Wood stove testing facility

May 5, 2009, Trondheim

by

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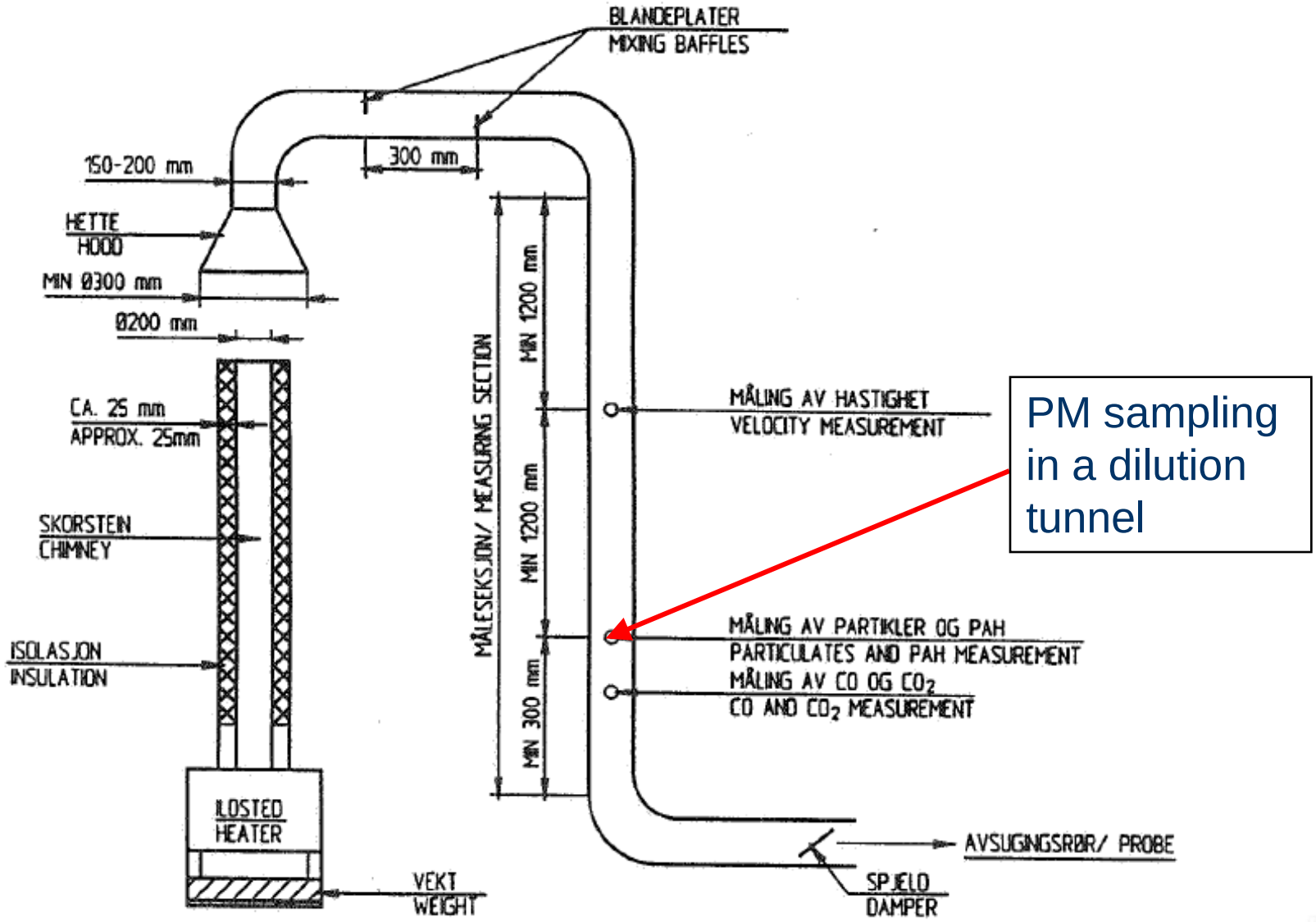
System overview



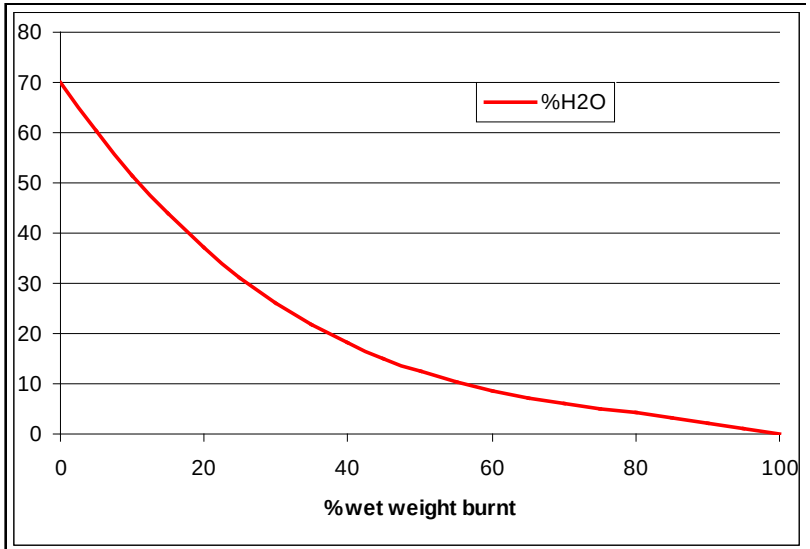
Areas of use

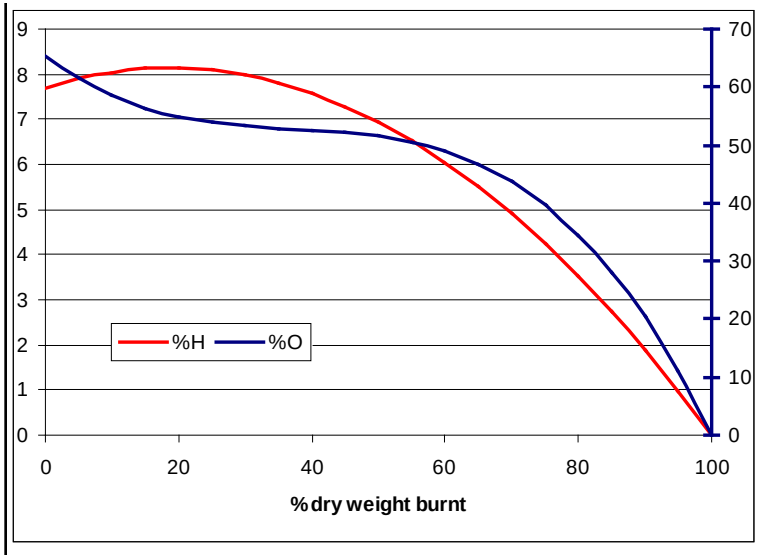
- Development and testing of wood stoves and other small-scale batch combustion units
- Fundamental research

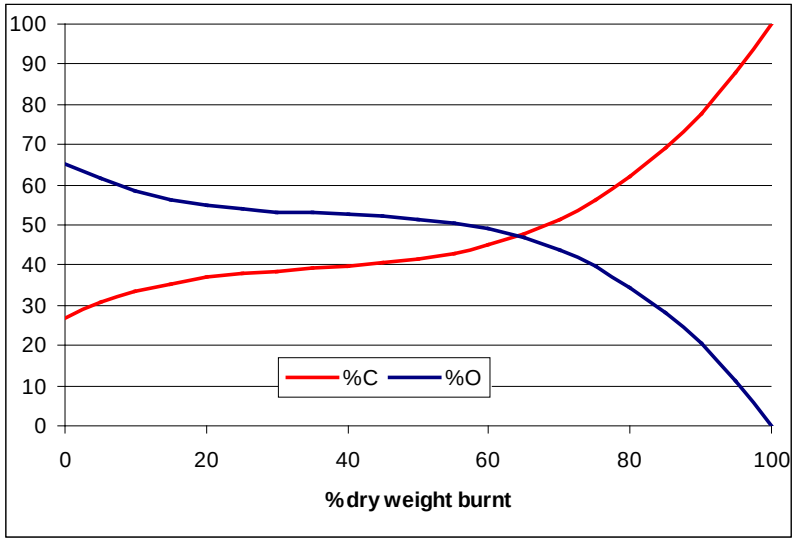
The transient nature of wood log combustion

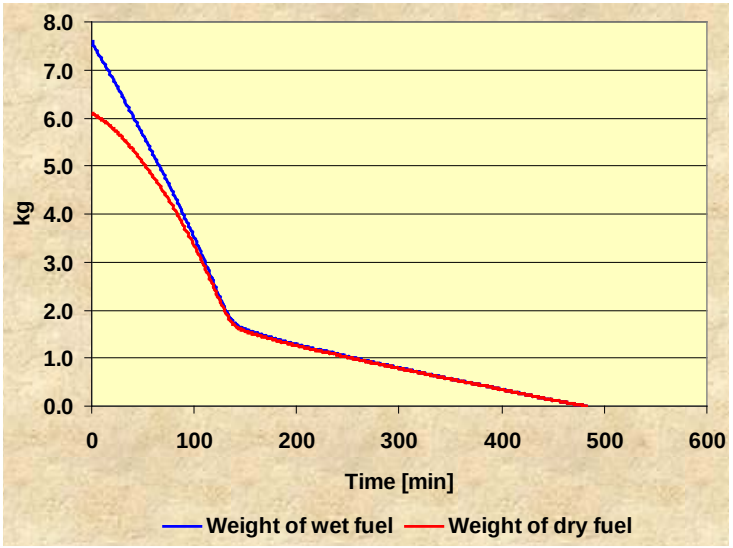
- Wood consists of about 80 wt% volatile compounds
- The picture shows the combustion of the volatile compounds. The composition of the volatile compounds is transient!

