# Development of integrated stove control systems based on temperature sensors

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## Background

- All over Europe there is a growing awareness that residential wood fuel appliances are potentially responsible for a great deal of environmental hazards. At the same time the performance of stoves and the knowledge about proper stove operation are progressing.
- The end user can today choose between much better stove products than in the past. But above all it is the end user's heating behaviour (i.e. fuel selection, stove operation and maintenance) which is most decisive for achieving high efficiencies and low emissions.
- Integrated automated control systems provide the basis for a low emission stove operation at increased efficiency since they contribute to a minimisation of user induced operation errors.
- Therefore, the introduction of such systems, which are presently not widely-used, can have a huge impact on emission reduction from stoves.

## Basics of automated control systems for stoves (I)

- Common logwood stove concepts are manually controlled. Therefore, process control efforts are usually limited to a change of the combustion air distribution at the end of the ignition phase.

- An automated control system for a stove can control and optimise the operation of the stove but cannot influence the fuel used.

- Advantages of an automated control system
  - Reduces the user influences (operating errors)
  - Increases the operational comfort for the user
  - Provides the possibility to react on the changing process conditions throughout the entire batch
  - Reduces emissions (only gaseous) and increases the thermal efficiency
  - Reduces standing losses (by closing combustion air flaps)

## Basics of automated control systems for stoves (II)

- **Challenges and requirements of automated control systems**
  - **robust sensors are needed**
  - **the technical solution has to be economically competitive**
  - **a 230 V electrical connection is required**
  - **the automated control concept needs to be suitable for different fuel qualities and loads**

- **Technical solutions for automated control systems**
  - **thermo-mechanically operated primary air flap**
    - simplest way but with restricted accuracy and effects
  - **electronic sensor driven automatic control**
    - more efficient but also more costly
    - the temperature (for example in the post combustion chamber) or the oxygen concentration of the flue gas can be applied as guiding parameter for automated adjustments of the combustion air flow and combustion air distribution by flaps

# Stove control based on temperature measurement – Fundamentals (I)

- **As the control concept should be cheap and robust, the following basic strategy has been chosen:**
    - **The different combustion phases can be identified by temperature changes and since temperature sensors are the cheapest sensors available and also rather robust they offer a suitable opportunity for stove control**
      **→ furnace temperature based control**
    - **The combustion air supply can be easily controlled by appropriate dampers (air box)**
      **→ temperature controlled combustion air supply**

- **Thus, the integrated control concept for the automated control of logwood fired stoves of RIKA is based on a temperature measurement in the combustion chamber and air flaps for the combustion air supply control.**

# Stove control based on temperature measurement – Fundamentals (II)

## Control strategy

- **Ignition phase**
  - Mainly primary air and a low amount of window purge air is injected in order to facilitate a quick ignition and rapid increase of the combustion chamber temperatures

- **Transition to main combustion phase**
  - As soon as the temperature in the combustion chamber exceeds a certain level the primary air damper is closed to avoid excessive burning rates
  - At the same time the window purge air flow is increased to maintain adequate combustion air supply
  - During the main combustion phase the window purge air flow should be kept rather constant

# Stove control based on temperature measurement – Fundamentals (III)

## Control strategy (cont.)

- **Transition to charcoal burnout phase**
  - When the furnace temperature starts to drop below a certain value, the amount of window purge air should be reduced to keep the temperature at a reasonably high and nearly constant value until the end of the batch
  - Thereby, excess oxygen is kept low and too much cooling of the combustion chamber is prevented.
  - As soon as the flames extinguish the CO and OGC emissions strongly increase. Thus, re-charging of fuel should be performed as soon as the flames extinguish.
- **The air flaps should be closed at the end of the stove operation in order to reduce standing losses.**

