Advanced combustion control for a wood log stove, Expert workshop - Highly Efficient and Clean Wood Log Stoves

Illerup, Jytte Boll; Hansen, Brian Brun; Lin, Weigang; Nickelsen, Joachim; Dam-Johansen, Kim

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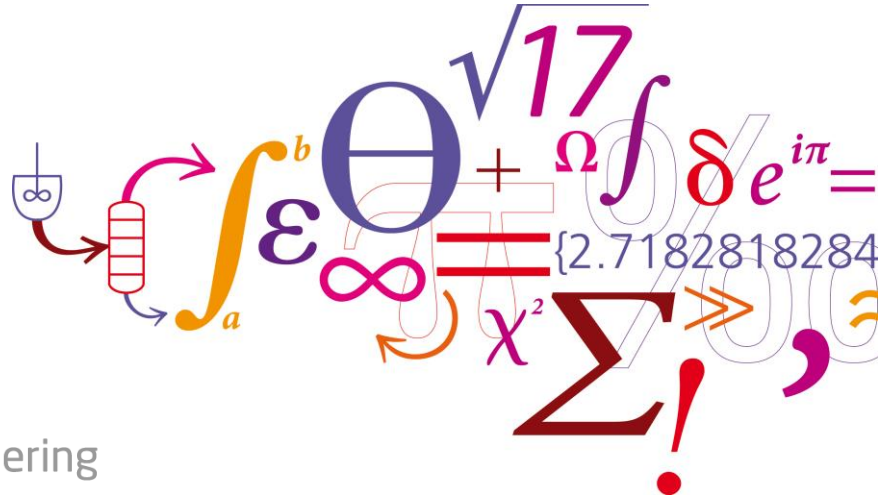
Advanced combustion control for a wood log stove

Expert workshop - Highly Efficient and Clean Wood Log Stoves
Berlin 29 October 2015

Jytte Boll Illerup
Brian Brun Hansen
Weigang Lin
Joachim Nickelsen
Kim Dam-Johansen



DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

Intelligent Heat System

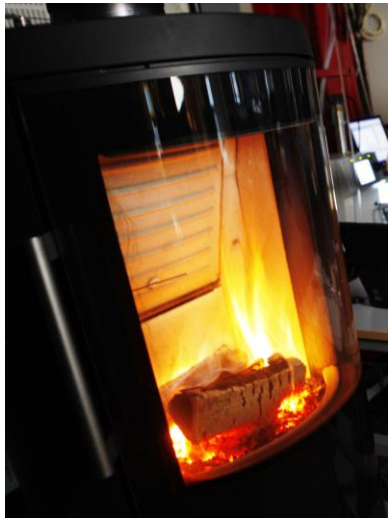
High-energy efficient wood stoves with low missions

- Collaboration between HWAM A/S and DTU Chemical Engineering
- Periode 2011 – 2015
- EUDP - project

  (Energy Technology Development and Demonstration Program)

Development of a new automatically controlled wood stove with:

- High energy efficiency
- Reduced emissions (CO, particles etc.)
- High comfort for the wood stove users



Main results

- *A new advanced control system has been developed based on experiments conducted at experimental facilities at HWAM og DTU Chemical Engineering*
- *HWAM has launched an automatically controlled modern wood stove on the market*
- *Field and laboratory tests has shown reduced emissions and higher efficiency for stoves with the control system - and high comfort for the wood stove users*

Content

- Background for the project –why an automatic control system?
- Concept of the automatically controlled wood stove
- Our results from
  - Field tests
  - Experiments at the wood stove set-up at DTU Chemical Engineering

Regulation and legislation

New wood stoves are approved according to national and European standards.

Standards:

Approval of Wood stoves	**Eff. (%)**	**CO (mg/ Nm³)**	**PM (mg/Nm³)**	**PM (g/kg)**	**OGC (mg/Nm³)**
Danish Statutory of order	-		<40	<5	<150
Danish Statutory of order (from 2017)	-		<30	<4	<120
Swan label (optional)	≥76	≤1250		<3	<100
Swan label (from 2017)	≥76	≤1250		<2	<100

The emissions can be much higher when the stoves are used by ordinary wood stove users

Challenges

The emission level can be high due to challenging conditions:

- batch firing in small combustion chambers
- wide range of various wood types and wood log sizes
- combustion air flows and fuel loads are manually controlled

Difficult to achieve an optimal combustion

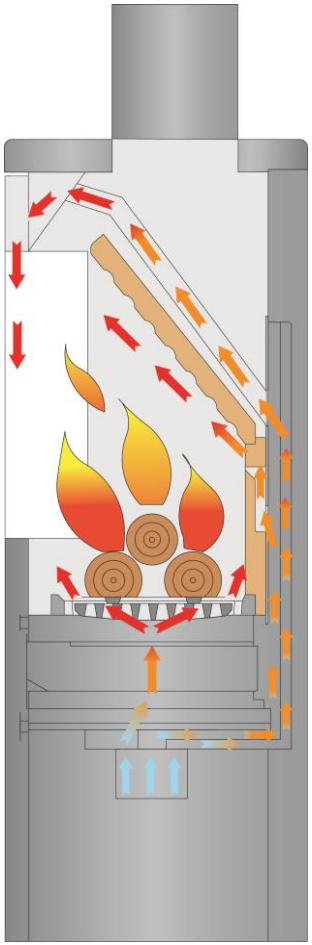
Improved technologies

Modern stoves with air staging:

Three combustion air inlets:

- Primary air at the bottom (ignition)
- Secondary air at the top of the front window (air-wash, second combustion)
- Tertiary air at the back wall (high temperature gas combustion)

However, well-designed stoves can also cause high emissions and low efficiency



Field tests – measurements at stoves in private homes

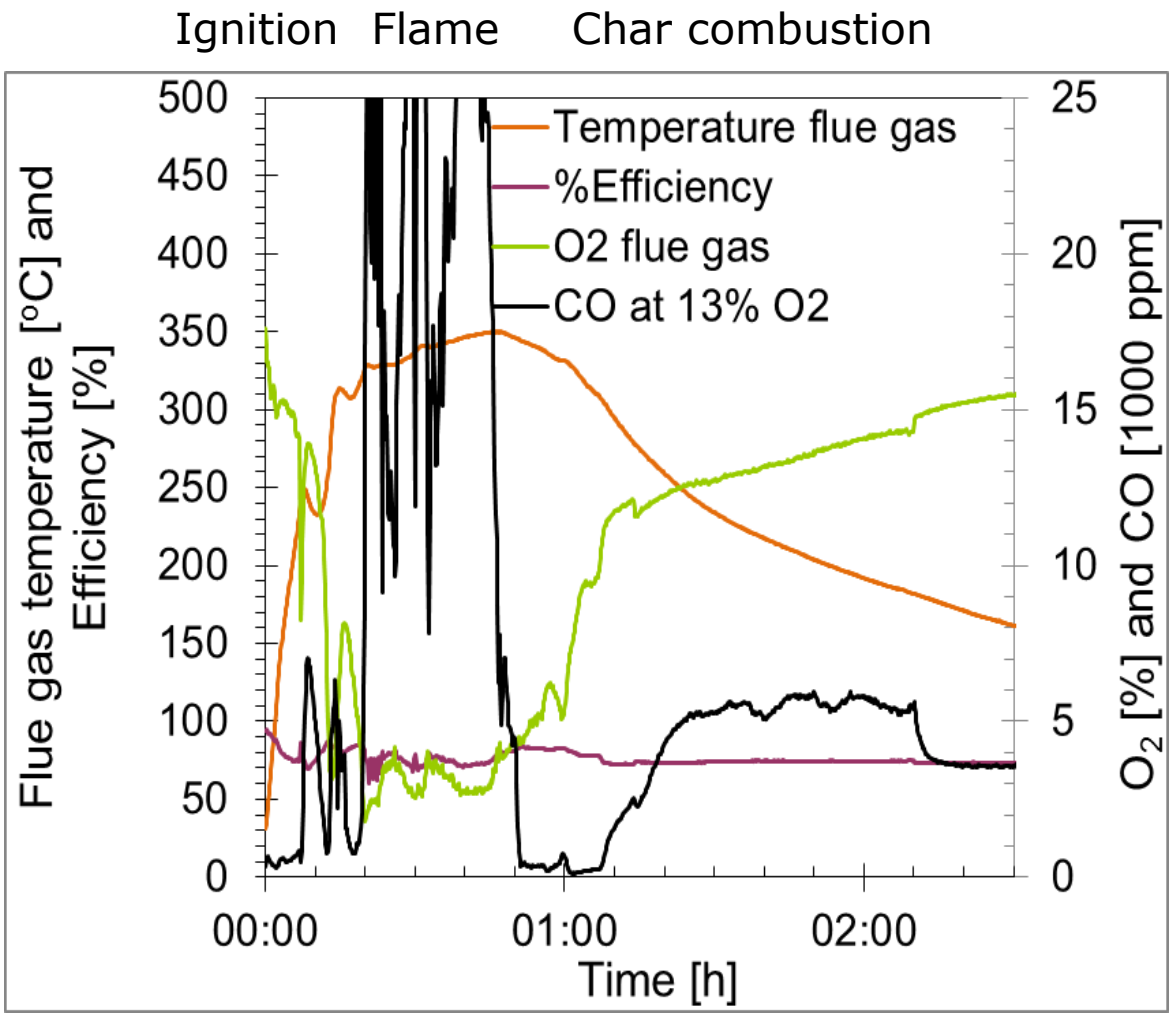
Field tests in six private homes

Measured 1 week:

- Existing (modern) stove
- Automatically controlled wood stove
- O_2, CO_2, CO, flue gas temp.
- Amount of wood
- Temp. in– and outdoor

It is difficult to control the combustion air flows manually in an optimal way.