The transient nature of wood log combustion

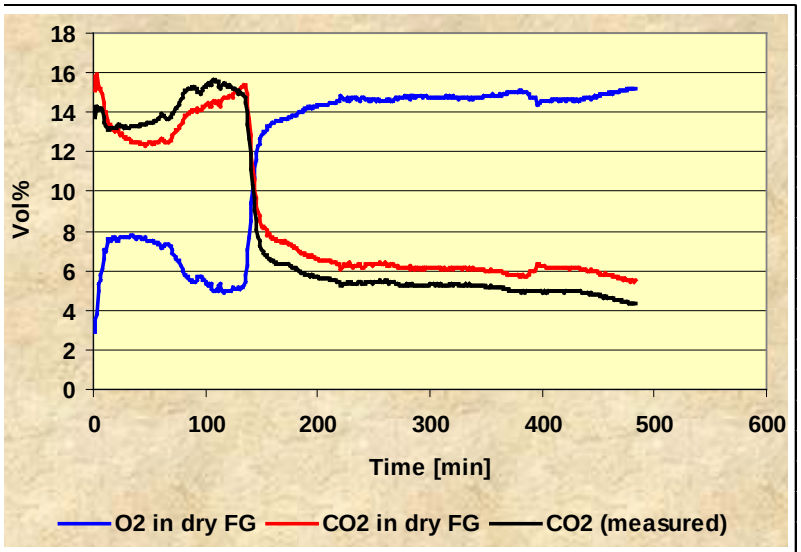


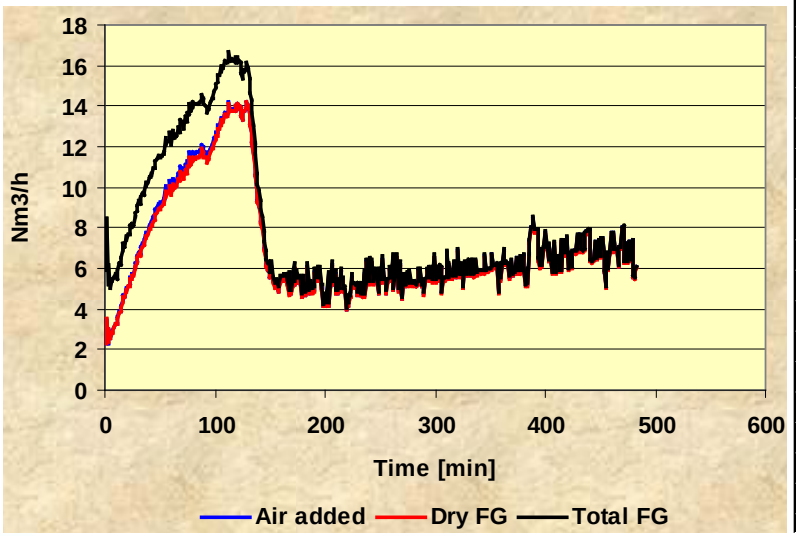


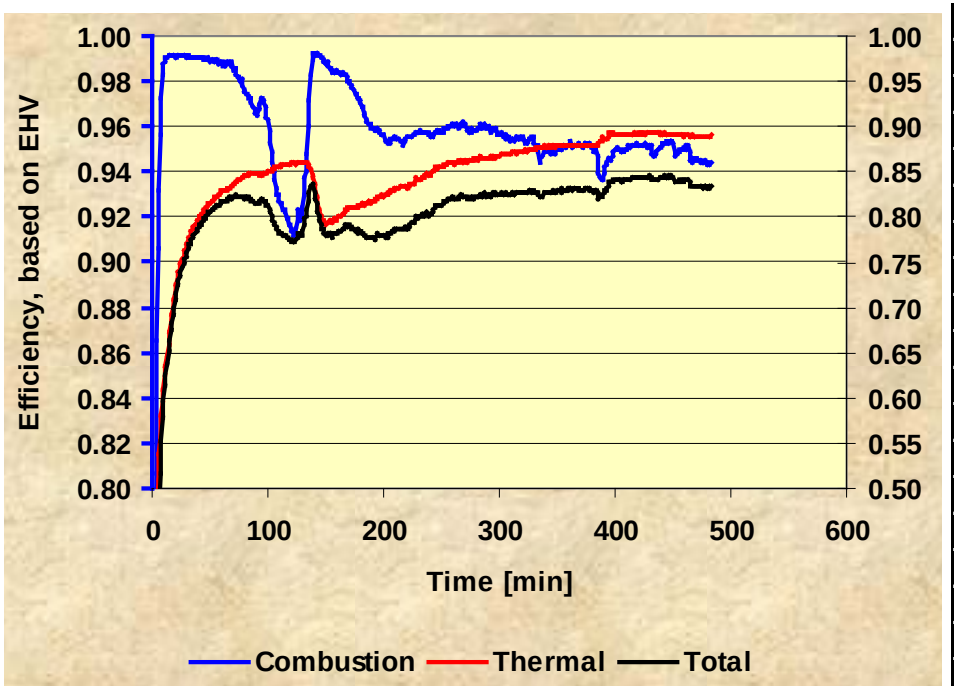




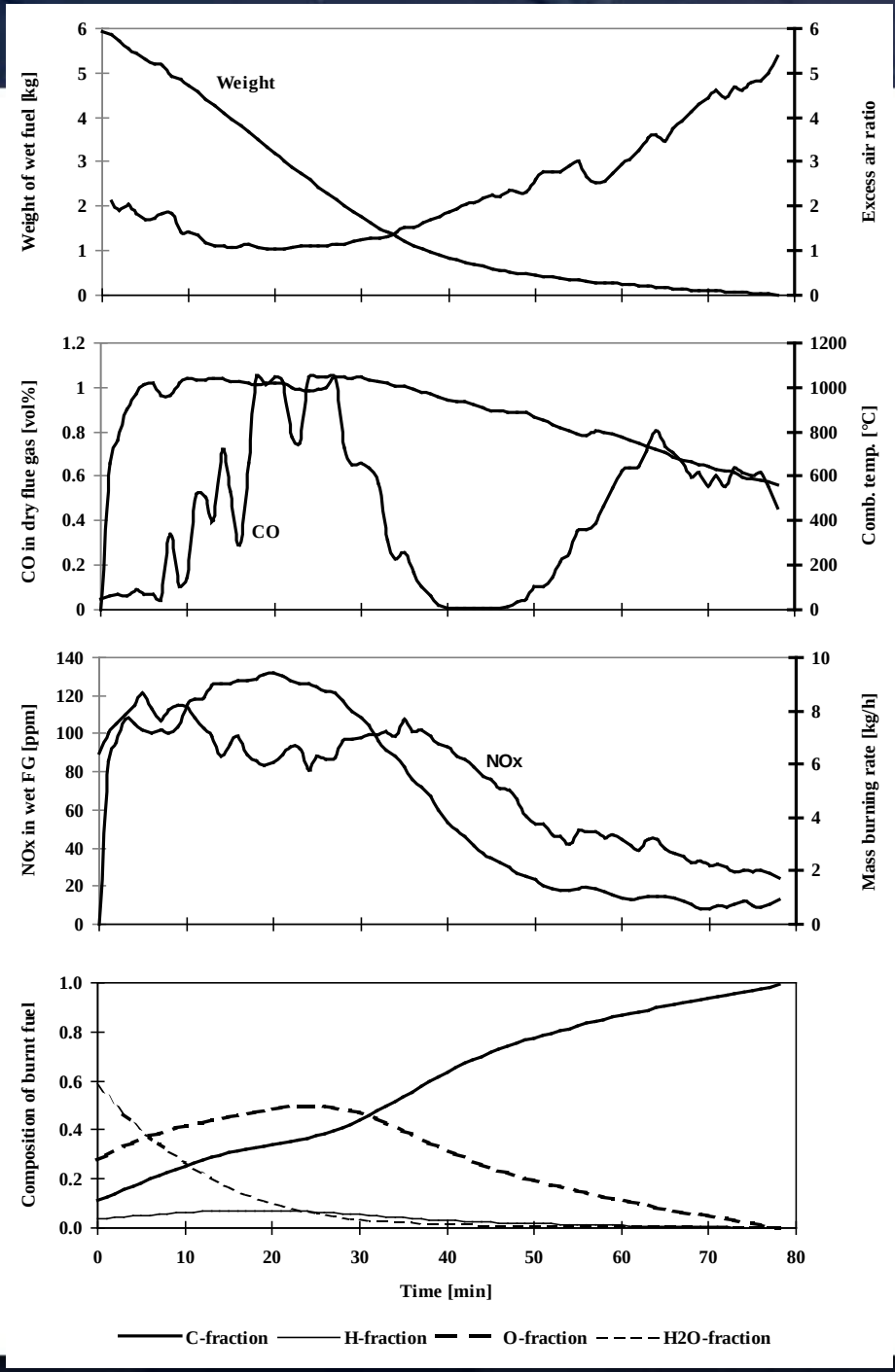
The transient nature of wood log combustion







