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Technical guidelines for design of low emission stoves

IEA Bioenergy



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Prepared for

IEA Bioenergy



Why are we introducing guidelines?

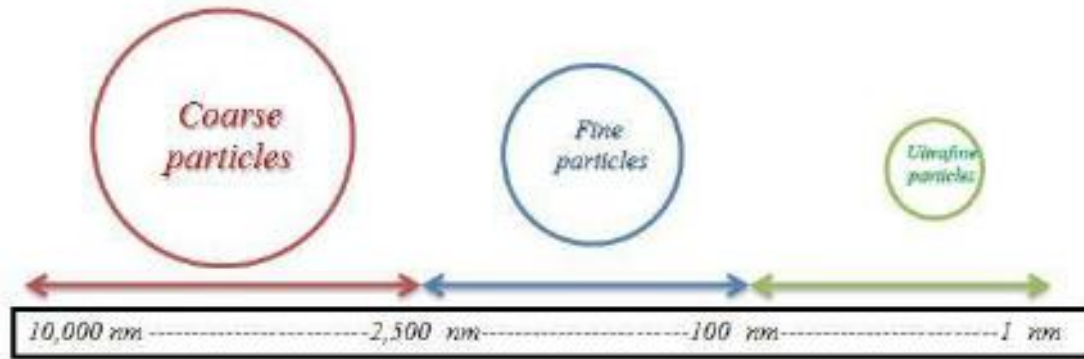
- Reducing emissions in general for wood stoves
- Sharing of knowledge from European research projects
- Balance between combustion and design



Source: Danish Technological Institute



Main emissions categories to minimize



https://www.researchgate.net/profile/Hitesh_Waghvani/publication/262843669/figure/fig1/AS:296445971320833@1447689635765/Classification-of-particles-on-the-basis-of-their-size-distribution-in-the-nanometer.png