Manually controlled wood stove – 1



One combustion cycle

Lack of combustion air in the flame phase and too much air in the char combustion phase

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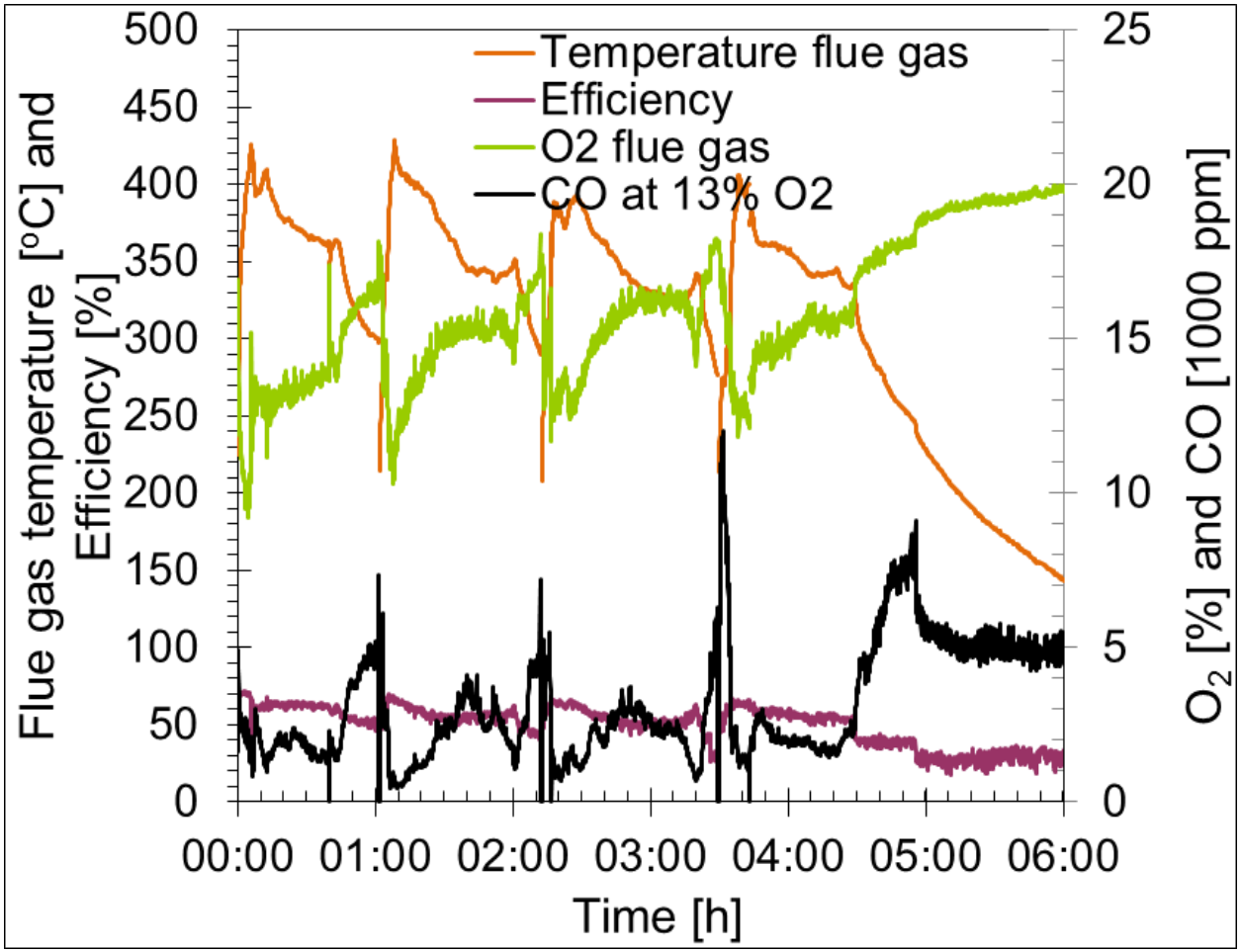
Manually controlled wood stove – 2



Four combustion cycles

High excess air and temperature in both the flame phase and the char combustion phase

A large potential for improving the combustion process by optimizing the combustion air flows

Automatically controlled wood stove

Modern wood stove

+

Air box (3 motor-controlled valves and a software program)

+

Process control (the process parameters are the O_2 concentration and the temperature in the flue gas)

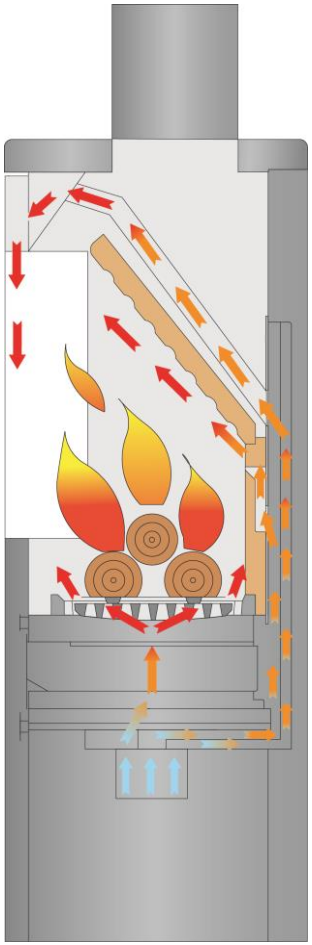
+

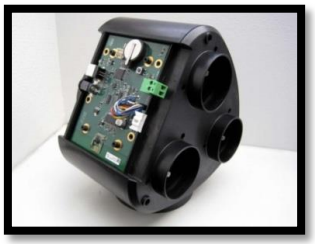
Remote control to starts the combustion and set the room temperature