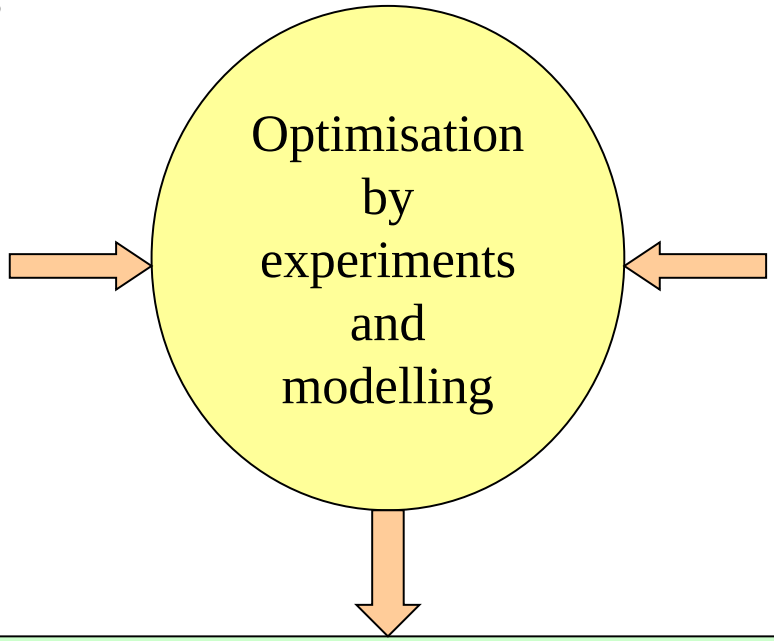
Weighted average values	Combustion efficiency	0.9583
	Thermal efficiency	0.8431
	Totalt efficiency	0.8015
	CO - vol%	0.6249
	CO emission - g/kg	71.7857



The transient nature of wood log combustion

The main variables influencing emission levels and energy efficiency in wood-stoves and fireplaces

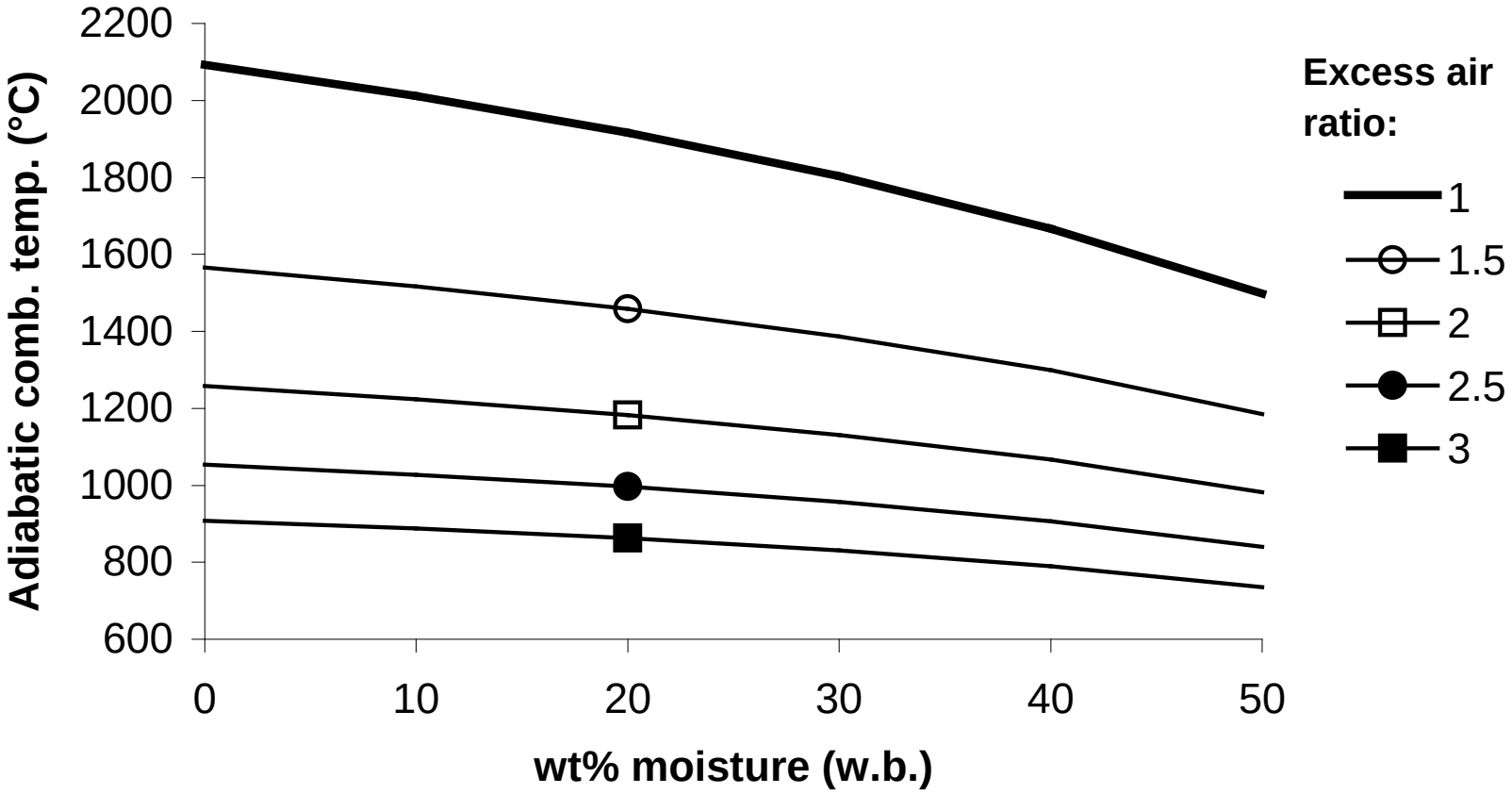
- Heat transfer mechanisms
- Heat storage
- Insulation
- Air preheating
- Excess air ratios
- Fuel type
- Fuel load
- Fuel composition
- Fuel consumption rate
- Moisture content in fuel
- Combustion temperatures
- Residence times
- Draught



- Design
- Materials
- Glass area and properties
- Heat exchanging
- Air staging
- Air distribution
- Fuel feeding
- Fuel distribution
- Heat distribution
- Radiation shields
- Regulation

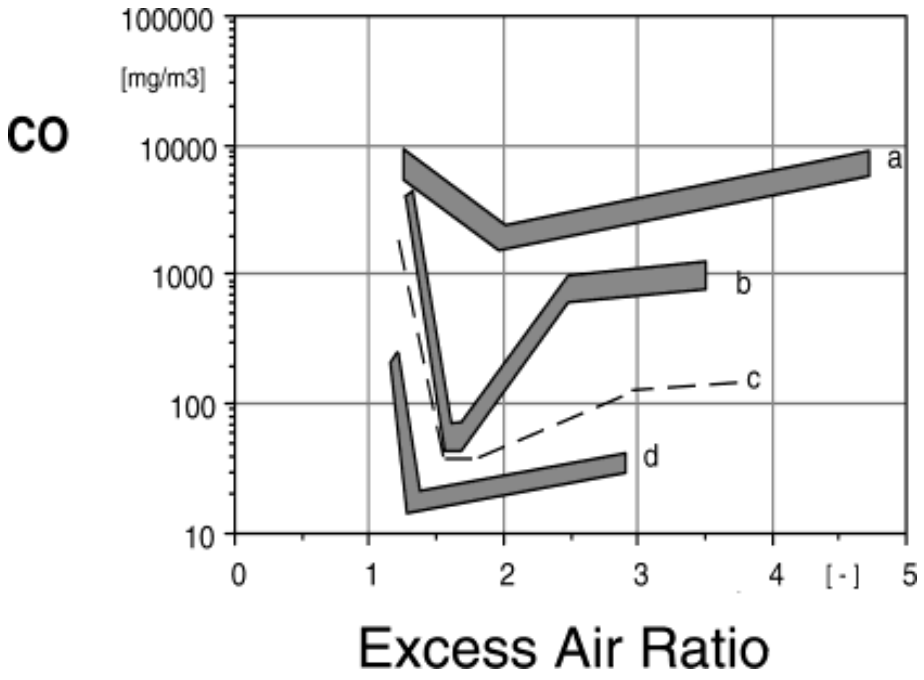
Emission reduction, high thermal efficiency and low surface temperatures
at low heat output

The main variables influencing emission levels and energy efficiency in wood-stoves and fireplaces



Adiabatic combustion temperature as a function of moisture content (w.b.) and excess air ratio for a continuous combustion process (Fuel composition: 50 wt% C, 6 wt% H and 44 wt% O, d.b.).