BC

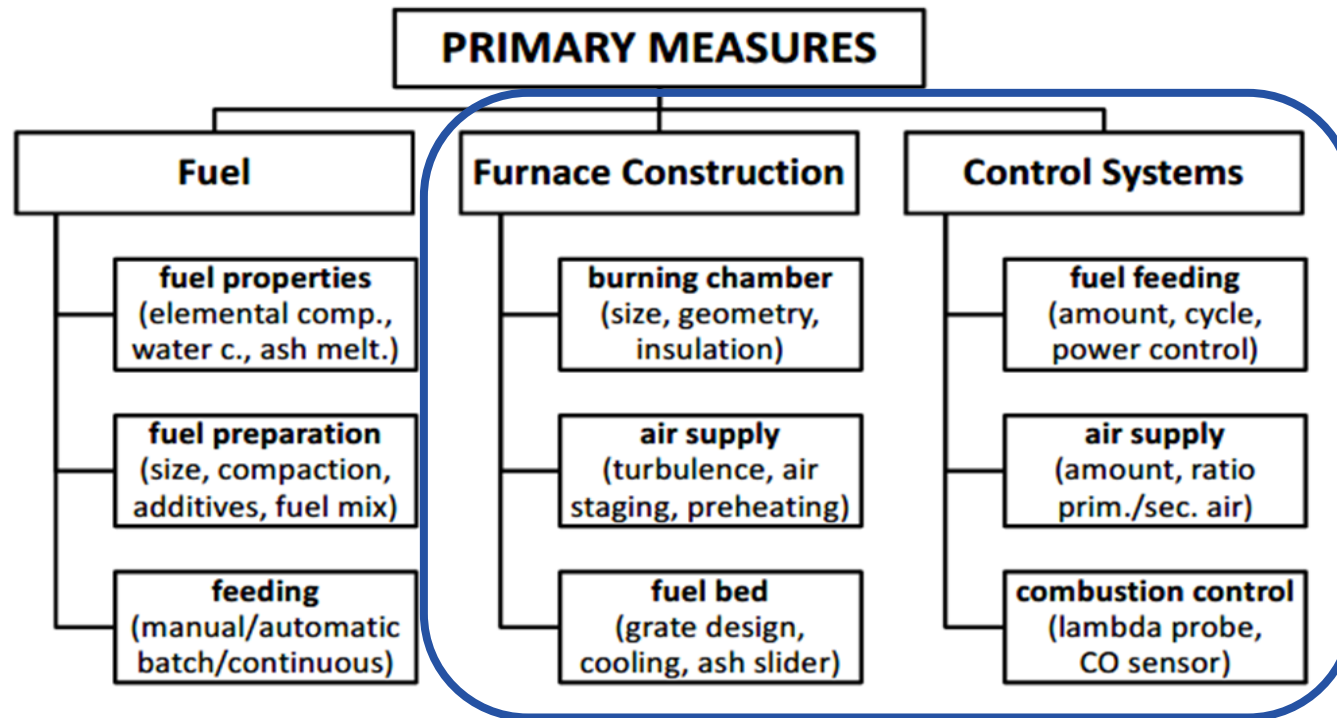
CO



<https://thumbs.dreamstime.com/z/black-ink-hand-drawing-smoke-coming-house-chimney-voc-volatile-organic-compound-air-pollution-concept-black-brush-132924878.jpg>