Control of the air supply

The three air inlets are automatically controlled by

- a software program based on the definition of *five combustion phases*
- and the process parameters – measured *temperature and O_2 in the flue gas*





Software – overall concept

Phase 0
(Cold stove)

- Primary
- Secondary
- Tertiary

Regulation:
None

Phase 1
(Ignition)

- Primary
- Secondary
- Tertiary

Regulation:
Temp. and O_2

Phase 2
(Flame)

- Primary
- Secondary
- Tertiary

Regulation:
Temp. and O_2

Phase 3
(Char combustion)

- Primary
- Secondary
- Tertiary

Regulation:
Temp. and O_2

Phase 4
(Shut down)

- Primary
- Secondary
- Tertiary

Regulation:
None

Phase Change:

Temperature,

O_2 and air flow –

in combination

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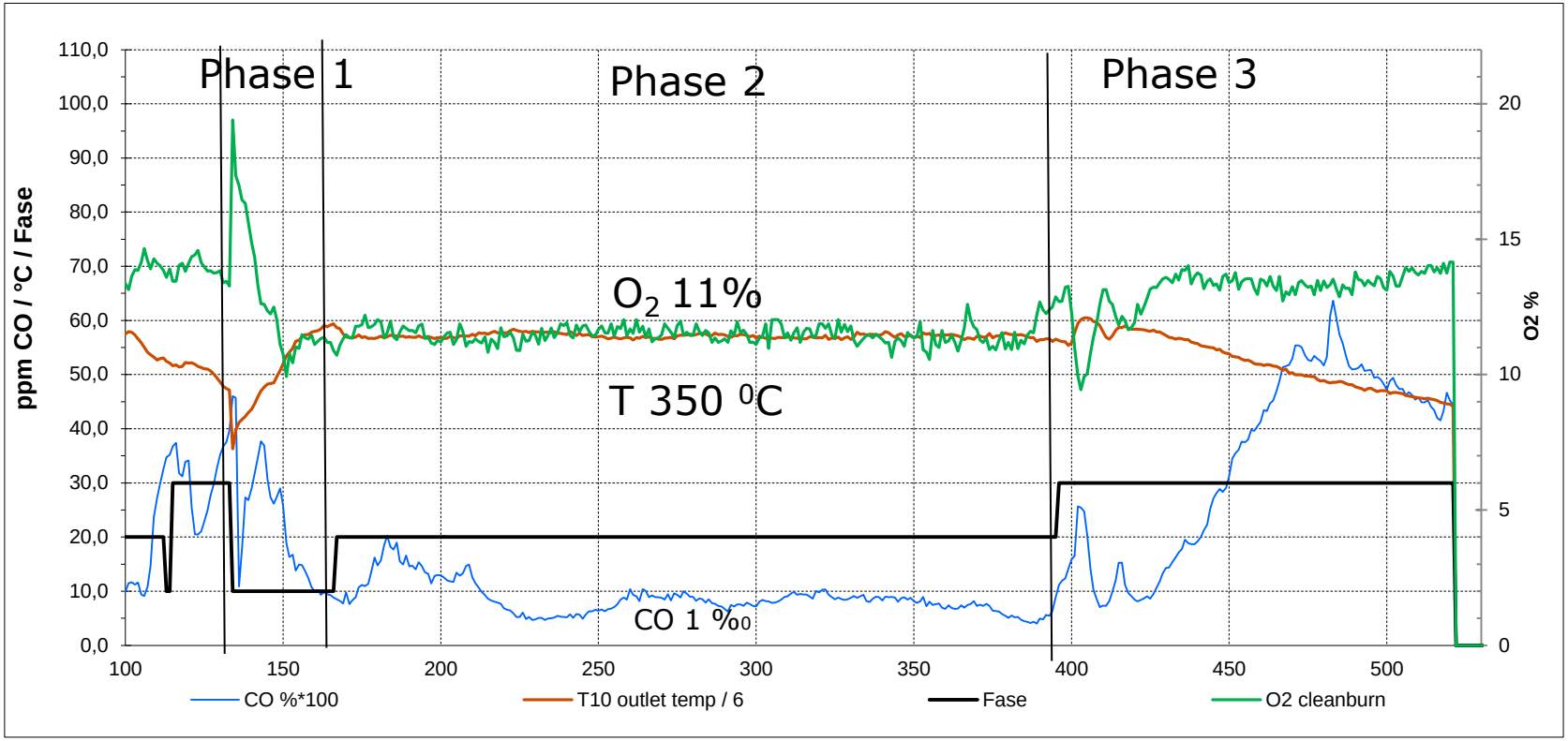
Standard combustion cycle