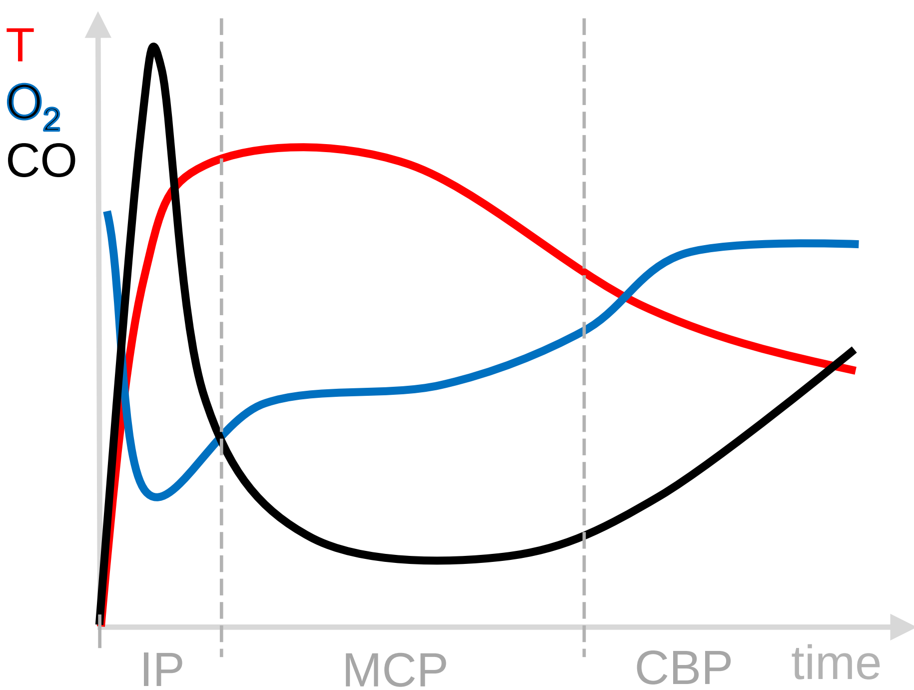
# Stove control based on temperature measurement – Fundamentals (IV)

- **Effects**
  - **Shorter ignition phase**
  - **With combustion air flow control during the main combustion and burnout phase more stable $O_2$ concentrations in the flue gas can be achieved**
  - **Generally, lower $O_2$ levels as well as sufficiently high temperatures can be achieved**
  - **Duration of char coal burnout with high gaseous emissions can be reduced**

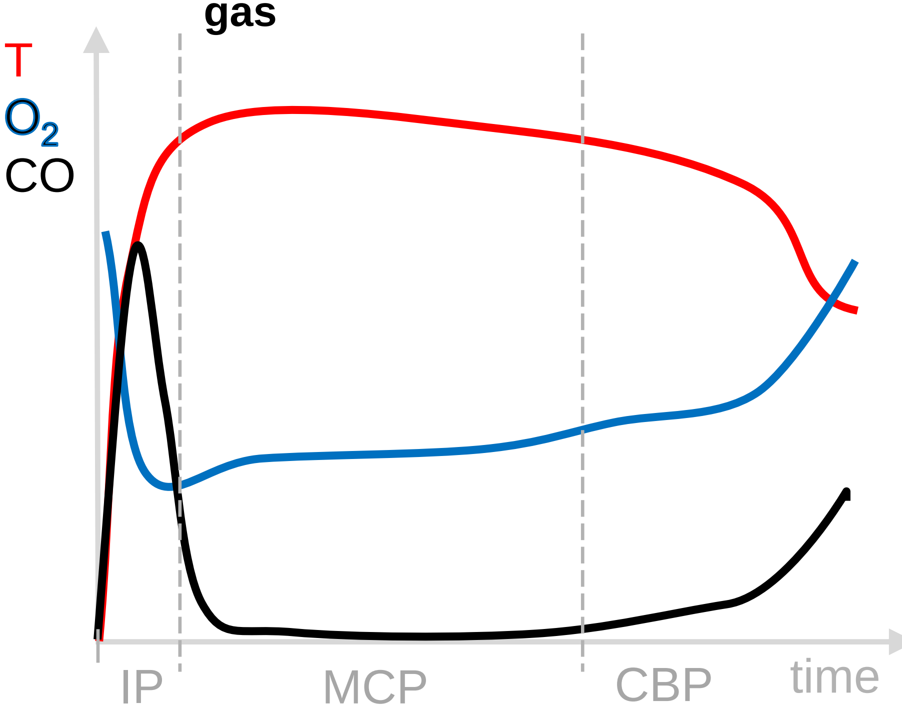
➔ **Lower emissions and higher efficiencies result**