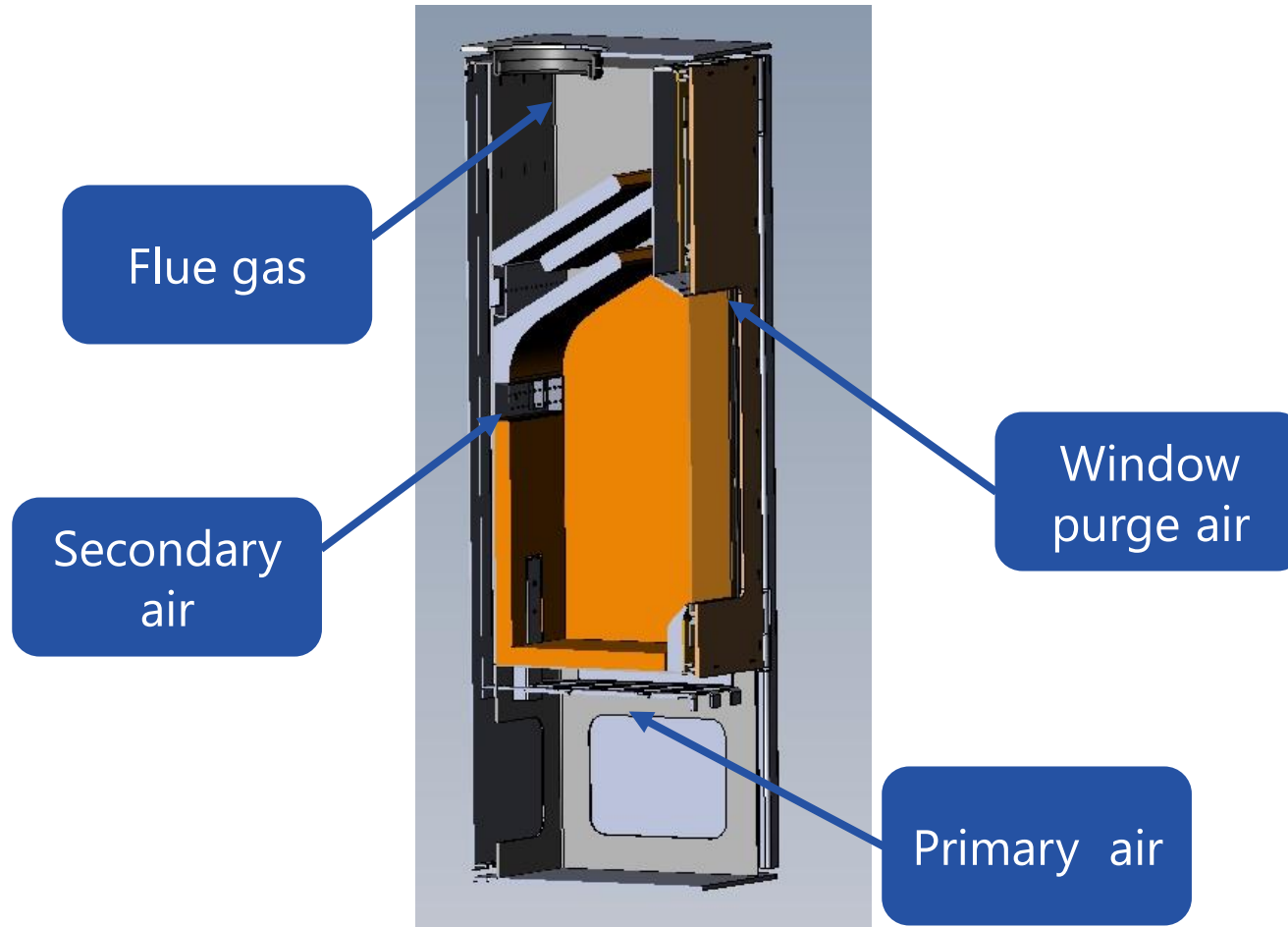


Primary design measures





Definition of terminology regarding airflows

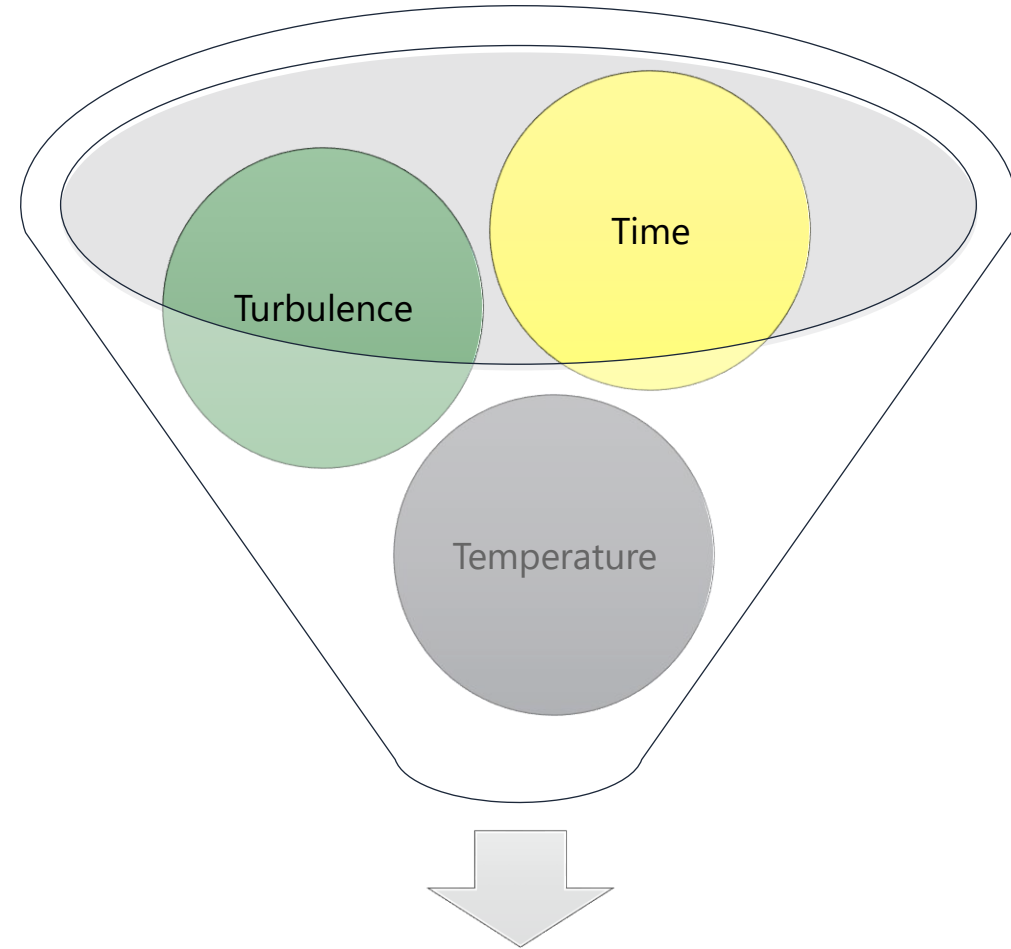




Combustion chamber optimization



Source: Danish Technological Institute



Ecodesign or better



Temperatures

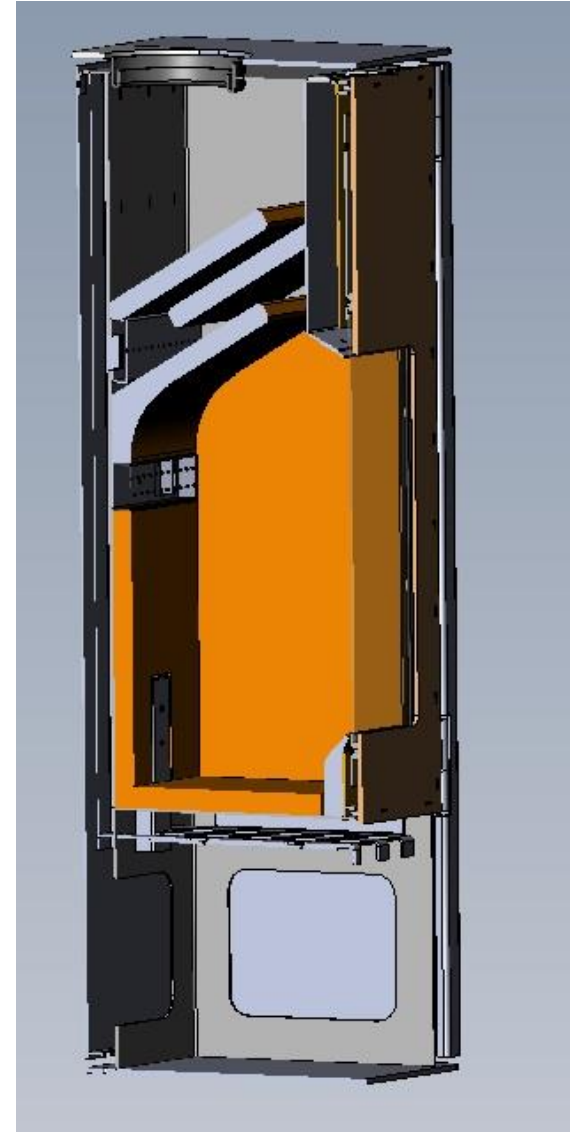
- Things to consider to keep up temperatures
 - Insulation in the combustion chamber
 - Shape and size of combustion chamber
 - Material and isolation of the door as well as size of window and its radiation coefficient or alternatively coated glasses or double/triple windows with air gap between
 - Windows should be of moderate size





Residence time

- Sufficient residence time is needed and is influenced by the following parameters