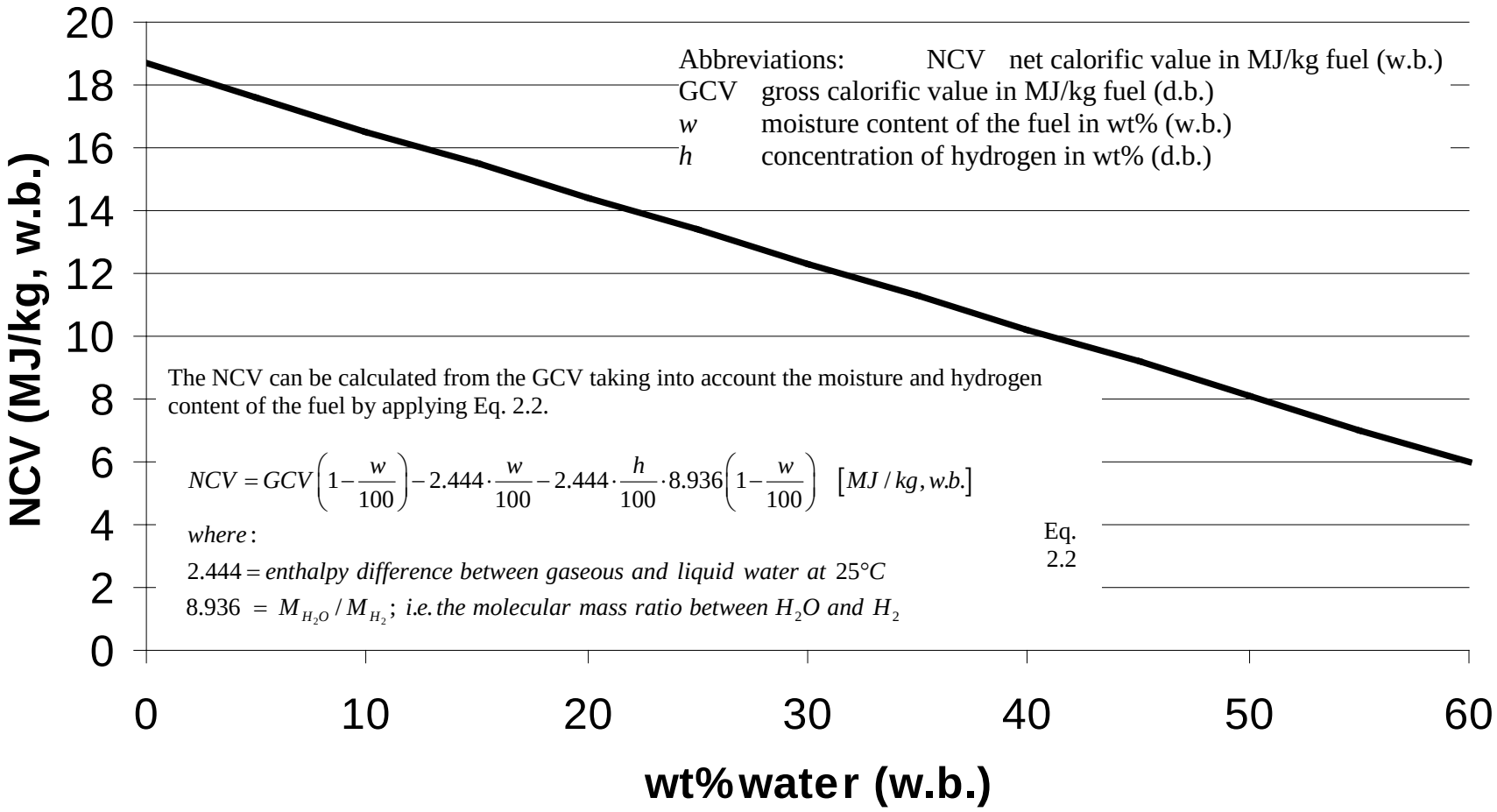
The main variables influencing emission levels and energy efficiency in wood-stoves and fireplaces



(a) Wood stove, (b) downdraft boiler, (c) automatic wood furnace, (d) advanced automatic wood furnace

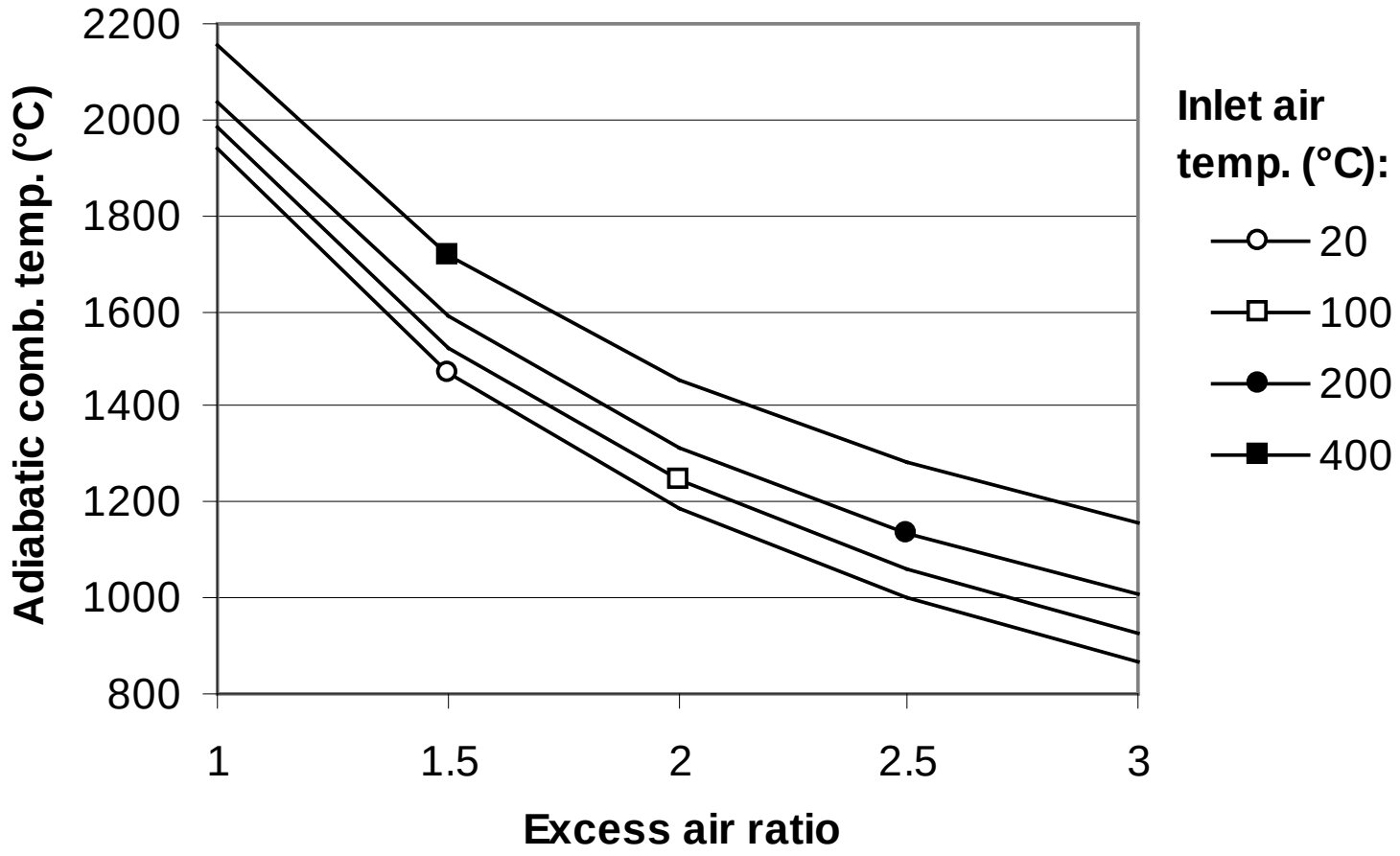
[Nussbaumer, 2003]

The main variables influencing emission levels and energy efficiency in wood-stoves and fireplaces



NCV as a function of wt% moisture (w.b.) for a fuel composition of 50 wt% C, 6 wt% H, and 44 wt% O (d.b.).

The main variables influencing emission levels and energy efficiency in wood-stoves and fireplaces



Adiabatic combustion temperature as a function of excess air ratio and inlet air temperature for a continuous combustion process (Fuel composition: 50 wt% C, 6 wt% H and 44 wt% O, d.b.; Moisture content: 18 wt%, w.b.).

