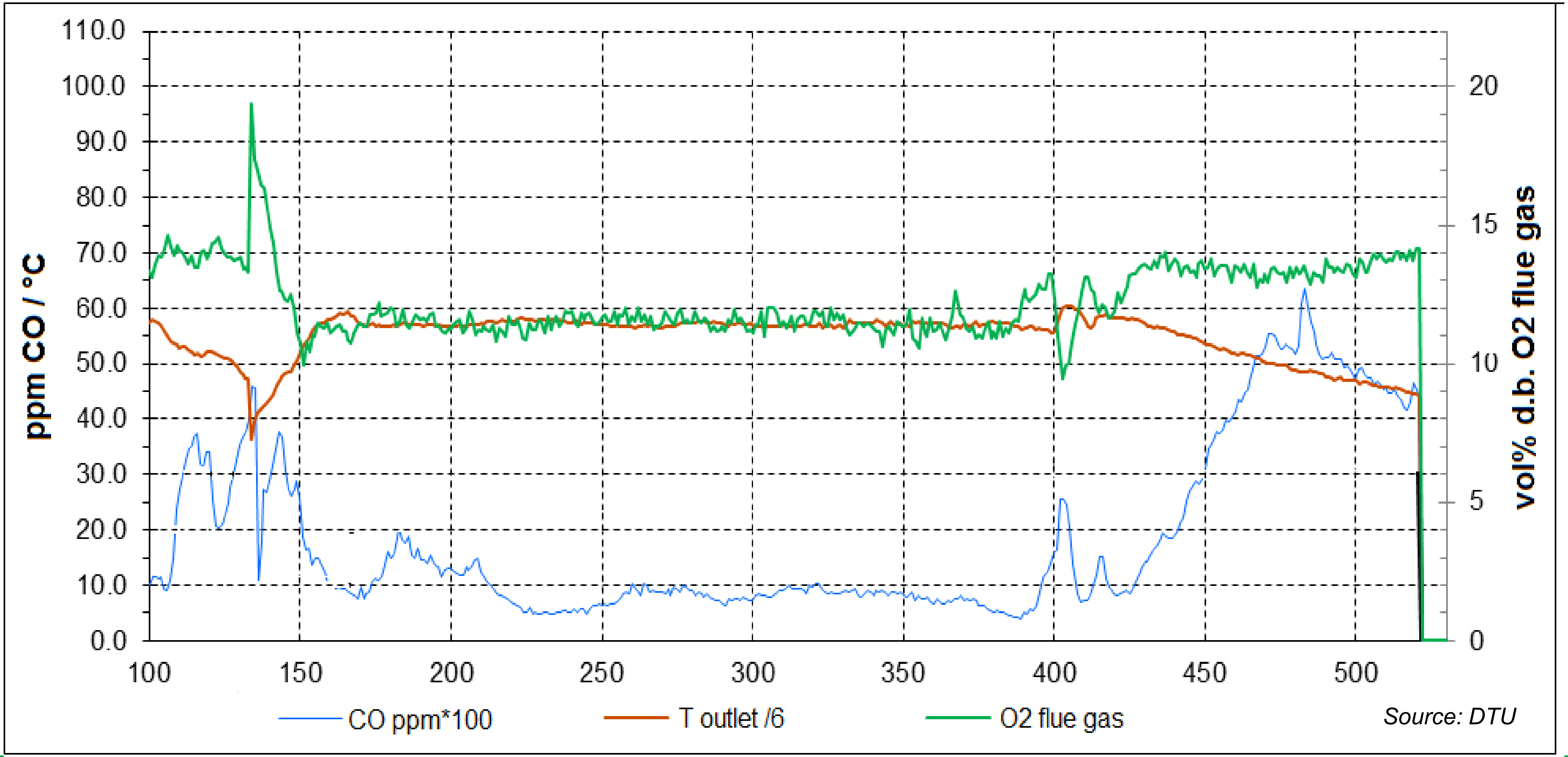
Typical trends of parameters and settings in a log wood stove with automated control system based on temperature