 - Gas volume flow
 - Distribution of flue gas over combustion chamber
 - Distribution of air
 - Height of the combustion chamber



Source: Danish Technological Institute



Turbulence or mixing of flue gasses

Consideration to get good mixing

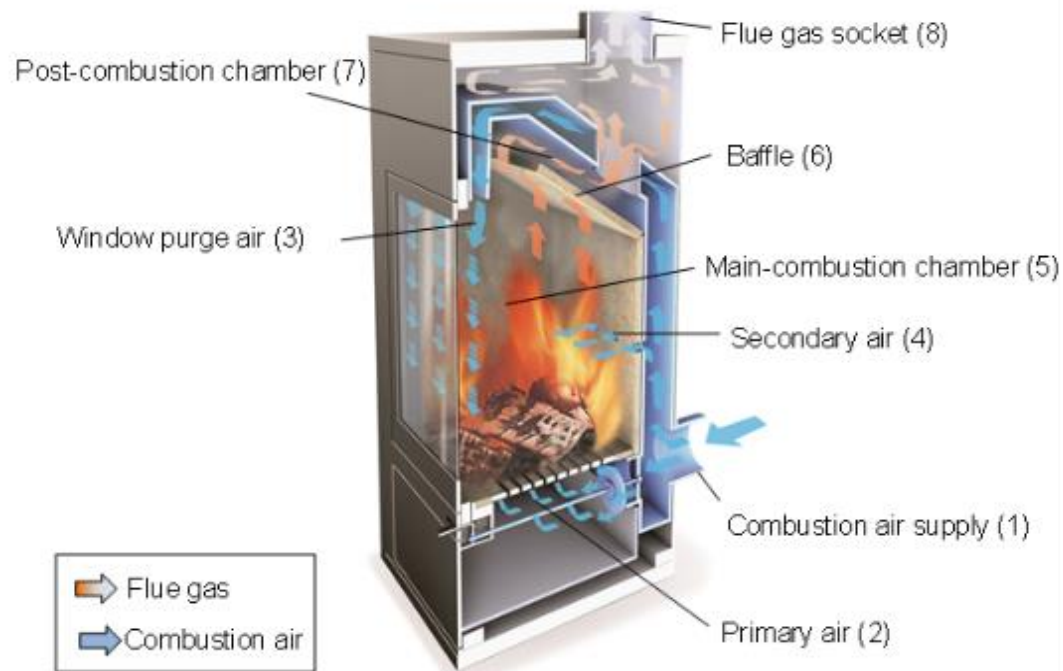
- Distribution of window purge air
- Direction and geometry of additional air
- Velocities of flue gas and combustion air
- Distribution of air to the different airflows
- Geometry of main as well as post combustion chamber
- Geometry of deflection plate and the use of baffles in post combustion chamber.
- Avoidance of leakage streams (sealing)
- Avoidance of short-circuiting of the flue gas stream
- Grooved surfaces