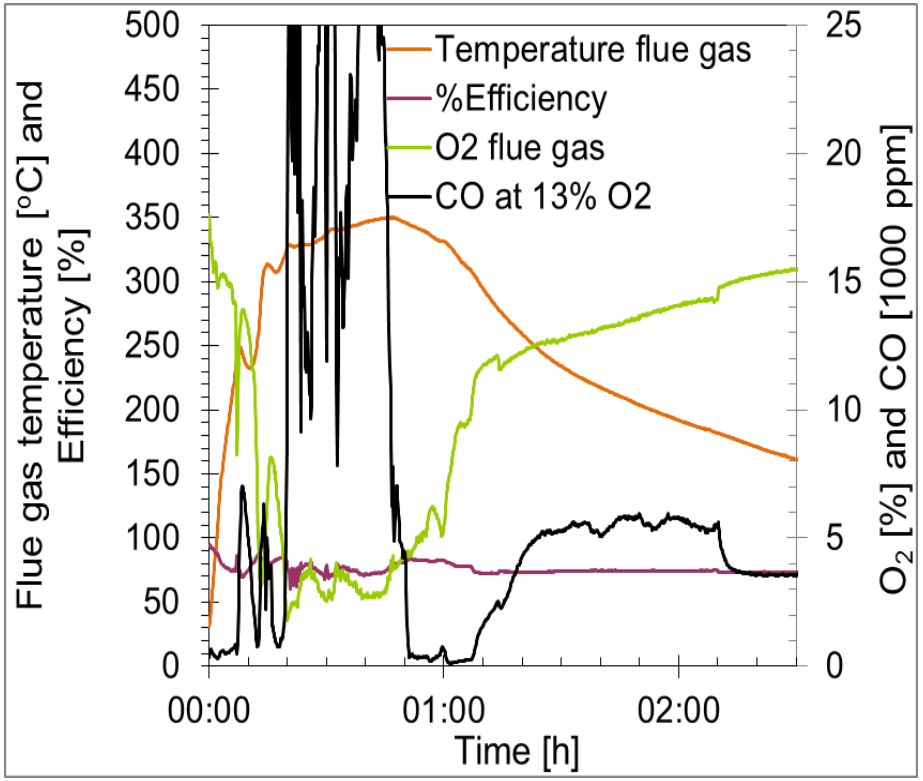
Temperature and O_2 concentration constant and optimal during most of the combustion cycle

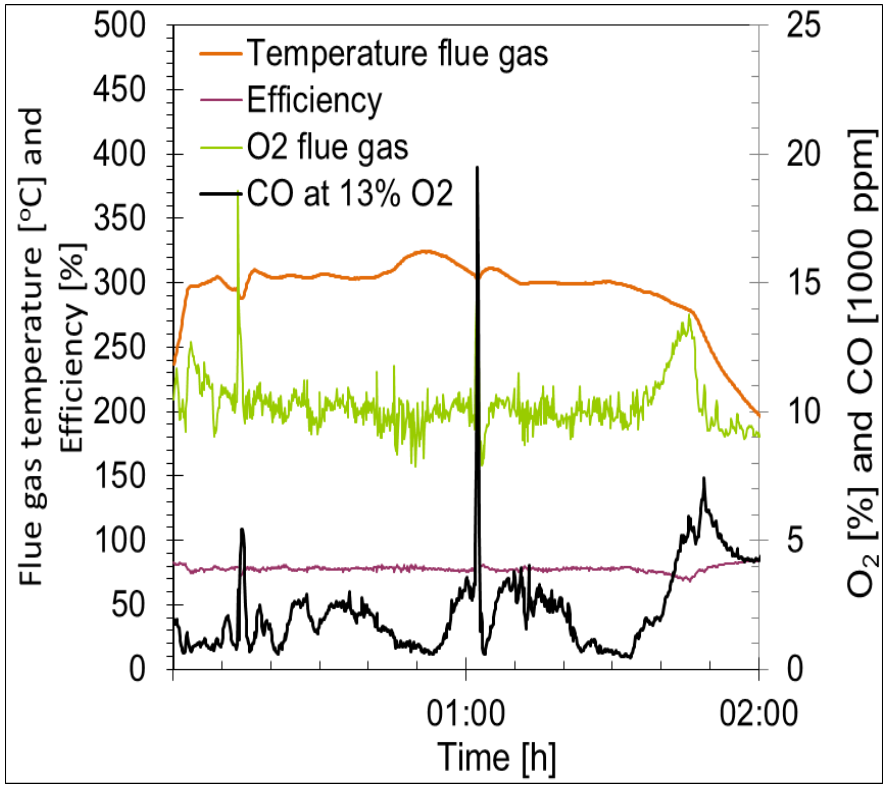
Phase 1:
- Ignition of wood
- A few minutes

Phase 2:
- Combustion of pyrolysis gases
- Intensive combustion with flames.
- 25 - 30 minutes

Phase 3:
- Combustion of char
- The combustion intensity deceases
- The temperature decreases, the O_2 and CO emission increase