Note that $PM_{10-2.5}$ is the difference of PM_{10} and $PM_{2.5}$

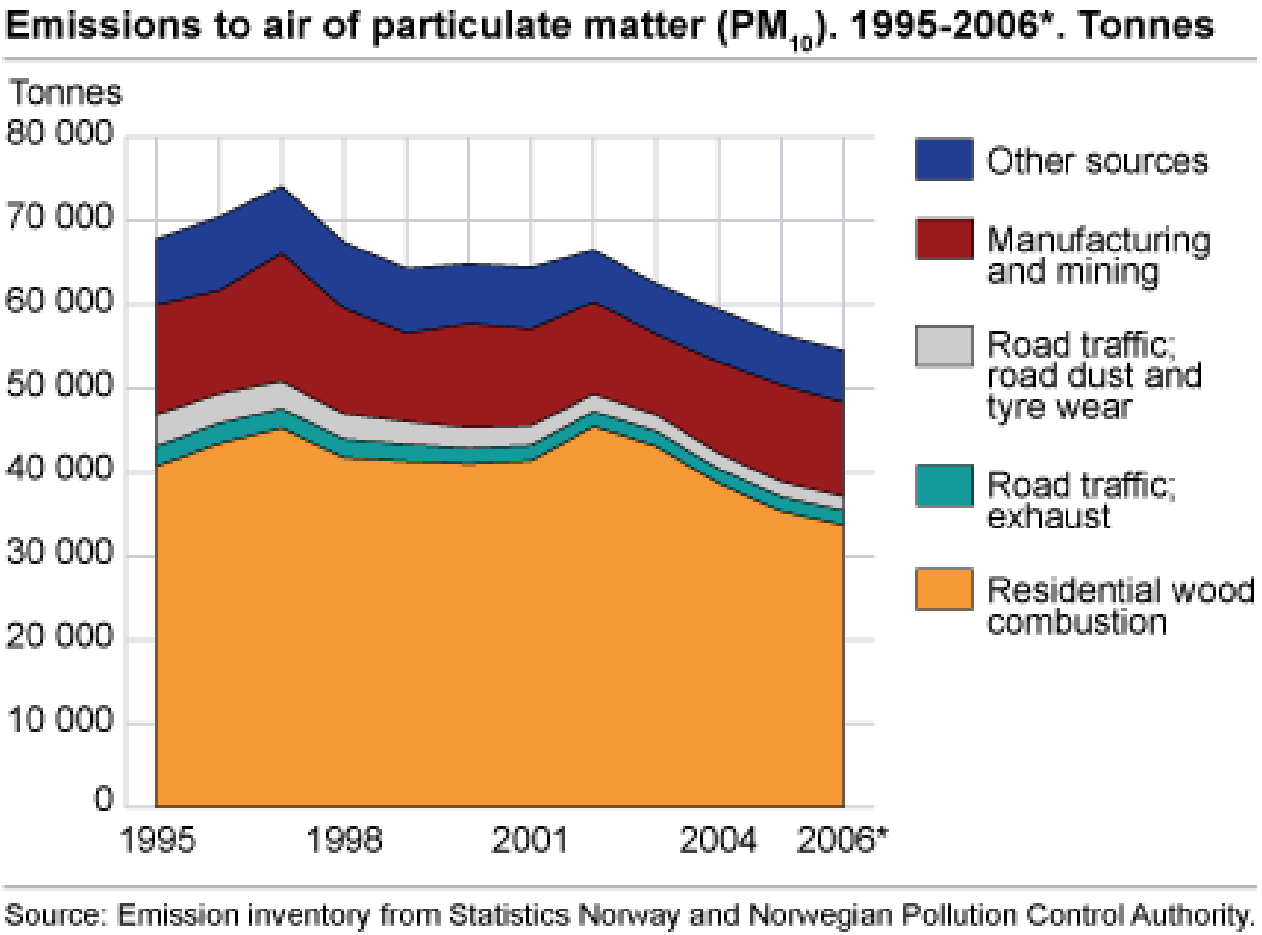
History, background and standards

- No particle emission limits in Norway for wood stoves before 1997
- NS 3058 came into force in 1997
- 10 g/kg dry fuel particle emission limit from 1997 for non-catalytic wood stoves
- 5 g/kg dry fuel particle emission limit from 1997 for catalytic wood stoves

Fraction	Size range
PM_{10} (thoracic fraction)	<=10 µm
$PM_{2.5}$ (respirable fraction)	<=2.5 µm
PM_1	<=1 µm
Ultrafine (UFP or UP)	<=0.1 µm
PM_{10}-$PM_{2.5}$ (coarse fraction)	2.5 µm - 10 µm

Note that $PM_{2.5}$ - PM_{10} is the difference of $PM_{2.5}$ and PM_{10}

History, background and standards



- half of all biomass (7 TWh) in Norway is used for space heating in wood stove and fireplaces
- residential wood combustion still large source for PM in Norway
- 2006 62%

NS-3058/3059: Enclosed Wood heaters

- since 1997, type approval of fireplaces and wood stoves required
- 4 tests at different burning rate categories

burning rate category [dried fuel kg/h]	1	2	3	4
grade 1	< 0,80	0,80 – 1,25	1,26 – 1,90	> 1,90
grade 2	< 1,25	1,25 – 1,90	1,91 – 2,80	> 2,80

- → weight value
- emission limits for particles above 1 micrometer, sampled on cold filter

EN 13240: Roomheaters fired by solid fuels

- safety
- efficiency > 50%
- CO < 1 vol% at 13 O_2

- DINplus
  - CO < 0.12 vol% at 13 O_2
  - NO_x < 200 mg/Nm^3 at 13 O_2
  - C_xH_y < 120 mg/Nm^3 at 13 O_2
  - Dust < 50 mg/Nm^3 at 13 O_2
  - efficiency > 75%

Note that PM_{10} - $PM_{2.5}$ is the difference of PM_{10} and $PM_{2.5}$

History, background and standards

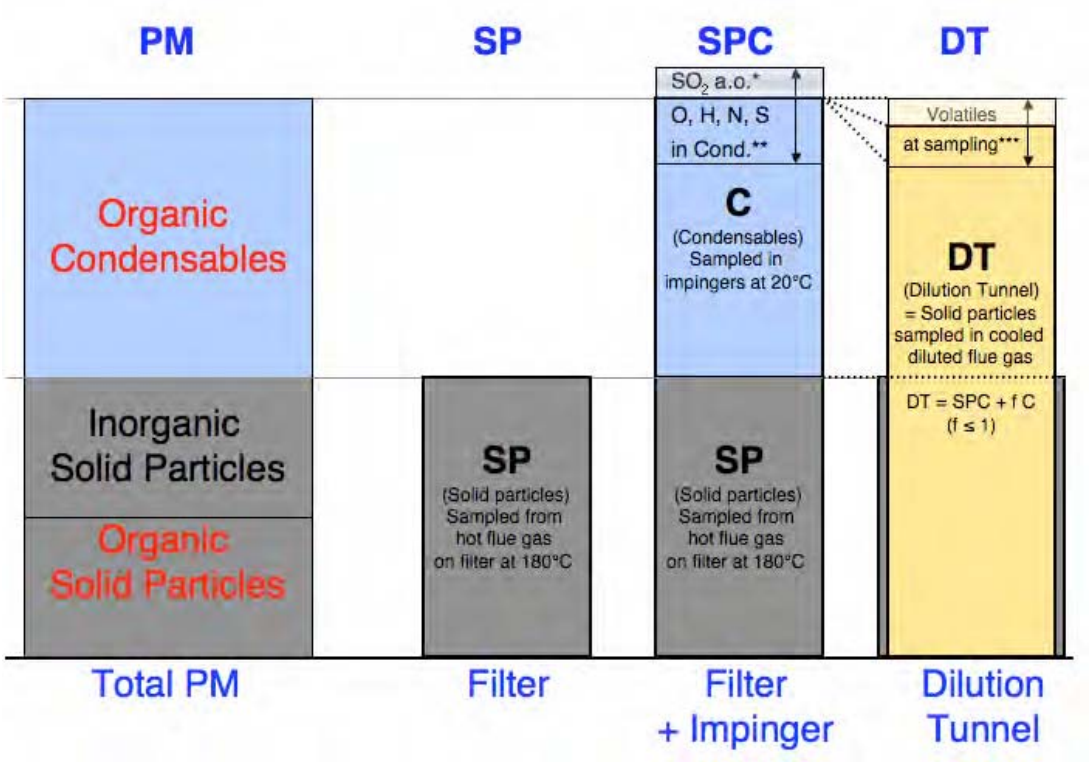
Differences of the test methods for particle measuring

	DINplus 13240	NS 3058
Sampling period	30 min	Whole load
Fuel	hardwood	softwood
Location	Chimney	Dilution tunnel
Sampling temperature	70°C	35°C
PM	Solid particles	Solid + condensed particles
Draught	Forced 12 Pa	natural
Test condition	Nominal heat output	4 burning categories

Note that $PM_{1-2.5}$ is the difference of PM_{10} and $PM_{2.5}$

History, background and standards

Comparison of emission values of different particle test methods



[Nussbaumer, 2008]

- Reported emission values: D: 94 mg/MJ (SP), NO: 1932 mg/MJ (DT) depending on the used sampling method

Note that $PM_{1-PM_{0.1}}$ is the difference of PM_1 and $PM_{0.1}$

History, background and standards

- Solid particles stack + THC vs. PM in the dilution tunnel
- 35 % of the measured HC in the stack condense along the Dilution tunnel and form liquid particles
- 85 % of the particles sampled with the dilution tunnel are condensed organic matter
- the ratio between PM in the stack and dilution tunnel increases with unfavorable conditions 5 → 15

→ a dilution tunnel provides more realistic emission factors

Note that $PM_{2.5}$ - $PM_{1.0}$ is the difference of $PM_{2.5}$ and PM_1

History, background and standards

- Open and closed fireplaces

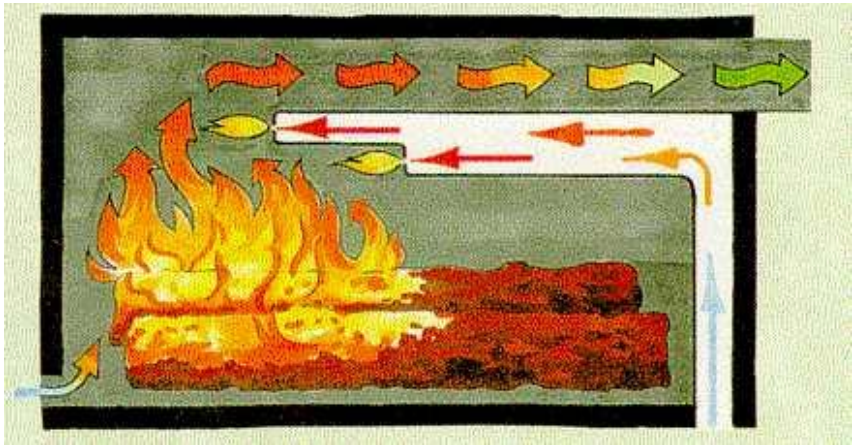
cosiness
efficiency 15%
source for increased emissions