Source: BIOS Bioenergiesysteme GmbH

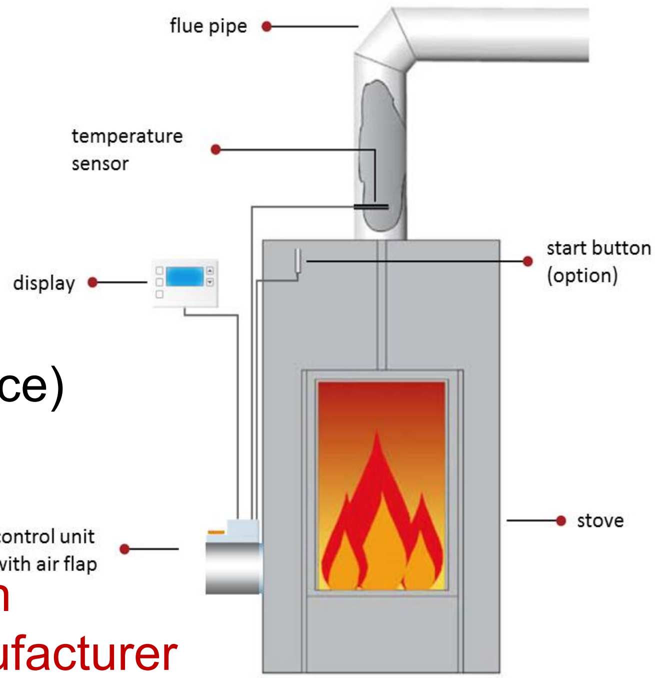
Integrated air control strategy: Based on combined temperature and flue gas measurement sensors

- Better identication of different combustion phases with help of gas sensors (e.g. O_2)
- Higher flexibility in case of unexpected events
- Enables a gradual reopening of primary air flaps for sound charcoal burnout



Retrofit air control devices: Examples

Components: • control unit • electrically driven air flap • sensor for flue gas temperature



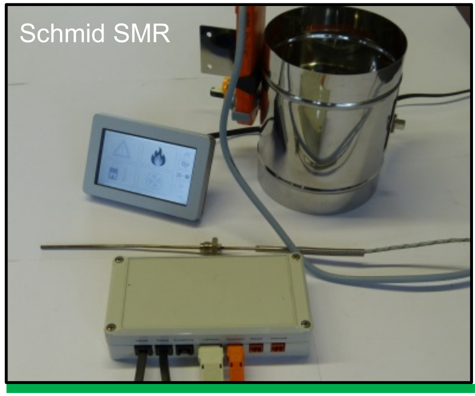
Stove required: - High air-tightness
- Central air inlet socket

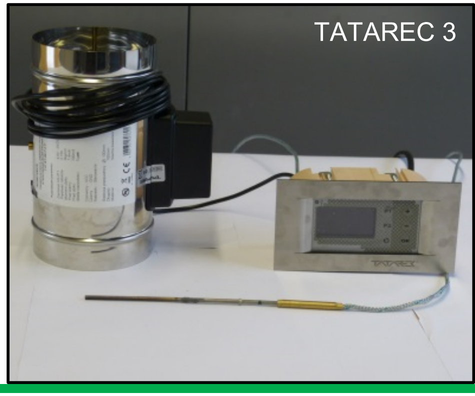
Installation: - Temperature sensor close to flue gas socket,
- Air flap to central air inlet socket

Test results: - Reduced CO emission (in “beReal” test sequence)
- But: <u>higher</u> PM emission with control device

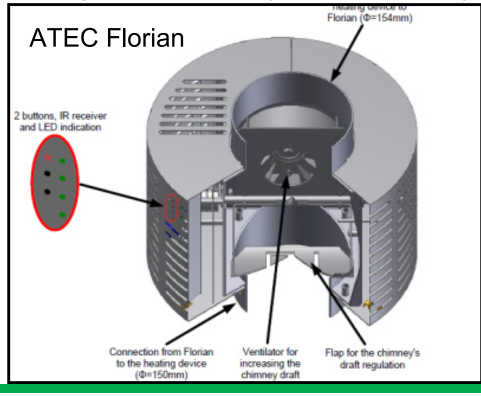
Conclusion: - Reduced standing losses is largest benefit
- Possible benefit by avoidance of false operation
- Installation only with autorization by stove manufacturer

Air controllers tested (source TFZ):