The same user





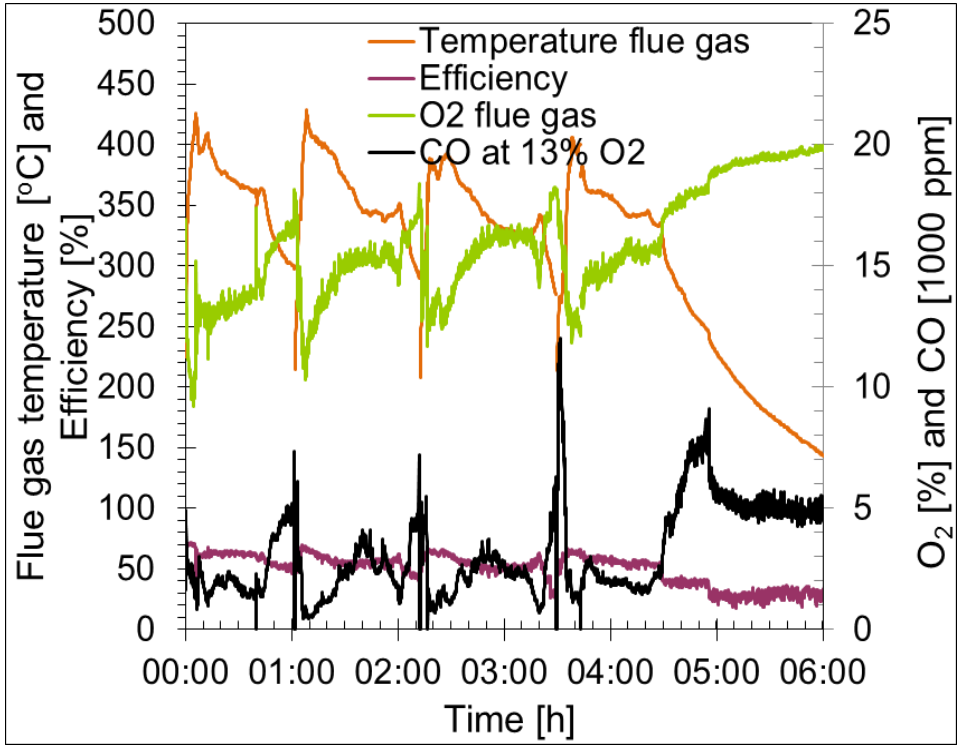
Manually controlled

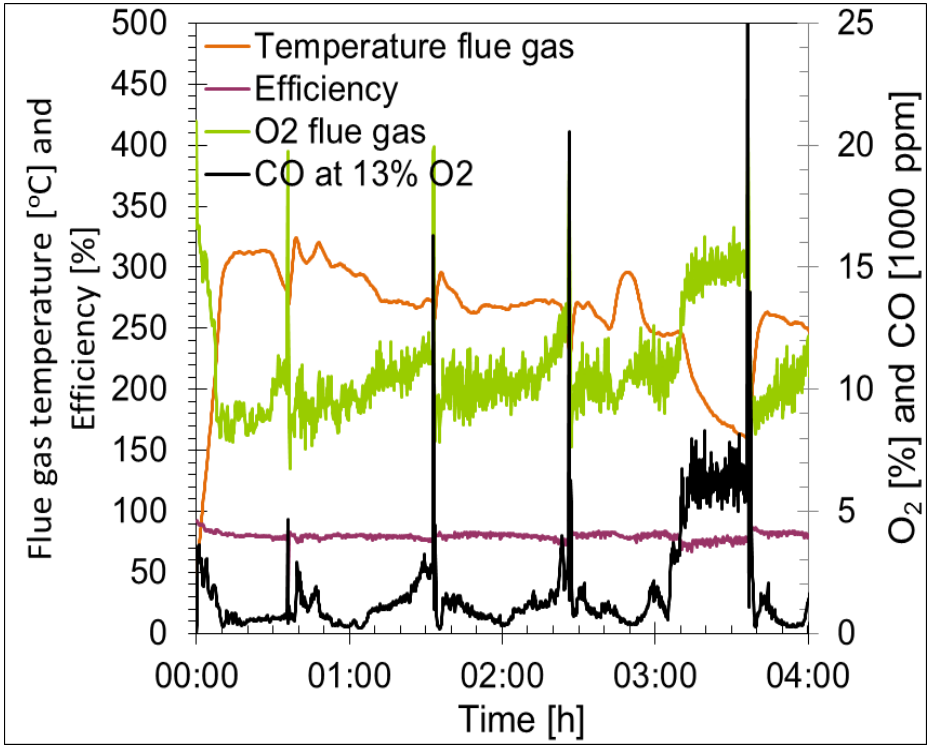
Lack of combustion air in the flame phase and too much air in the char combustion phase

Automatically controlled

Stable O_2 and temperature, and low CO

The same user





Manually controlled

High excess air and temperature in both the flame phase and the char combustion phase