## Stove control based on temperature measurement – Fundamentals (V)

- **Conventional uncontrolled stove: scheme of a combustion batch**

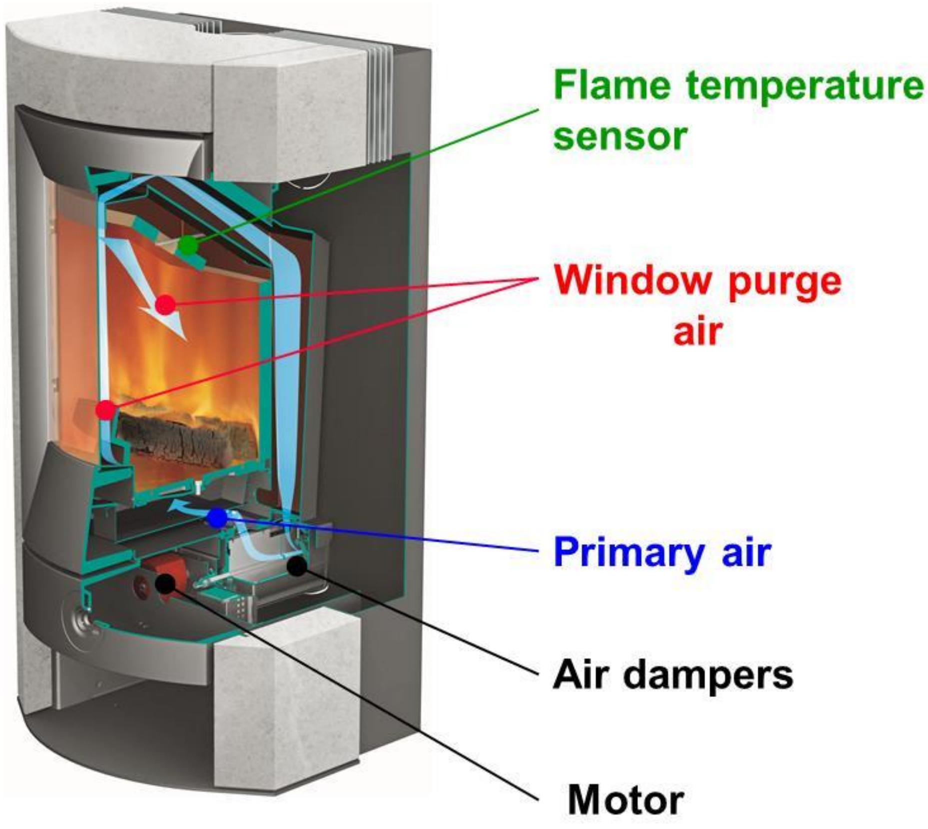



- **Automatically controlled stove: scheme of a combustion batch**
  - **shorter ignition phase**
  - **higher temperatures**
  - **lower emissions (CO, OGC, dust)**
  - **lower average $O_2$ content in the flue gas**



# Stove control based on temperature measurement – Implementation (I)

- At the stove
  - Primary air through the grate and
  - Window purge air are supplied.
- Primary air and the window purge air have to be separately controlled by electronically driven dampers.
- The combustion air flows are controlled in dependence of the furnace temperature (measured by a flame temperature sensor) and calculated time dependent temperature gradients.