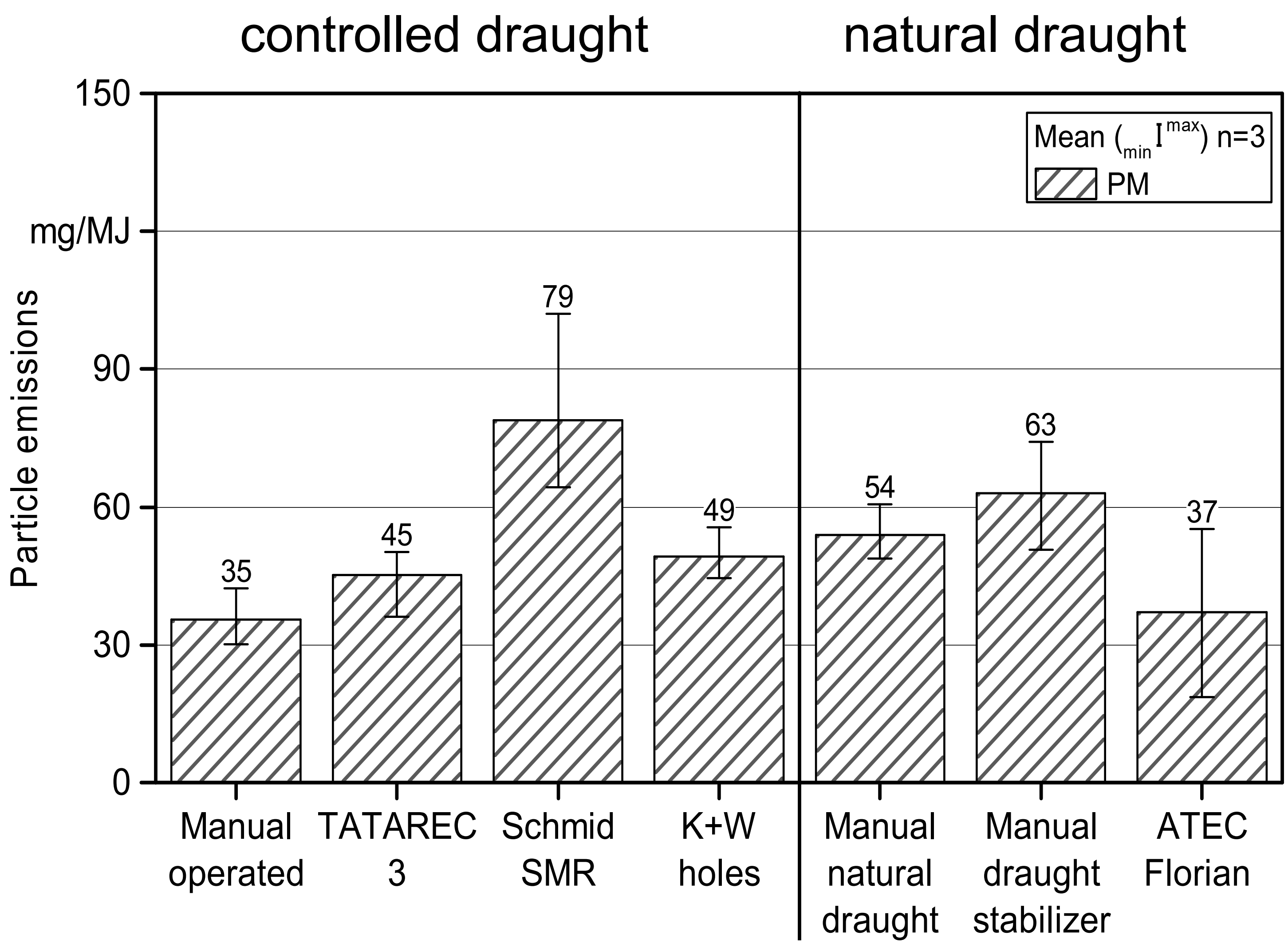




Draught stabilizer (source ATEC):