Source: Danish Technological Institute



Geometry of combustion chamber

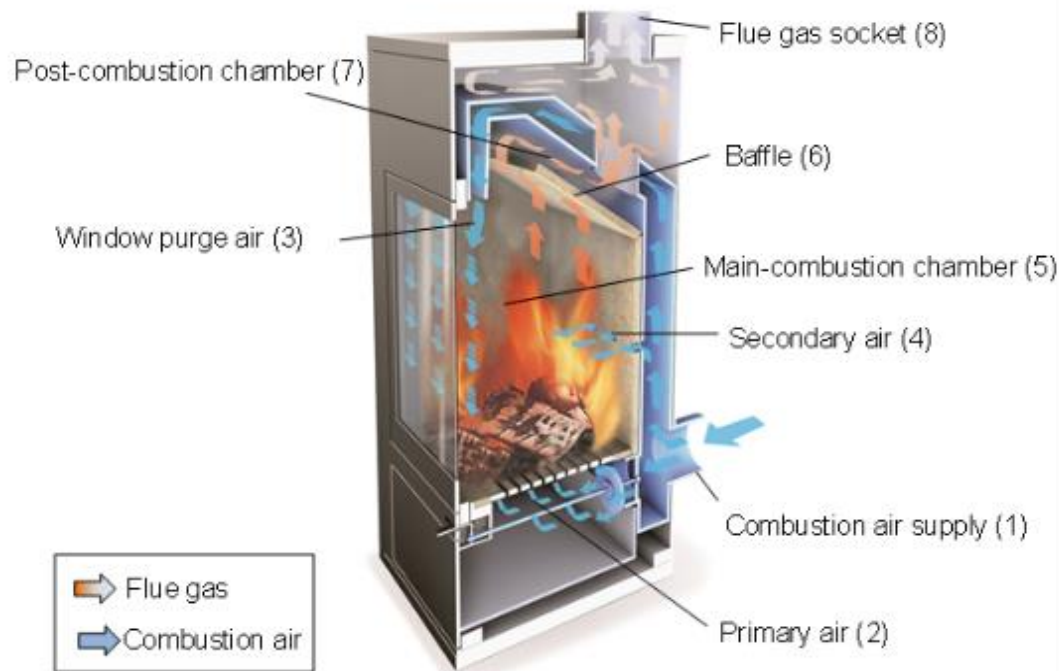


Source: http://www.tfz.bayern.de/mam/cms08/en/dateien/stoves2020-guidelines_low_emission_concepts.pdf

- High and slim geometry improves flame dispersion and result in more homogeneous residence pattern of pyrolysis gases in the hot zone.
- Should be dimensioned according to the desired effect
- No glass side panes
- No or limited radius or angel on front glass
- Well isolated chamber and stable and high temperatures in the combustion chamber is important.
- Airtight door and system
- Grooved surface pattern to obtain local turbulence and reduce elementary carbon emission