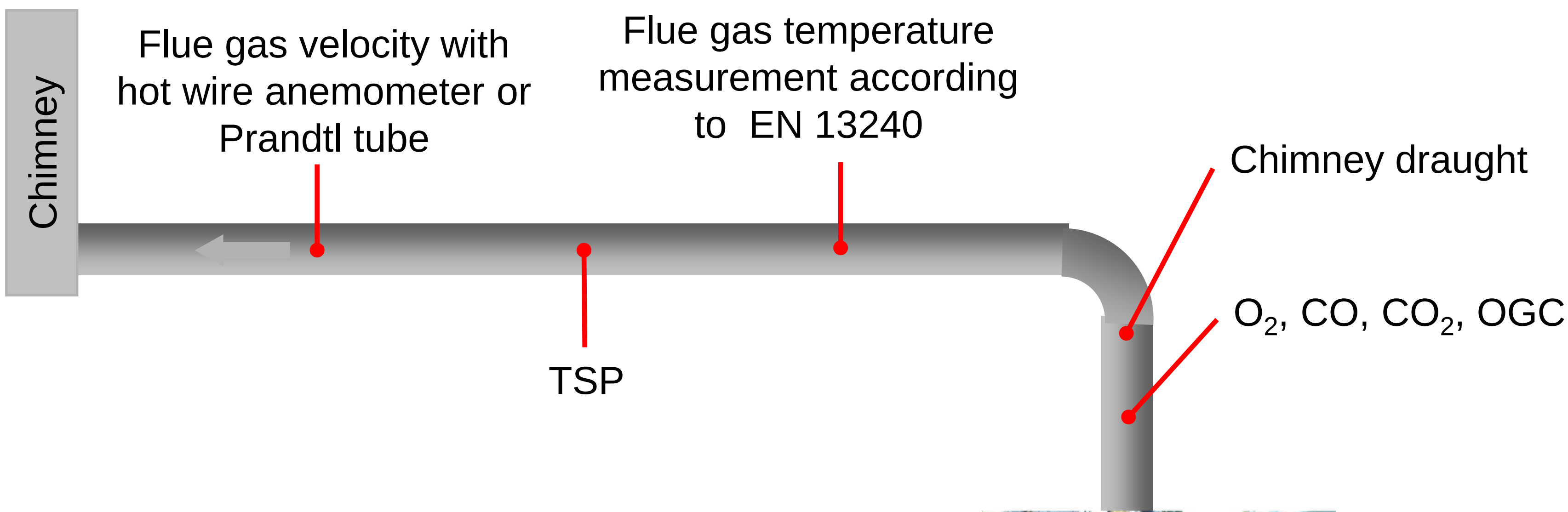


## Stove control based on temperature measurement – Implementation (II)

- **The automated control has been integrated into a new low emission wood stove with integrated PCM heat exchanger of RIKA.**


<u>Explanations:</u> The stove concept is protected by a patent; nominal fuel power input: 9 kW

# Evaluation of the integrated stove control system based on temperature sensors (I)




- **Flue gas composition downstream the stove using standard flue gas analysers for $O_2$ (paramagnetic sensor), CO (NDIR) and OGC (FID)**
- **Determination of the total fly ash (TSP) concentration in the flue gas downstream the stove according to VDI 2066**

# Evaluation of the integrated stove control system based on temperature sensors (II)

## General operation conditions

- **Constant draught of 12 Pa over the stove**
- **Test fuel: hardwood (beech) without bark, moisture content: 12 -16 wt% w.b.**