Automatically controlled

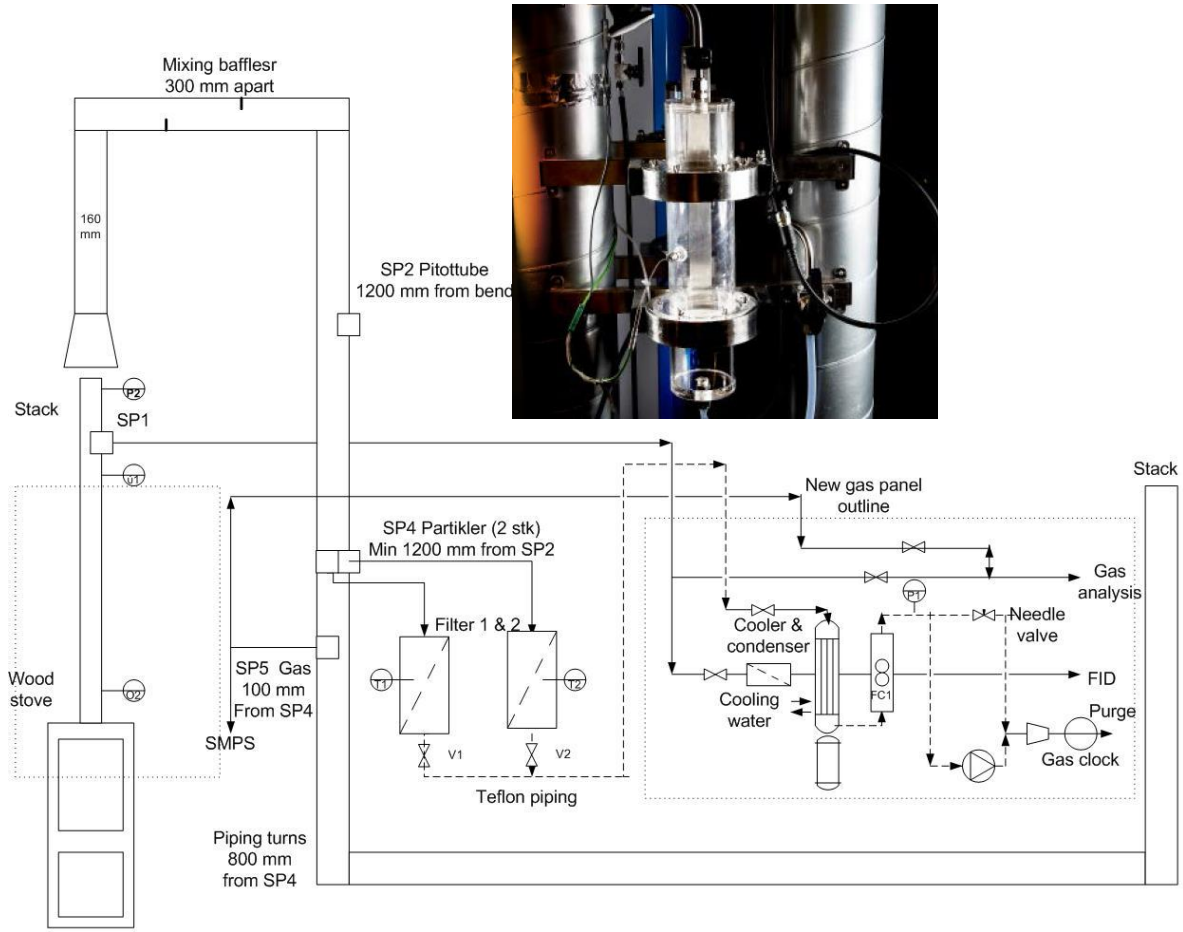
Lower O_2 and temperature, and *much* higher efficiency