Air supply and air staging

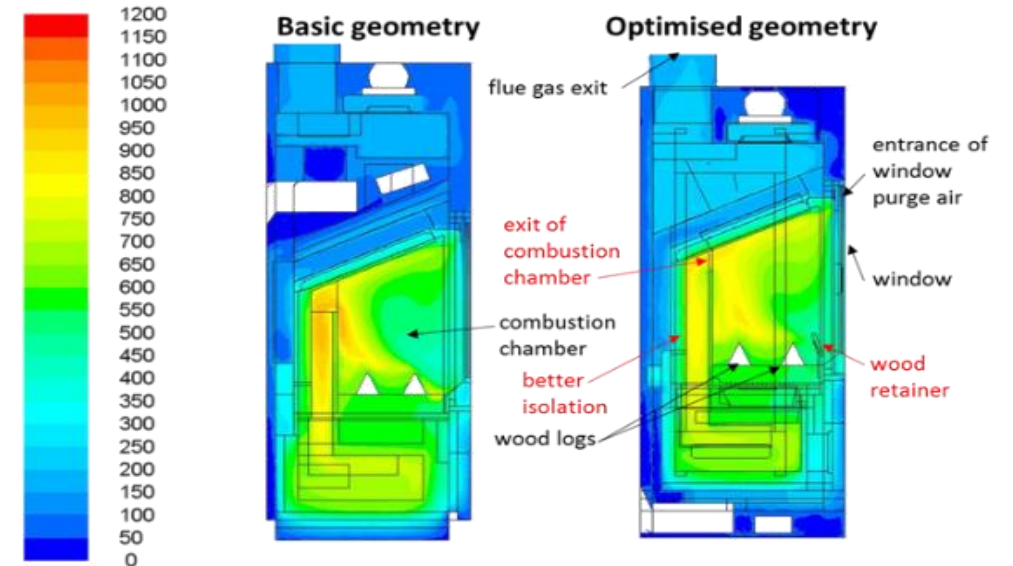


- Air staging should result in equally distributed fuel decomposition and charcoal burnout as well as almost gas phase burn out by introducing different airflows
- Minimum or no primary air
- Primary air should not be preheated whereas air streams to secondary combustion chamber should be pre-heated.
- Precaution about window purge air and secondary air nozzles functioning as primary air
- Secondary air should be applied in multiple levels



Computational Fluid Dynamics - CFD

- Velocities and temperatures of the combustion air
- Convective air and flue gas
- Path lines and flue gas
- CO and O₂ concentrations in the flue gas
- Material and surface temperatures
- Heat transfer
- Efficiency
- Pressure losses



Source: http://www.tfz.bayern.de/mam/cms08/en/dateien/stoves2020-guidelines_automated_control_systems.pdf

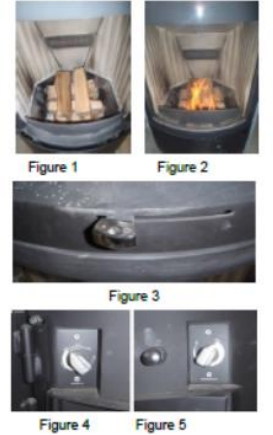


Reduced impact from user behavior

- QUG or improved information
- Automated control systems

1. Preparation & Ignition

- Clean and open the grate and empty the ash box
- Crosswise placement of four firewood pieces (2 layers) on top of shavings(3 layers) on the grate (Bottom-up ignition) (Fig. 1 & Fig. 2)
 - Length of firewood: 25 cm
- Use only dry and natural firewood – at least 1 year stored
 - 3 layers shavings, crosswise placed - total: 0.6 kg
 - 1. layer 2 firewood pieces, each 0.35 kg
 - 2. layer 2 firewood pieces, each 0.35 kg
 - Whole mass of the ignition batch has to be 2.0 kg (Fig. 1)
- Air inlet flap settings for ignition:
 - Bypass foamed ceramic: fully open "A" (Fig. 3)
 - Primary air supply: fully open "Max" (Fig. 4)
 - Secondary air: fully open "Max"(Fig 5)
- Lighting of starting aid (placed on the grate) (Fig. 2)
- Closing of combustion chamber door