heating
80%
clean burning

Note that $PM_{2.5}$ - $PM_{1.0}$ is the difference of $PM_{2.5}$ and PM_{1}

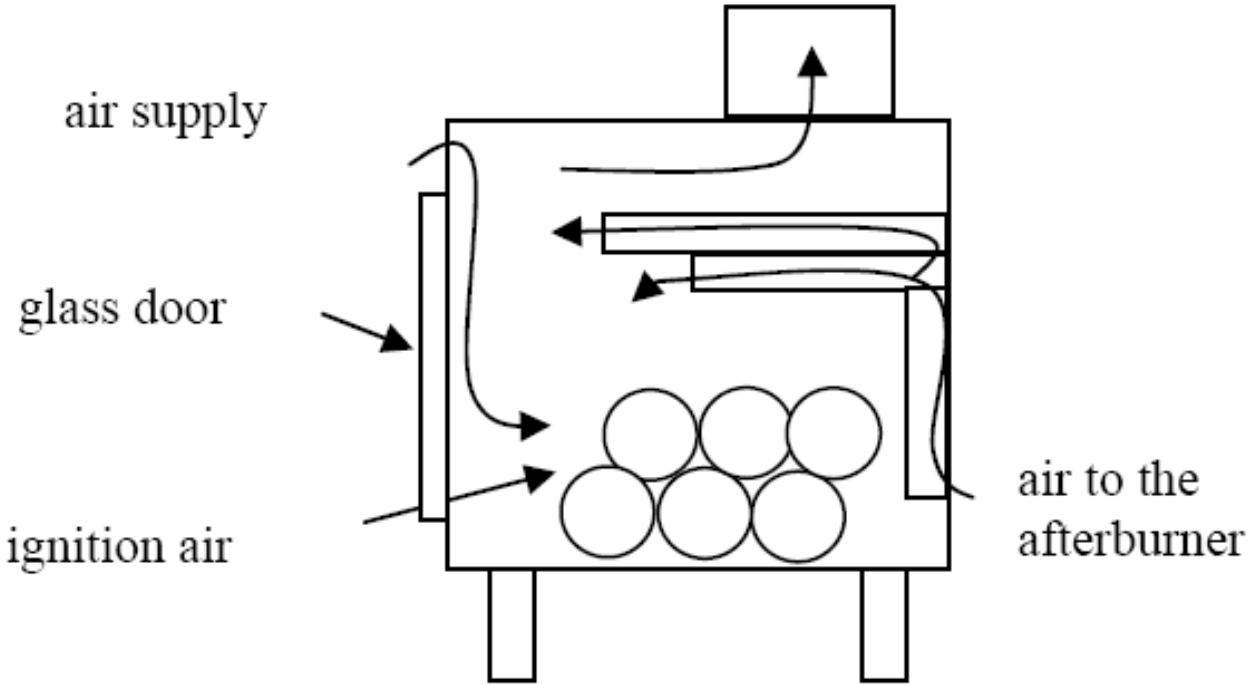
History, background and standards

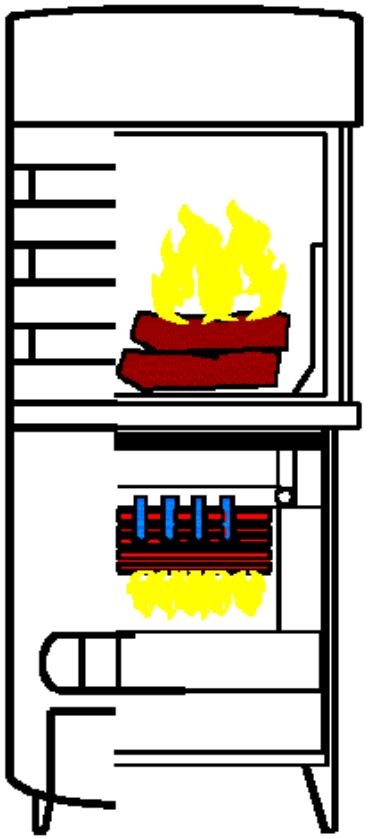
- Wood stoves
  - new technology reduced emission by 60% increased efficiency from 50% to 85%



History, background and standards

Staged combustion





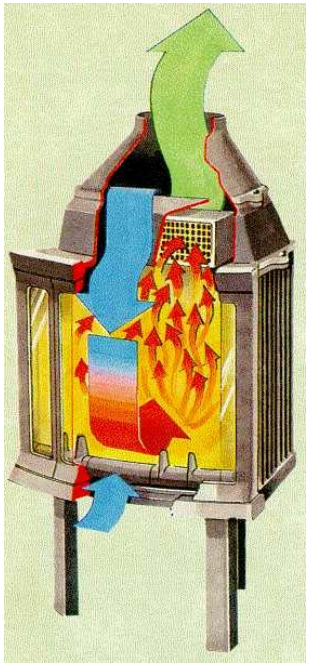
Airflow pattern inside the Jøtul F3

Note that PM_{10} - $PM_{2.5}$ is the difference of PM_{10} and $PM_{2.5}$

History, background and standards

Wood stoves with catalyst

- very efficient, burn out the gases at low temperature
- consumed over time
- sensitive to impurities



Note that PM_{10} - $PM_{2.5}$ is the difference of PM_{10} and $PM_{2.5}$

History, background and standards

Heat storing stove

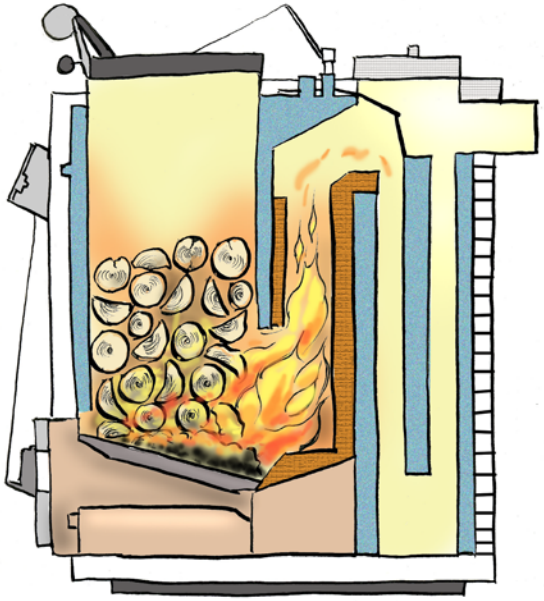
- heat storing material: soapstone, tiles
- 300 kg-1000 kg

History, background and standards

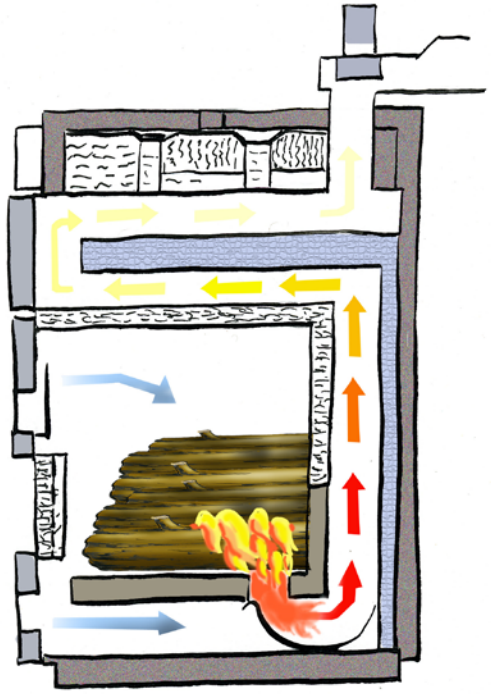
Boilers

- new boilers are equipped with an automatic air control (blower)

updraft



side draft



downdratt

History, background and standards

Pellet stove

- clean and efficient burning
- automatic feeding and air control

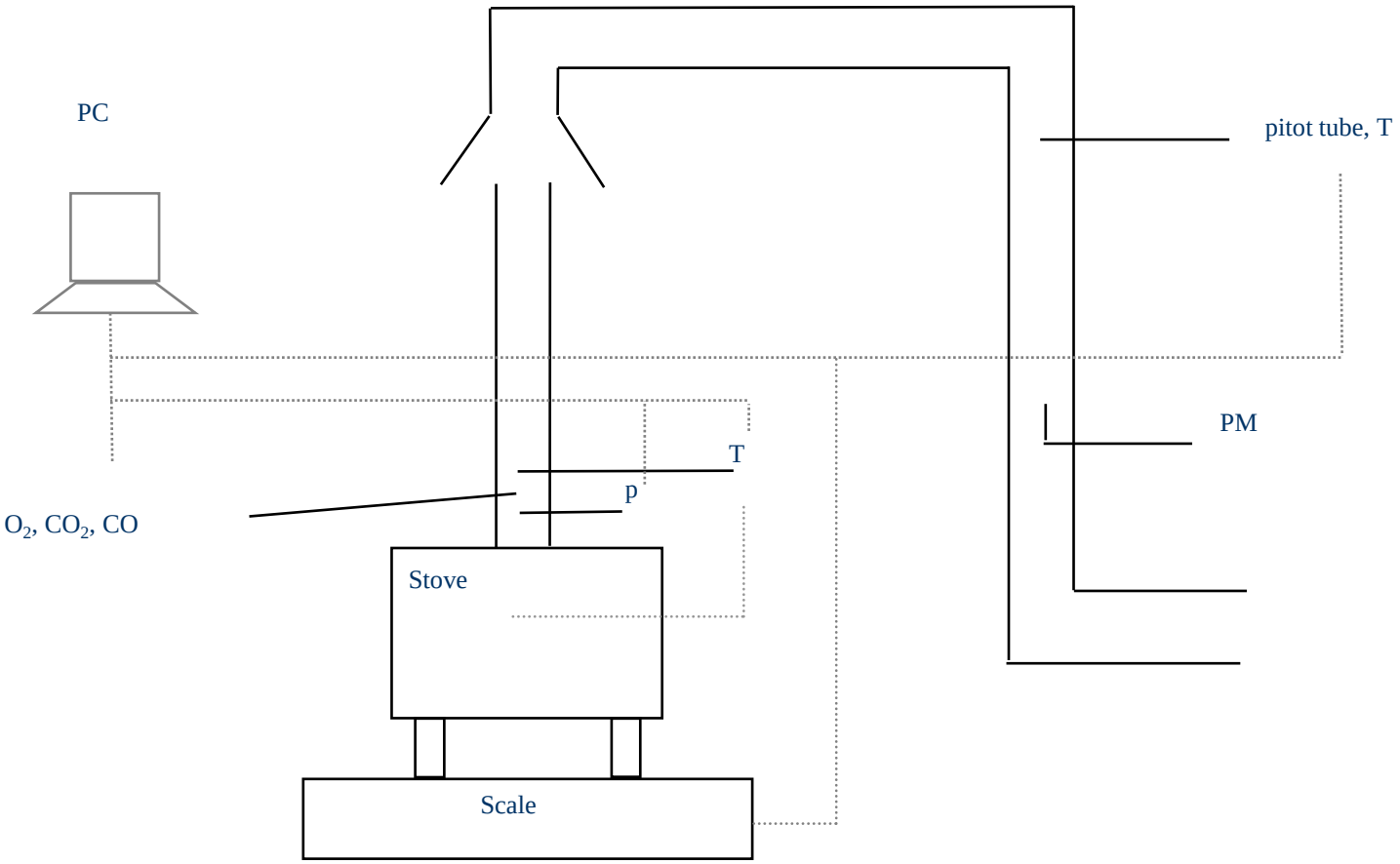
Note that PM_{10} - $PM_{2.5}$ is the difference of PM_{10} and $PM_{2.5}$

History, background and standards

Old wood stoves, wood with poor quality and wrong firing habit are not only health and environmental damaging, it is also a waste of money.