Retrofit air control devices: Results for PM emission

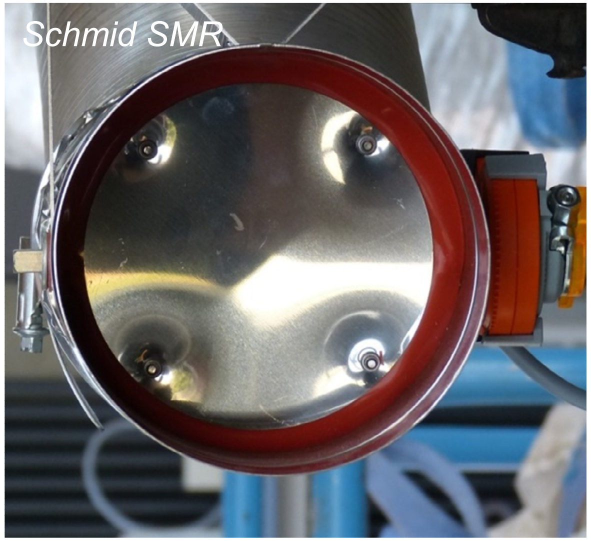


Source: TFZ

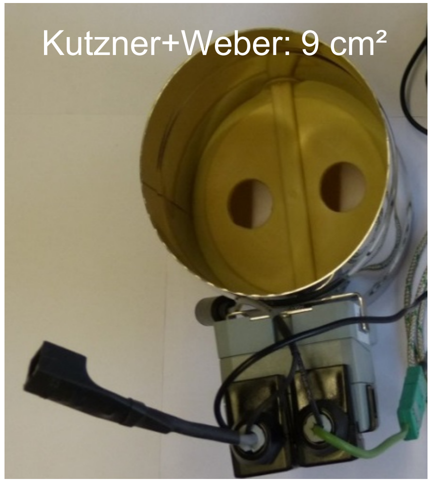
Each measurement is an average of three full test sequences of 8 batches each (“beReal method”).
Log wood stove: 8 kW nominal heat power output

Standing losses: Preventing hot standing losses by flap closure

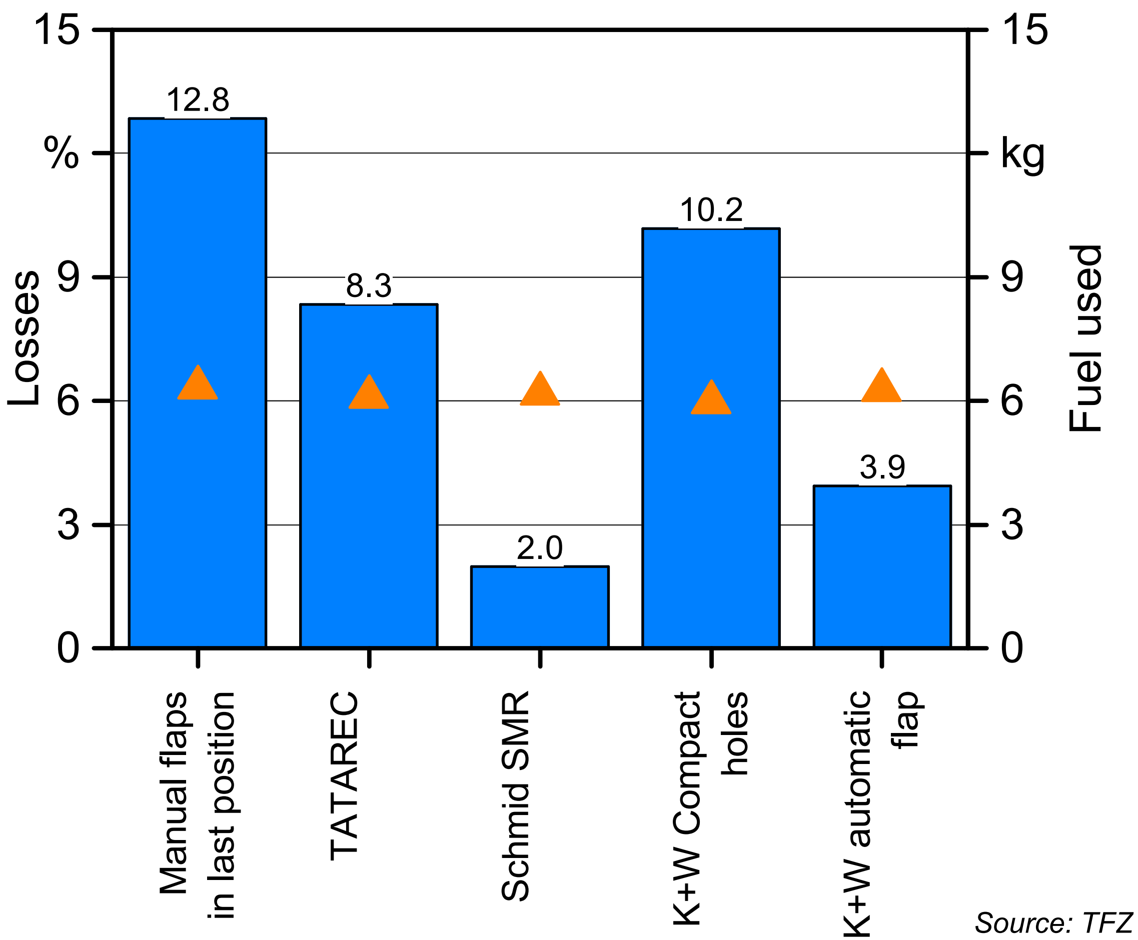
Complete air flap closure:



Remaining open cross sections:

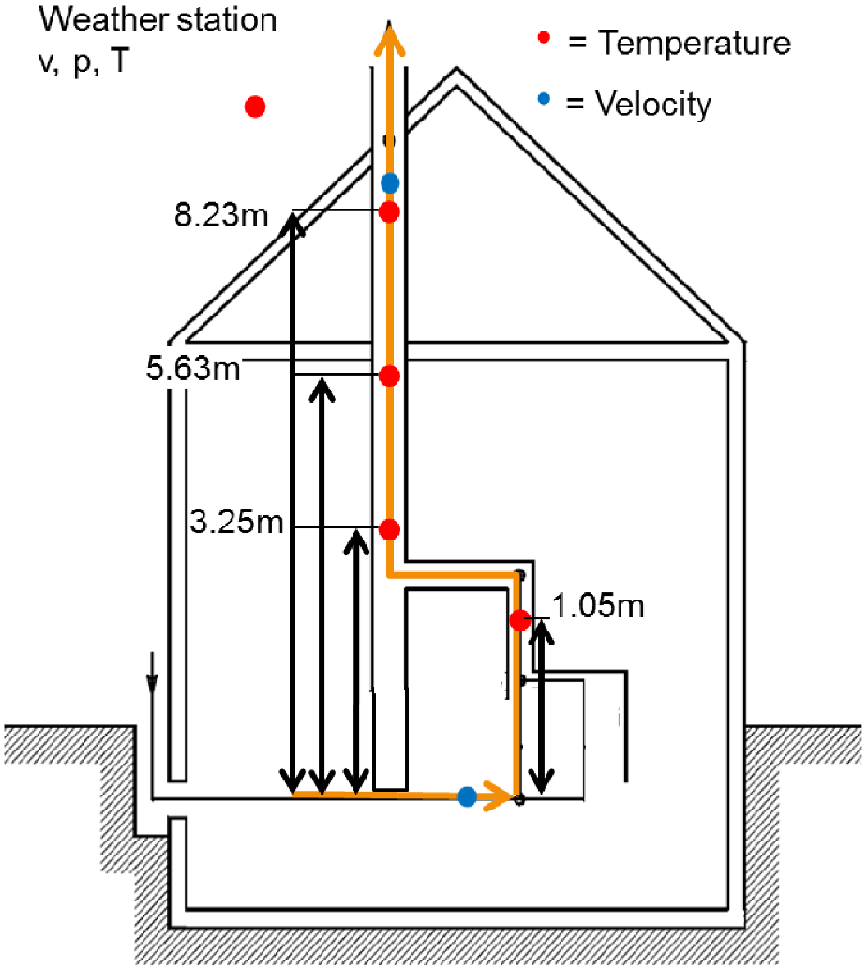


Hot standing losses via chimney:
(measured after 3 batches during the cool-down-phase of an 8 kW stove)