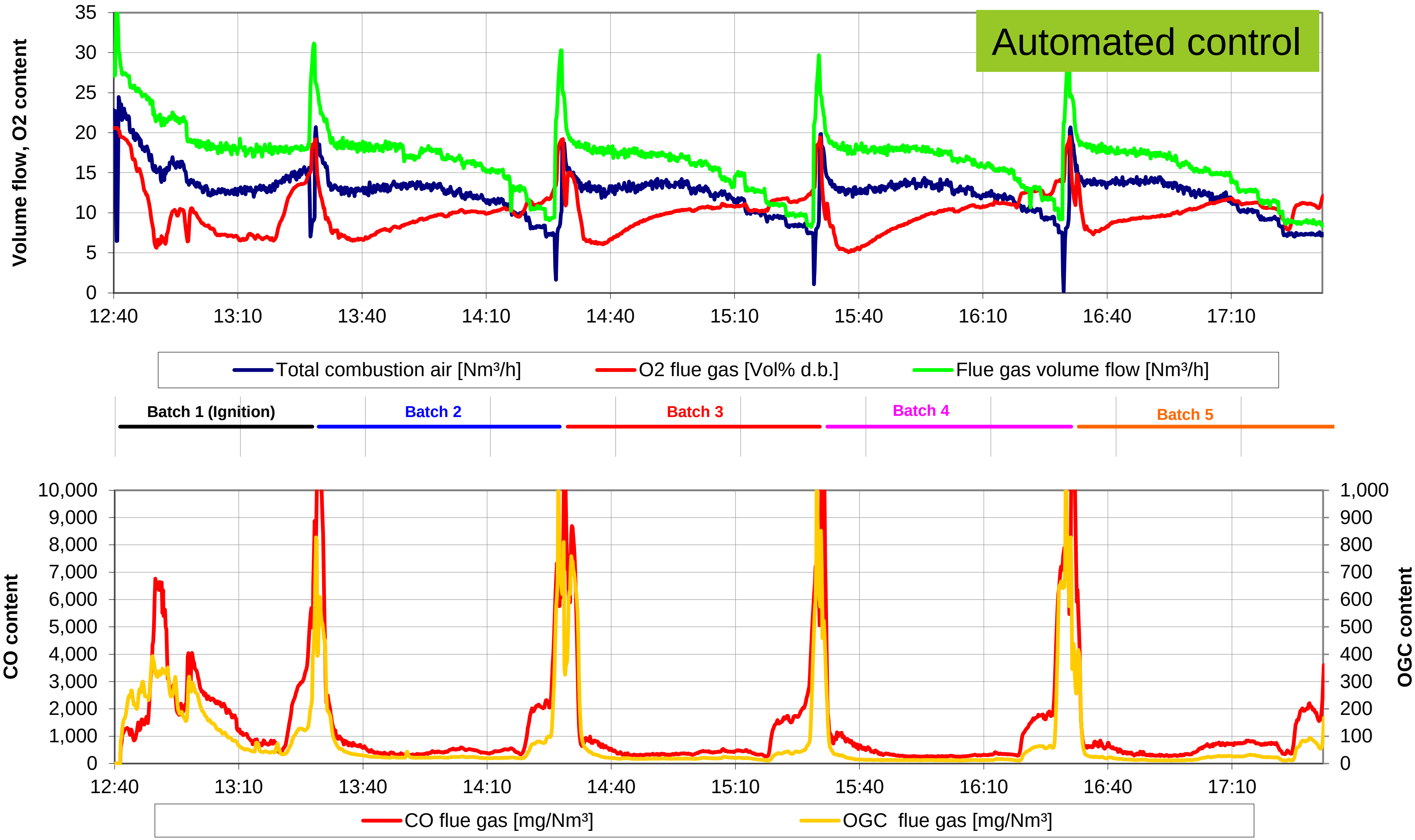
## Performance of gaseous and PM emission measurements

- **Gaseous emissions (CO, OGC) and $O_2$: continuous measurement from before ignition of batch 1 until the end of batch 5**
- **PM emissions: over the whole batch (from closing the door until opening it again)**

## Mode of re-charging as defined by the manufacturer

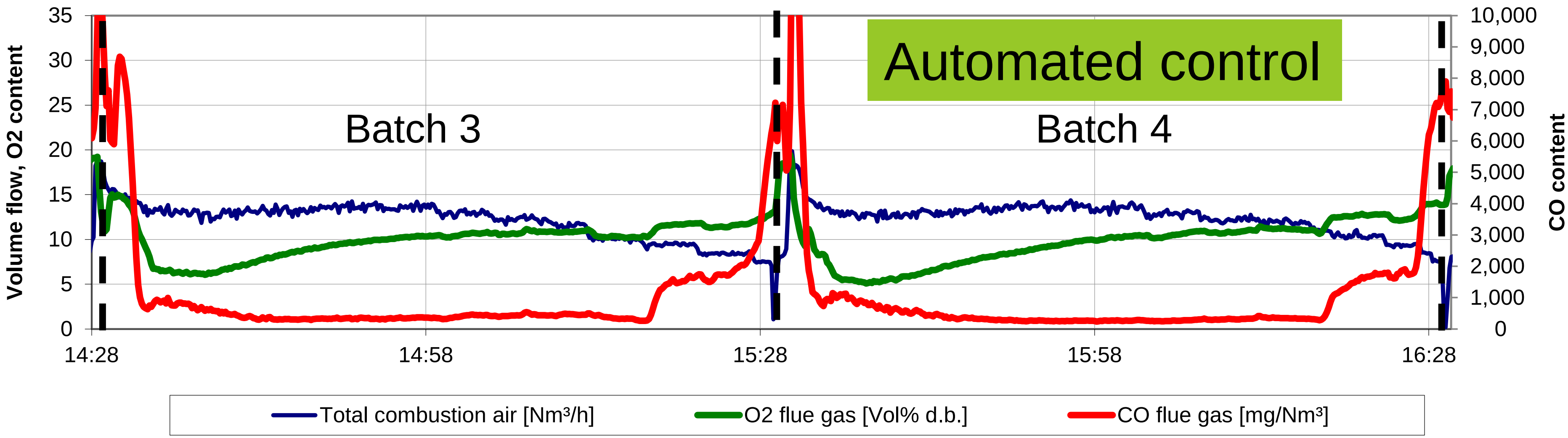
- **Number of logs: 2 for batch 2 to 5 (3 for ignition batch)**
- **Mass per batch: 2.4 kg w.b. (full load)**
- **Dimensions of firewood pieces: 25 cm length**