2. Recharging

- Recharge when flames are extinguishing or when no flames visible, but enough firebed is available
- After the 1st batch: (Fig. 5)
 - Firewood: 2 pieces, each 1.0 kg, Total mass 2.0 kg
- After the 5th batch: (Fig. 6)
 - Firewood: 1 piece, Total mass 1.0 kg
- Placement according to Fig. 6 – only parallel to the window
- Air inlet flap settings:
 - Bypass foamed ceramic: closed "Z" (Fig. 7)
 - Primary air supply: reduced to Min (Fig. 8)
 - Secondary air: reduced to 50 % (Fig 9)



3. Finishing heating operation

- When flames are extinguished and when the firebed is not glowing any more (Fig. 7)
 - Close air inlet flaps (Fig. 8) for avoidance of heat losses
- Primary air supply: closed "Min" (Fig. 8)
- Secondary air: closed "Min" (Fig 9)



QUQ from BeReal project

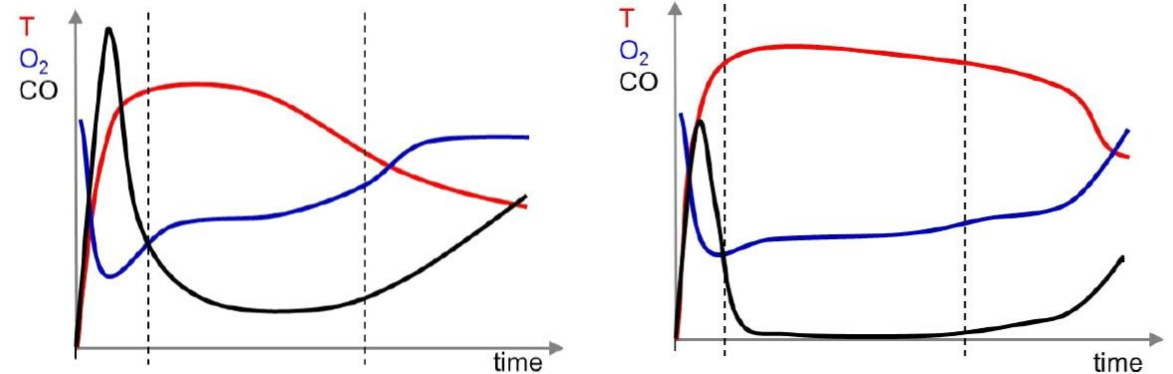
Source: http://www.bereal-project.eu/uploads/1/3/4/9/13495461/13.40_the_firewood_method_2.pdf



Automated Control Systems

Advantages with both integrated automatic control systems and retrofit solutions are

- Reduced user influence
- Reactions to changes throughout the batch
- Reducing emission in real life operation
- Increase thermal efficiency
- Increase operation comfort
- Reduce standing losses



Source: http://www.tfz.bayern.de/mam/cms08/en/dateien/stoves2020-guidelines_automated_control_systems.pdf



Types of Automated Control Systems

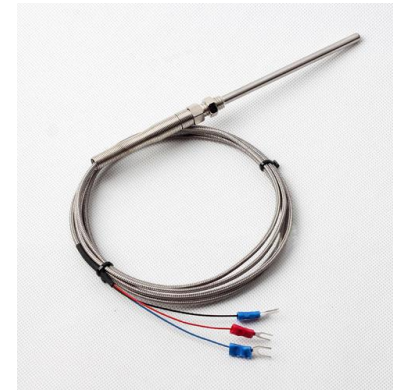
- Thermo-mechanically operated air flaps
- Electronic sensor driven automatic control concept
 - Flue gas temperature measurements in combustion chamber
 - Oxygen measurement in exhaust gas
 - Combined temperature and oxygen measurements
- Stoves add-ons and retrofit systems
 - Chimney draught stabilizer and flue gas fans
 - Air and flue gas flaps
 - Electronic air distribution system





Sensors available

- Temperature sensors
 - The cheapest solution, also being quite robust, is thermocouples
- Gas sensors
 - Oxygen – lambda probes
 - CO₂ sensors
 - CO – normally detects CO and hydrocarbons.
 - Combination sensors for oxygen and unburnt components.
- Pressure sensors
- Other sensors of interest
 - Recognizing flames
 - Recognizing door opening





Secondary measures





Catalysts

- Efficiency as catalyst has been seen to be very good for
 - CO reduction between 90%
 - 50-70% of HC's depending on the starting point for the stove
- No or limited effect documented with regards to PM/PN
- Challenges with applying an integrated catalyst in the wood stoves are
 - Flow resistance which can cause insufficient air flow
 - Flue gas backflow
 - Degradation
 - From very severe within a few weeks' time, to almost no during long time or application
 - Pressure drop varies from a few Pa to double digit number.