The construction

The construction



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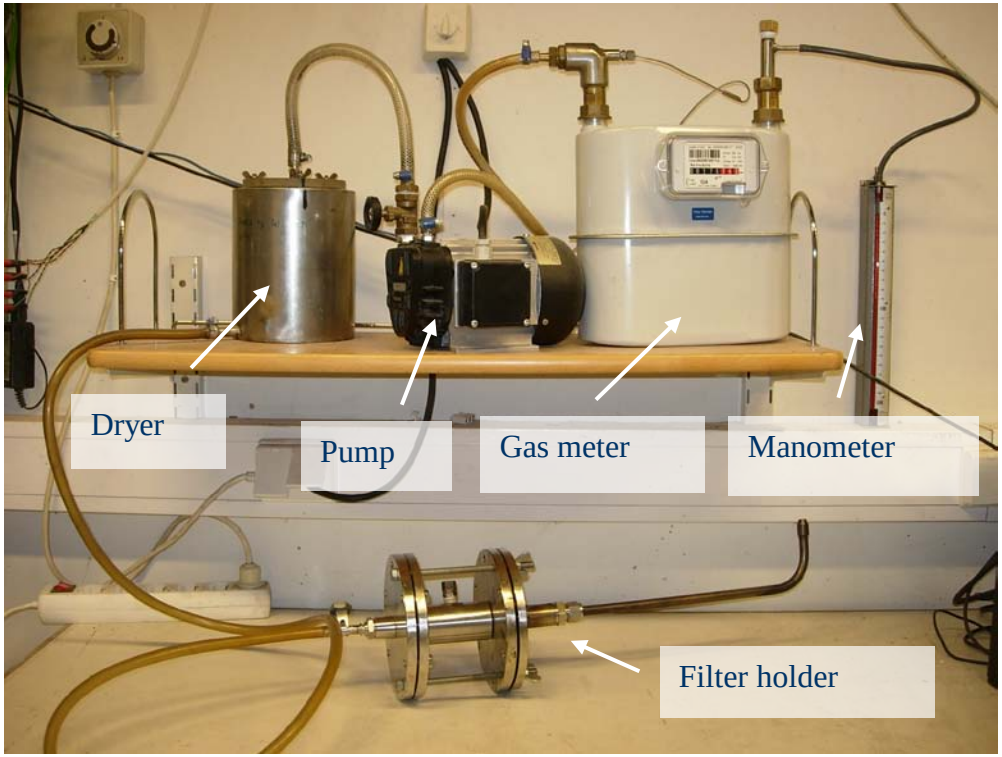

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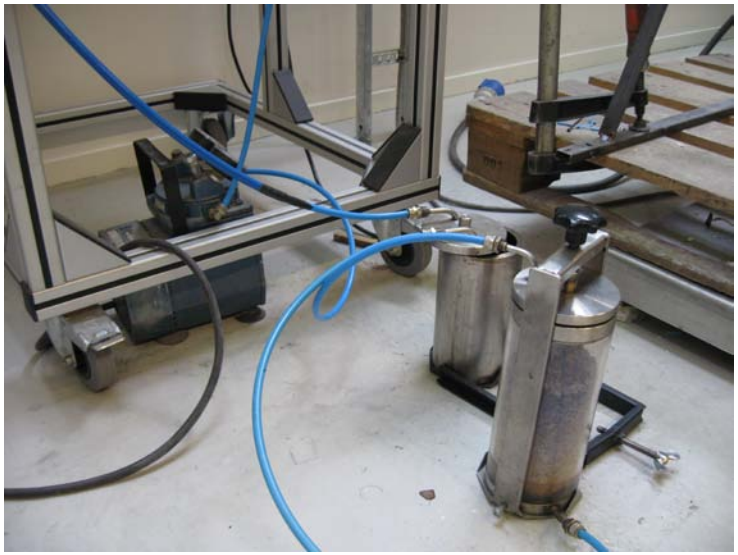
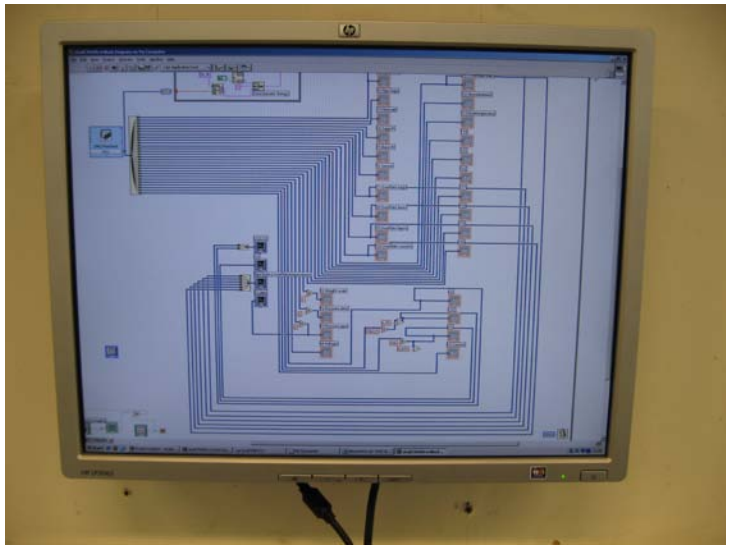




The instrumentation

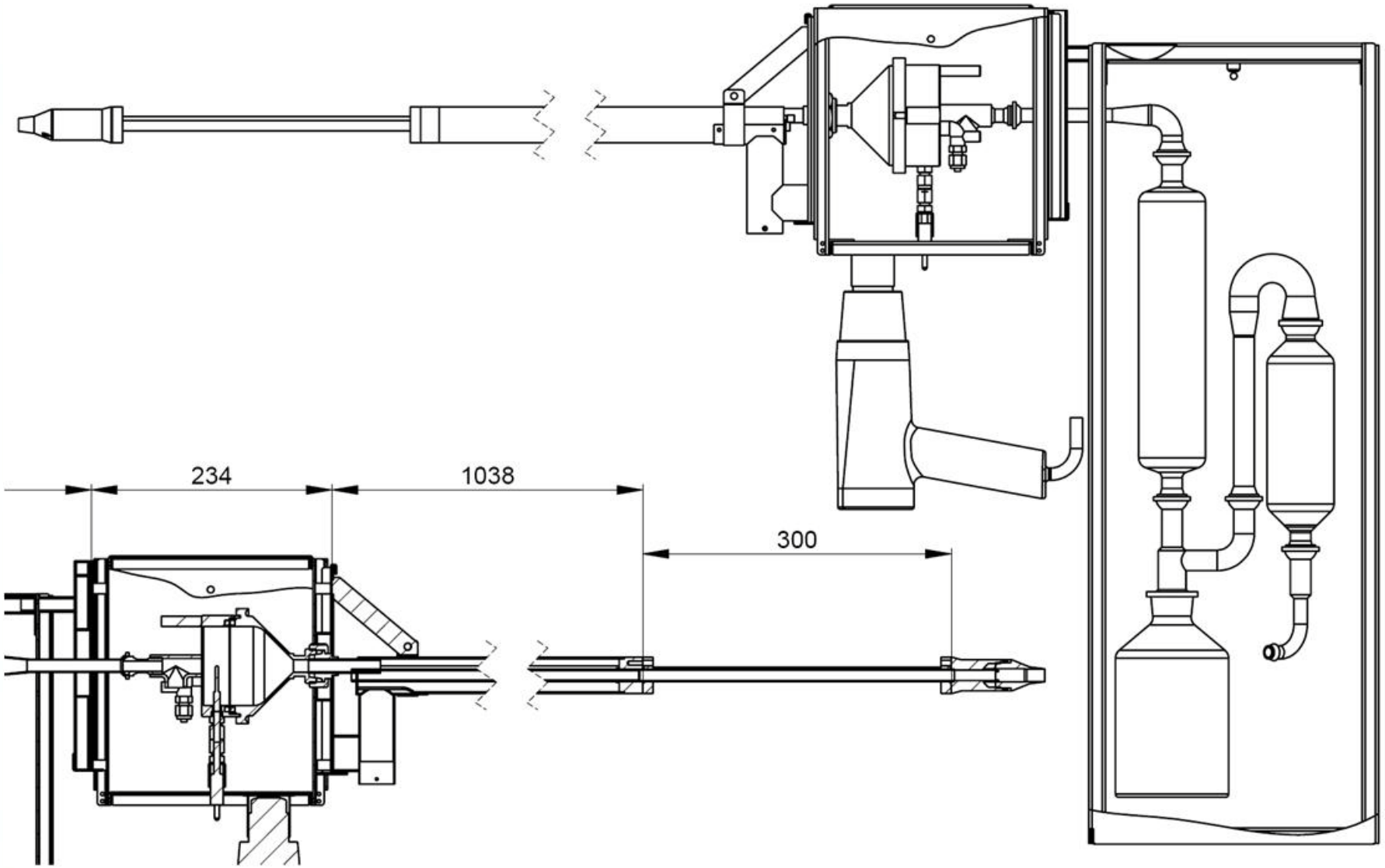
- Fuel consumption (scale)
- Temperatures (including chimney inlet temperature)
- Chimney draft (pressure measurement)
- Equal dilution tunnel speed (fan and pitot pressure measurement) and particle sampling suction speed (pump and flow meter) gives isokinetic suction of particles from the dilution tunnel