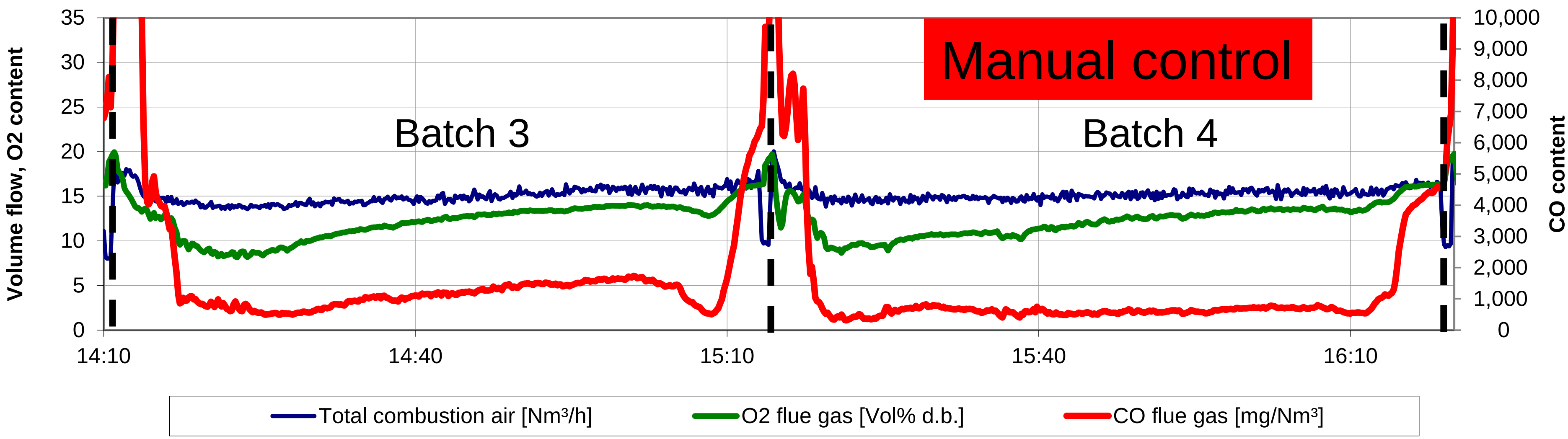
# Evaluation of the integrated stove control system based on temperature sensors (III)




Explanations: $O_2$ related to dry flue gas; emissions related to dry flue gas and 13 vol% $O_2$