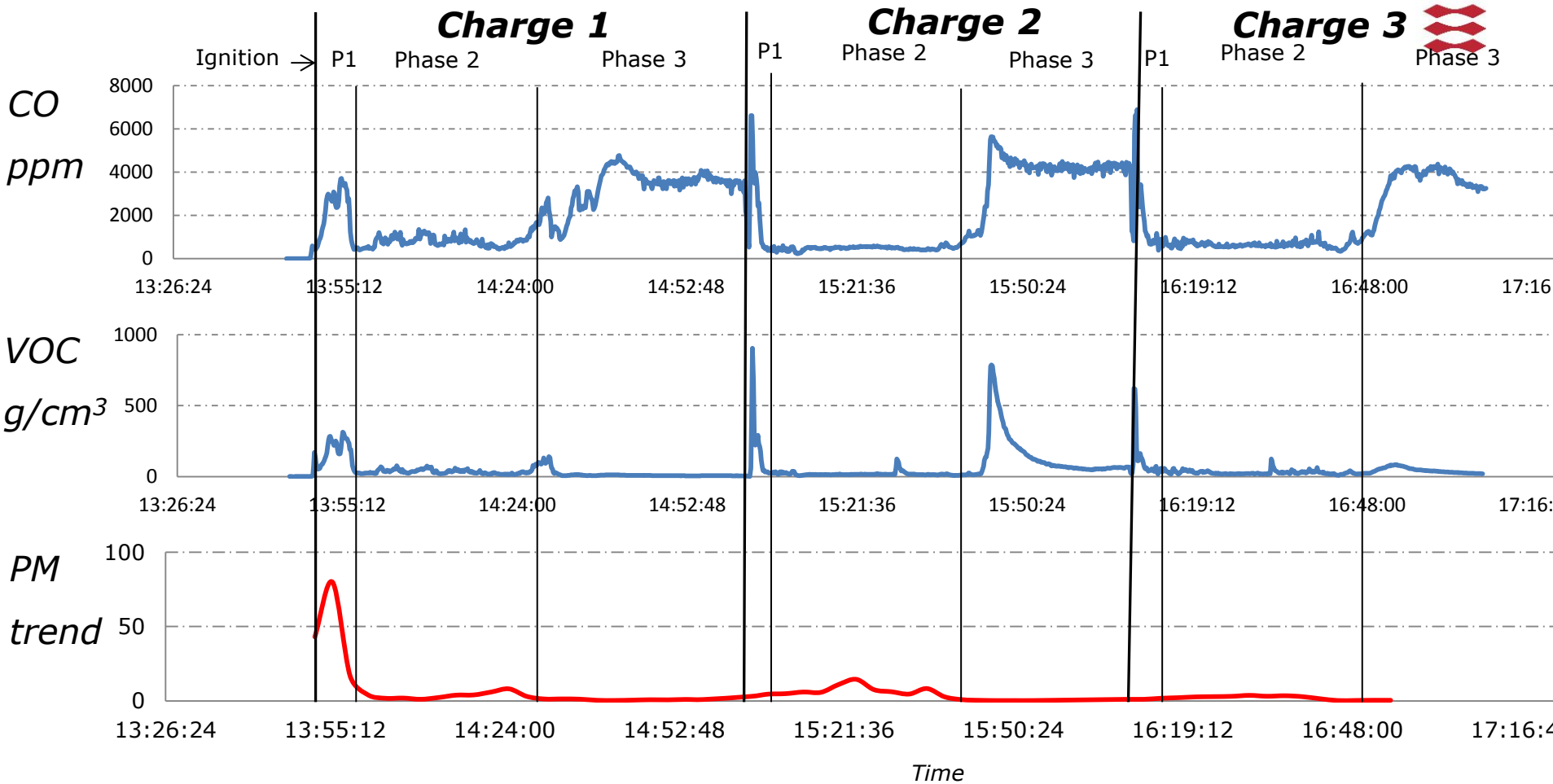
Experimental setup

Including: woodstove, stack, dilution tunnel, sampling sites, filters for particle collection and panel for gaseous analysis.

PM measurements:

- Filter collection based on the Noweigan Standard NS-3058
- Scanning mobility particle sizer (SMPS)





- Increase in CO/VOC/PM in phase 1
- PM peak in phase 2 but low CO/VOC
- Increase in CO (VOC) but low PM in phase 3

PM composition

- Condensable organic compounds
  Example hexane (T_{boil} = 69 ^oC)
  Example benzene (T_{boil} = 80 ^oC)
  Initial release of volatiles from fuel
  Temperature/mixing in the combustion zone

- Soot/Black carbon
  High temperature & O_2 lean formation
  Potentially caused by insufficient mixing

0-15 min *15-30 min*

Charge 1

Charge 2

Charge 3

Charge 4

Charge 1: 1.8 ± 0.2 g / kgdry

Charge 2: 1.8 ± 0.8 g / kgdry

Charge 3: 1.4 ± 0.4 g / kgdry

Charge 4: 0.5 g / kgdry

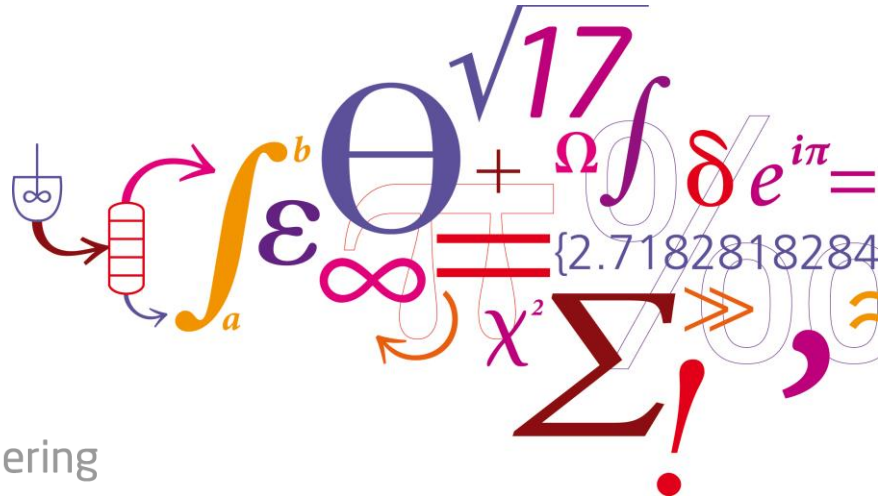
Conclusions

- A first version of an automatically controlled wood stove, HWAM IHS, has been developed and launched on the market.

- Results from a development and demonstration project have shown significantly reduced emissions and high efficiency for the automatically controlled stoves compared to manually controlled stoves.

- The new control system ensures improved stove operation even when used by private wood stove owners.

Thanks for your attention



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