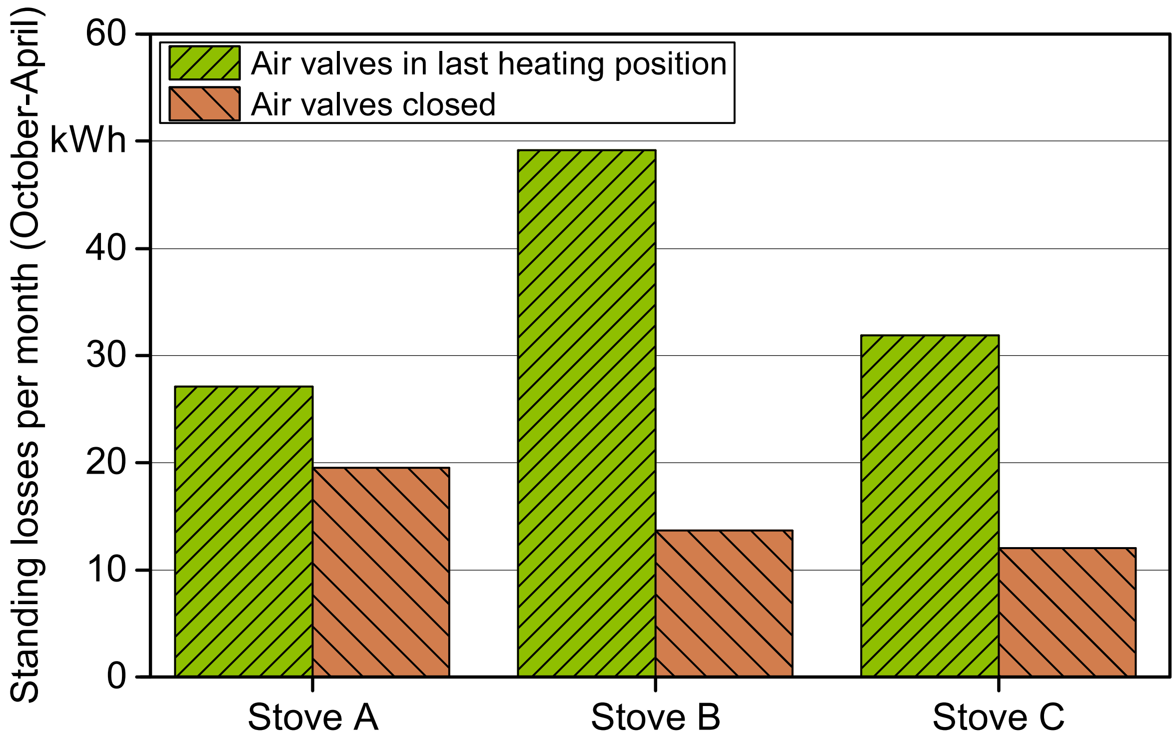


Source: TFZ

Standing losses: Preventing <u>cold</u> standing losses by flap closure



Monitoring of 3 log wood stoves (8 kW) over the heating season at comparable climatic conditions:



<u>Conclusion</u>
- Cold + hot standing losses through chimney account for about 750 kWh/a (results of a model calulation with 100 heating events, i.e. from cold to cold)
- they can largely be avoided by air flaps or by automatic air controls (if fully closing),
- and if the stove is fully air tight

Source: TFZ

CFD aided stove development: Existing developing tools

- BIOS Bioenergiesysteme GmbH in Graz/Austria has deveoped a CFD model for the development and optimisation of biomass grate furnaces (in-house empirical fixed bed combustion model applicable for wood log combustion).
- A time-dependent profile of wood log combustion was derived by the transformation of release profile along the grate calculated by the basic packed bed combustion model.
- To reduce calculation time, steady-state conditions needed to be defined (i.e. operating point when heat storage is zero, as given at around 2/3 of the batch length).

CFD aided stove development: Potential of CFD-tools

CFD simulation can analyse several processes:

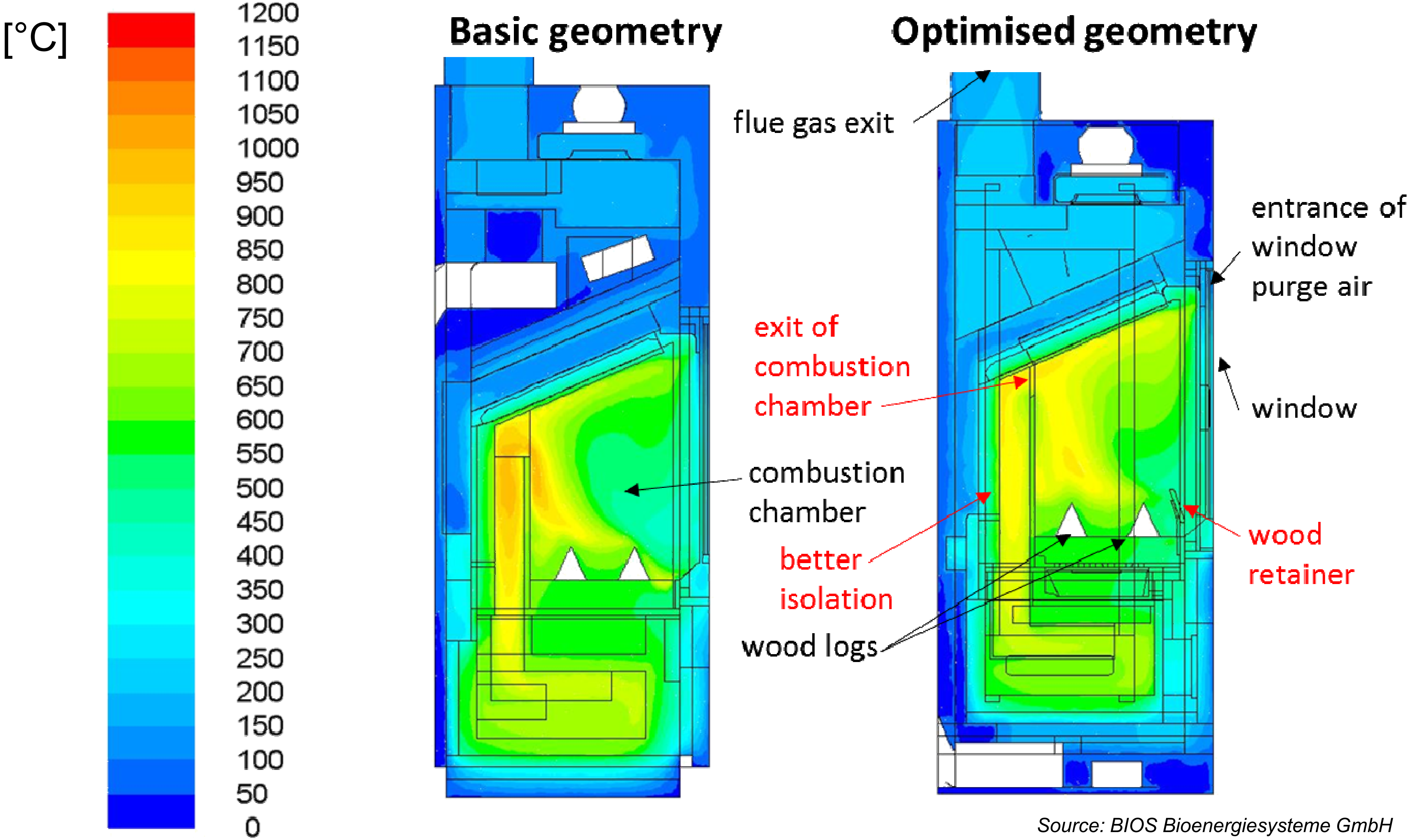
- the flow of the combustion air and the flue gas,
- the flow of the convective air in the air jacket of the stove,
- gas phase combustion in the stove,
- heat transfer between gas phase and stove material (insulation, sheets and glass windows).

Output parameters are:

- velocities and temperatures of combustion air,
- convective air and flue gas, and path lines of air and flue gas,
- O_2 and CO concentrations in the flue gas,
- material and surface temperatures of the stove materials,
- heat transfer,
- efficiency,
- pressure.

CFD aided stove develoment: Example of results

Here shown: Iso surfaces of temperatures in central vertical section



Source: BIOS Bioenergiesysteme GmbH

CFD aided stove development: Advantages

- reduced emissions (CO and fine particulate matter)
- better utilisation of the stove volume
- enhanced efficiency
- reduced development times
- lower test efforts
- increased security during development

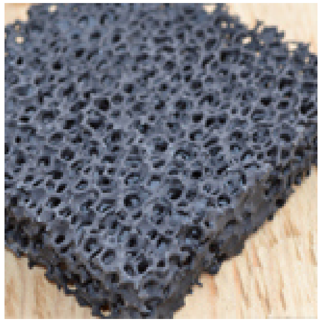
Disadvantage: - Development tools are not commonly available
- they usually require external assistance from professional developers!