# Evaluation of the integrated stove control system based on temperature sensors (IV)



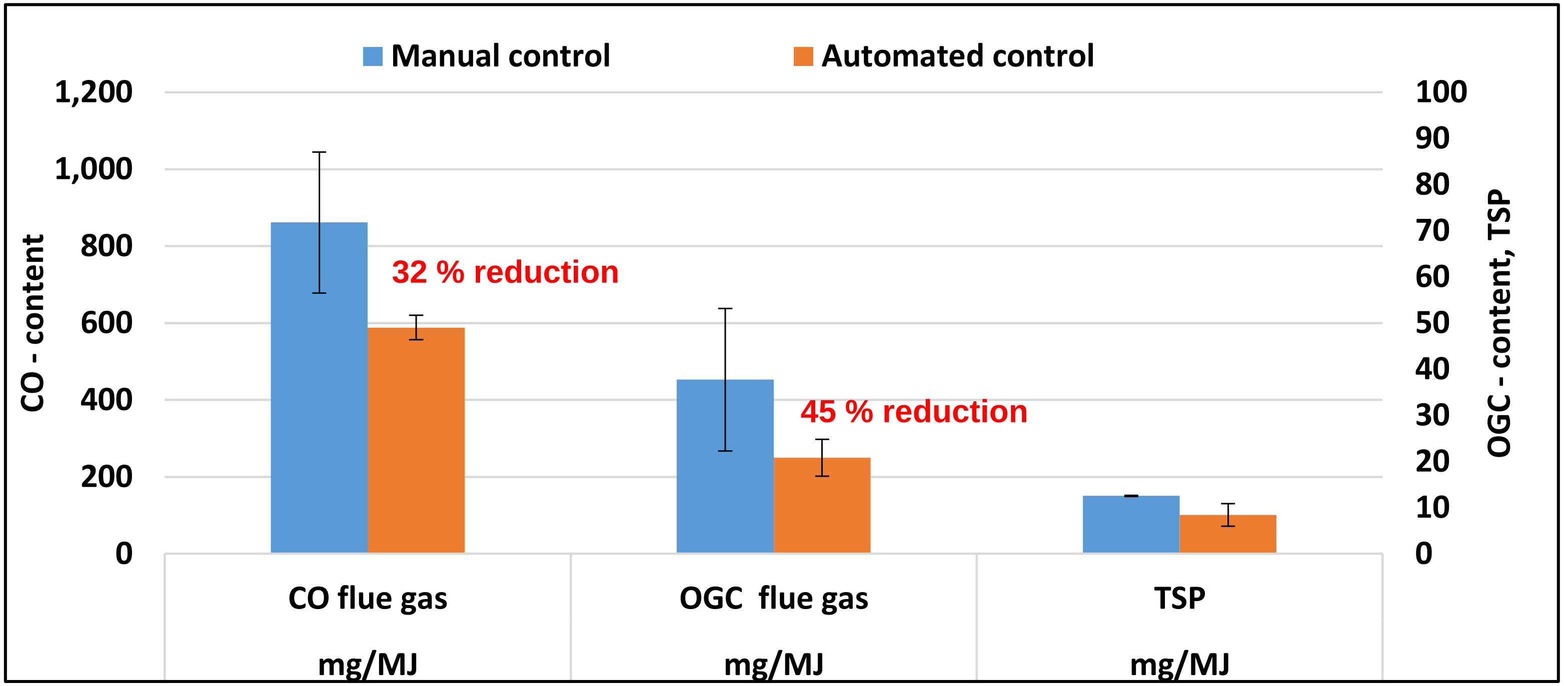




Explanations: $O_2$ related to dry flue gas; emissions related to dry flue gas and 13 vol% $O_2$; dashed line: start of batch (door closed)

# Evaluation of the integrated stove control system based on temperature sensors (V)

## Advantage of automated control system

- **Noticeable reduction of gaseous emissions**
- **Lower standard deviations regarding CO and OGC**
- **Minimisation of user induced errors**