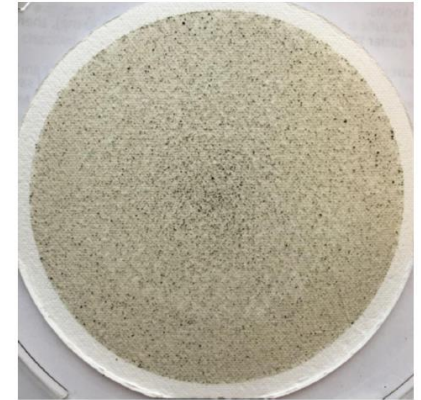
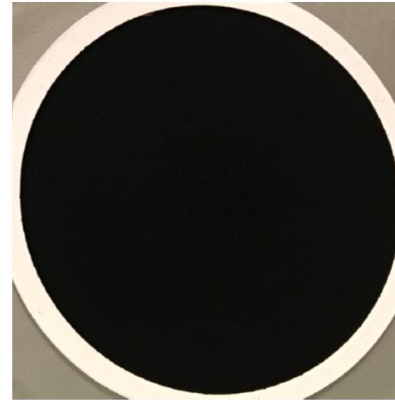




Electrostatic precipitators

- High efficiency reached 80-95 %
 - Both PM and PN
 - Reduction potential for Black Carbon
- No effect with regards to CO, HC, NOX

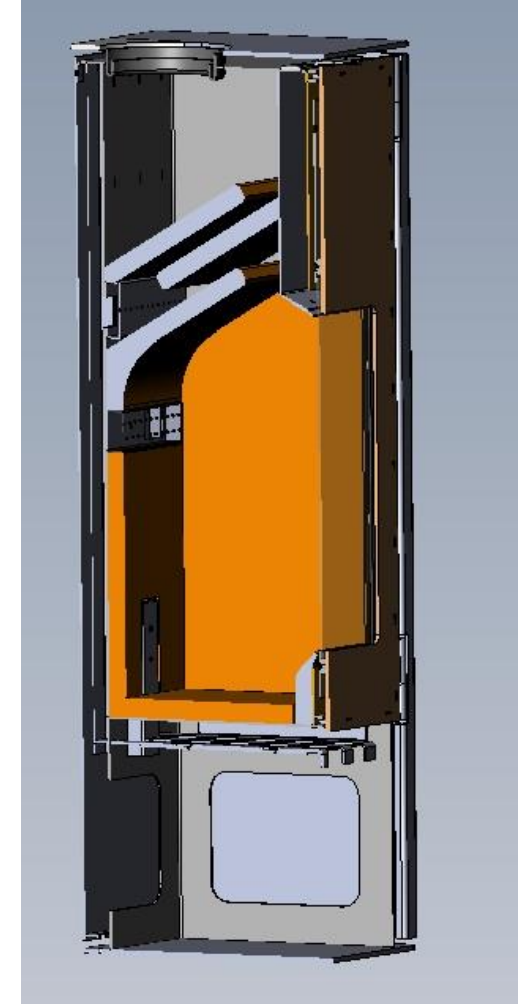
- Challenges applying an ESP in connection with wood stoves are
 - Expected lifetime and maintenance cost
 - Cleaning of the filter
 - Cost of the filter itself





Summary

- The most important aspects of stove development
 - The three T's
 - Time, temperature and Turbulence
 - Geometry of the combustion chamber
 - Air supply and air staging
 - Reduction of the user influence on the combustion – Automated systems





Technical guidelines

- Report will be published on
- <http://task32.ieabioenergy.com/>





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Thank you

Morten Gottlieb Warming-Jespersen, Head of Section
Mgjn@dti.dk