Integrating catalysts to wood stoves

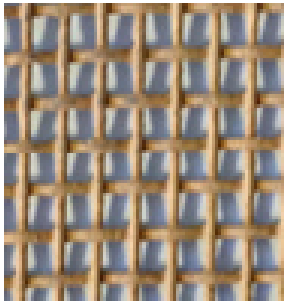
- Packed bed catalysts:


- Monolith catalysts (honeycomb/foam structure):





- Network/wire meshes:

<u>Active metals</u>
The surface is impregnated/coated with catalytically active components. Rank order of activities are:

Rh > Pd > Pt → oxidation of CO
Pt > Rh > Pd → oxidation of VOC
Rh > Pd > Pt → reduction of NO

Recommendations for catalyst integration

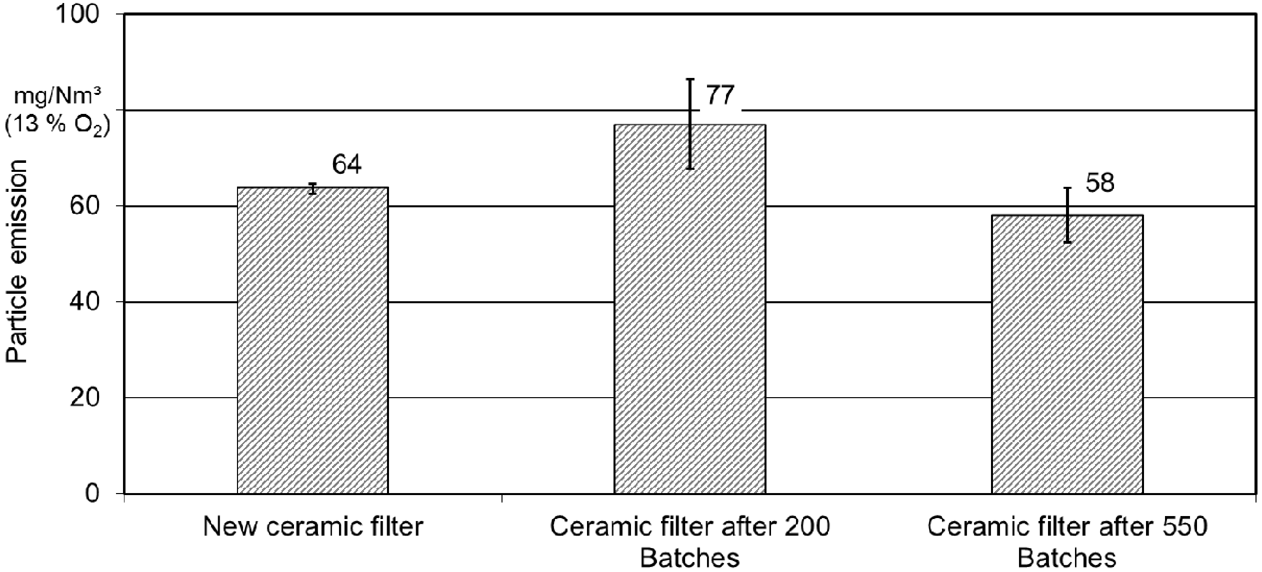
- The implementation of a high temperature catalyst **at the outlet of the post combustion chamber** (temperature range of about 500 °C) is not recommended (unstable reduction efficiencies).
  Reason: Decreasing reduction efficiencies over time due to catalyst de-activation by blocking and by aerosol condensation.

- High temperature catalysts **at the outlet of the main combustion chamber** (temperature range 600 - 800 °C) have showed sufficiently high emission reduction efficiencies regarding CO (69 – 73%) and OGC (27 – 38%) and seem basically to be suitable for logwood stoves.
  But: The emission reduction efficiency decreases over time (long term testing is required !)

- Efficient catalysts need high surface areas (e.g. by many by narrow channels). This causes certain pressure drops, which are usually too high for a stove operation with natural draught only (an active fan is required!).

- ***Use of catalysts can only be a final backup strategy after all other technical measures are utilized (i.e. geometry, air distribution, automatic air control, air tightness, etc.).***

Use of integrated foam ceramic filters ?



<u>Conclusion:</u>
No positive effect of foam ceramic filter elements in the outlet of the combustion chamber could be determined !

Concluding remarks

- A large potential for improvements of log wood stove performance is still available.
- More sophisticated stove concepts require acceptance of higher purchase prices.
- R&D measures should aim at minimizing the impact of false user behavior.
- ... but nevertheless, the teaching and instructing of stove users still needs to be emphasized!

Download of guidelines:
www.tfz.bayern.de/en/162907/index.php

Thanks for listening !

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