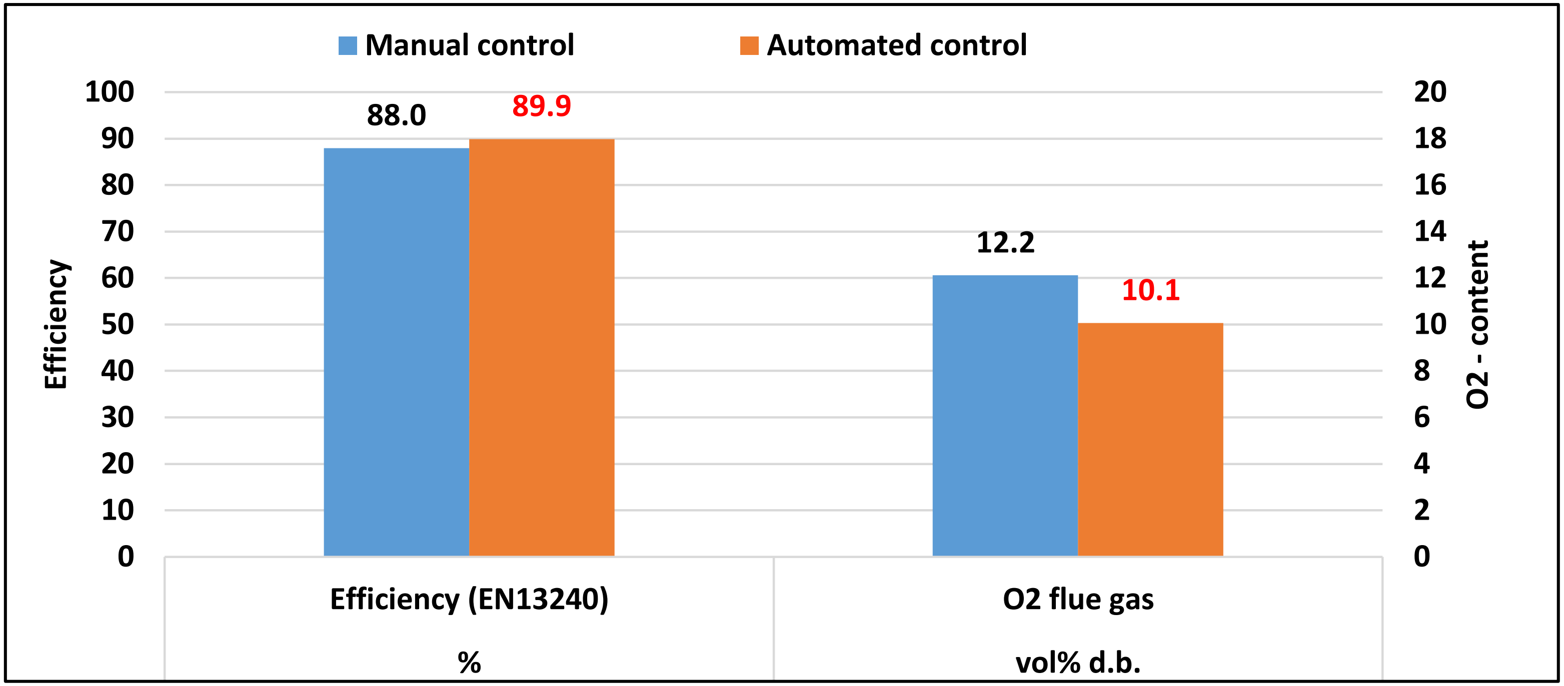



Explanations: mean values and standard deviations of averaged emissions over entire batches 3 to 5 (from closing the door until opening the door again for recharging) according to prEN 16510 / DIN EN 13240

# Evaluation of the integrated stove control system based on temperature sensors (VI)

## Advantage of automated control system

- **Higher thermal efficiency due to lower $O_2$ contents in the flue gas**




Explanations: mean values of $O_2$ over entire batches 3 to 5 (from closing the door until opening the door again for re-charging); calculation of efficiency according to prEN 16510 / DIN EN 13240)

## Summary and conclusions (I)

- An integrated automated stove control system based on combustion air control in dependence of the combustion chamber temperature has been developed and proven as suitable concept for stoves to lower emissions and to increase the efficiency.

- Test run results show that a considerable reduction of the gaseous as well as of the PM emissions is possible by an appropriate automated control of the air supply of the stove:
  - **High furnace temperatures and consequently lower emissions can be reached within a shorter time during the ignition phase by a proper balancing of primary and window purge air**
  - **More stable $O_2$ concentrations in the flue gas, generally lower $O_2$-levels as well as sufficiently high temperatures for improved burnout (= lower emissions) during the main combustion phase as well as during the burnout phase can be achieved**
  - **Re-charging after "flame off"**

## Summary and conclusions (II)

- By the implementation of the automated control the thermal efficiency could be increased (up to 2% points) mainly due to lower $O_2$-levels in the flue gas.
- Furthermore, standing losses can be reduced by an automated closure of the air flaps at the end of the stove operation.
- By the introduction of an integrated control system it could be shown that such control systems, which are presently not widely-used, can have a huge impact on emission reduction and efficiency increase.
- **Therefore, advanced automated control systems provide the basis for a low emission stove operation at increased efficiencies. In addition, they also contribute to a minimisation of user induced operation errors and improve the comfort for the user.**

## Summary and conclusions (III)

- The outcomes of the investigations regarding the improvement of wood stoves by the application of automated control concepts are summarized in:

**Guidelines for automated control systems for stoves**

- The guidelines (as well as the proceedings of the workshop) will be provided as download on the Woodstoves2020 webpage:

**http://www.tfz.bayern.de/cms08/en/index.php**

# Thank you for your attention

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