The analysis possibilities

- NS 3058 particle sampling system (dilution tunnel)
- Conventional gas analyzers (dilution tunnel (CO and CO2), and chimney)
- Multi-species gas analyzer
- Heated filter
- ELPI
- FTIR, GC

Impactor

Heated filter



Fuel Properties

- chemical composition
  → volatiles, heating value, ash content,
  bulk density: softwood less dense ~420 kg/m^3 (spruce);
  hardwood: ~500 kg/m^3 (birch)

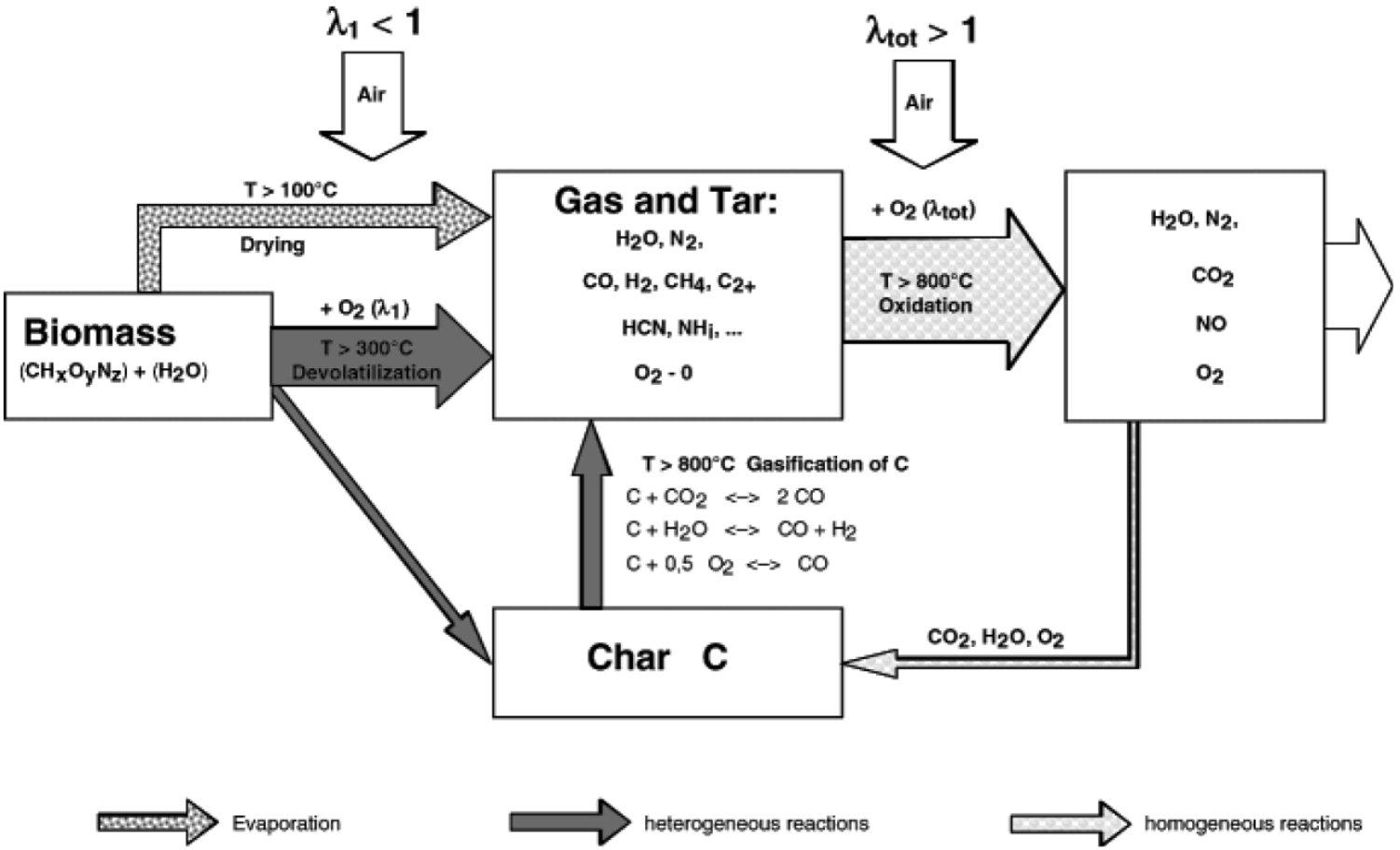
Weight fraction [%]	Cellulose	Hemicellulose	Lignin	Ash
hardwood	40-42	30-35	20-22	2-3
softwood	40-43	21-23	27-28	3-5

- physical characteristics
  - moisture

  → effective heating value
  - size

  → surface

Fuels



[Nussbaumer, 2003]

pyrolysis/devolatization → gasification → combustion

Fuels

small birch logs
(9-10%, 16-18%;
Ø 3-5cm)

medium birch logs
(9-11%, 19%;
Ø 6-7cm)

large birch logs
(9%; Ø 8-9cm)

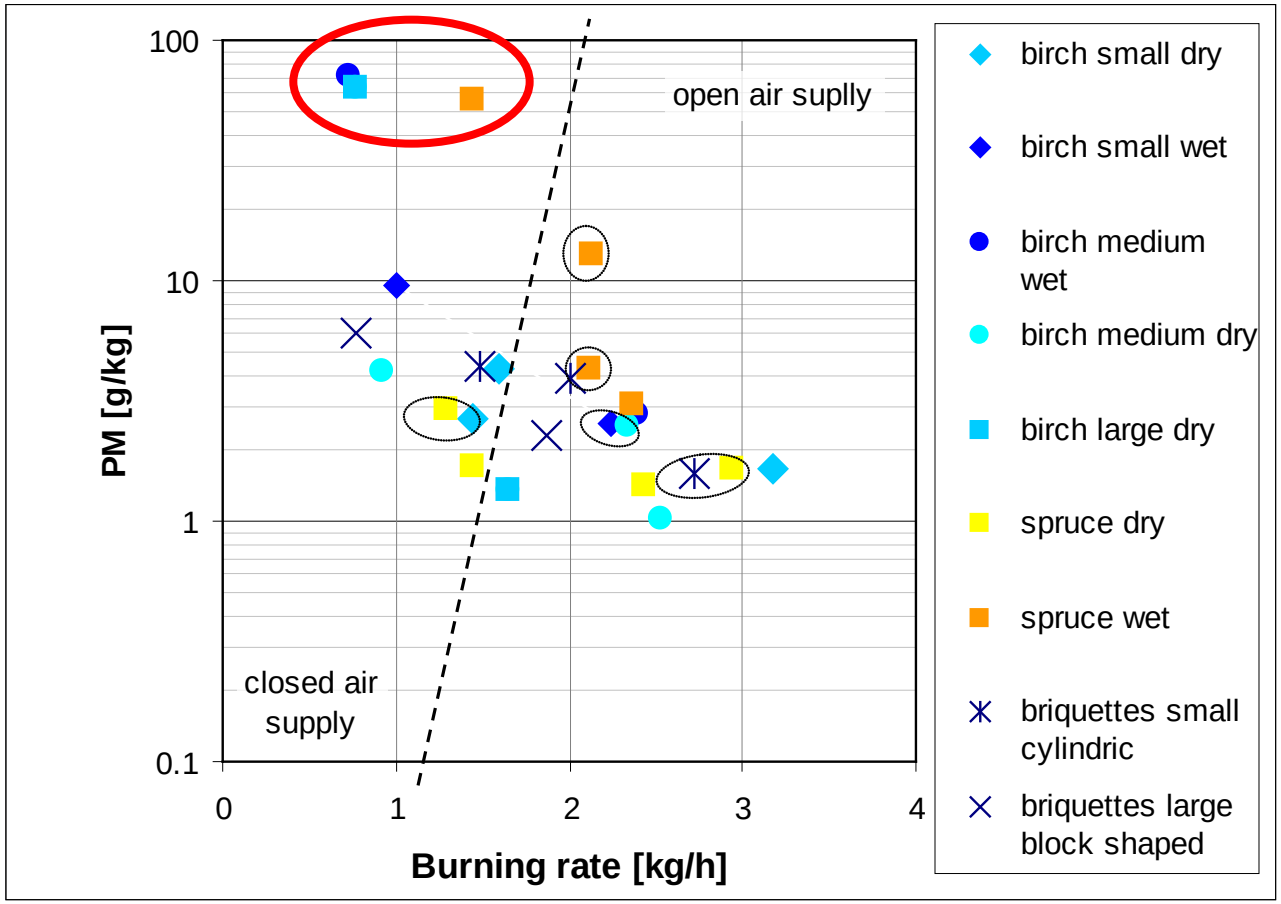
small round
briquettes (6%)

large blocked shaped
briquettes (7-8%)

standardized spruce
(7-9% ,18-24%)

(moisture and diameter)

Fuels



- size and moisture → main influence on particle emissions (60 g/kg) stove with reduced air supply (moisture → 30x; size → 15x)
- warm stove with sufficient air supply less sensitive

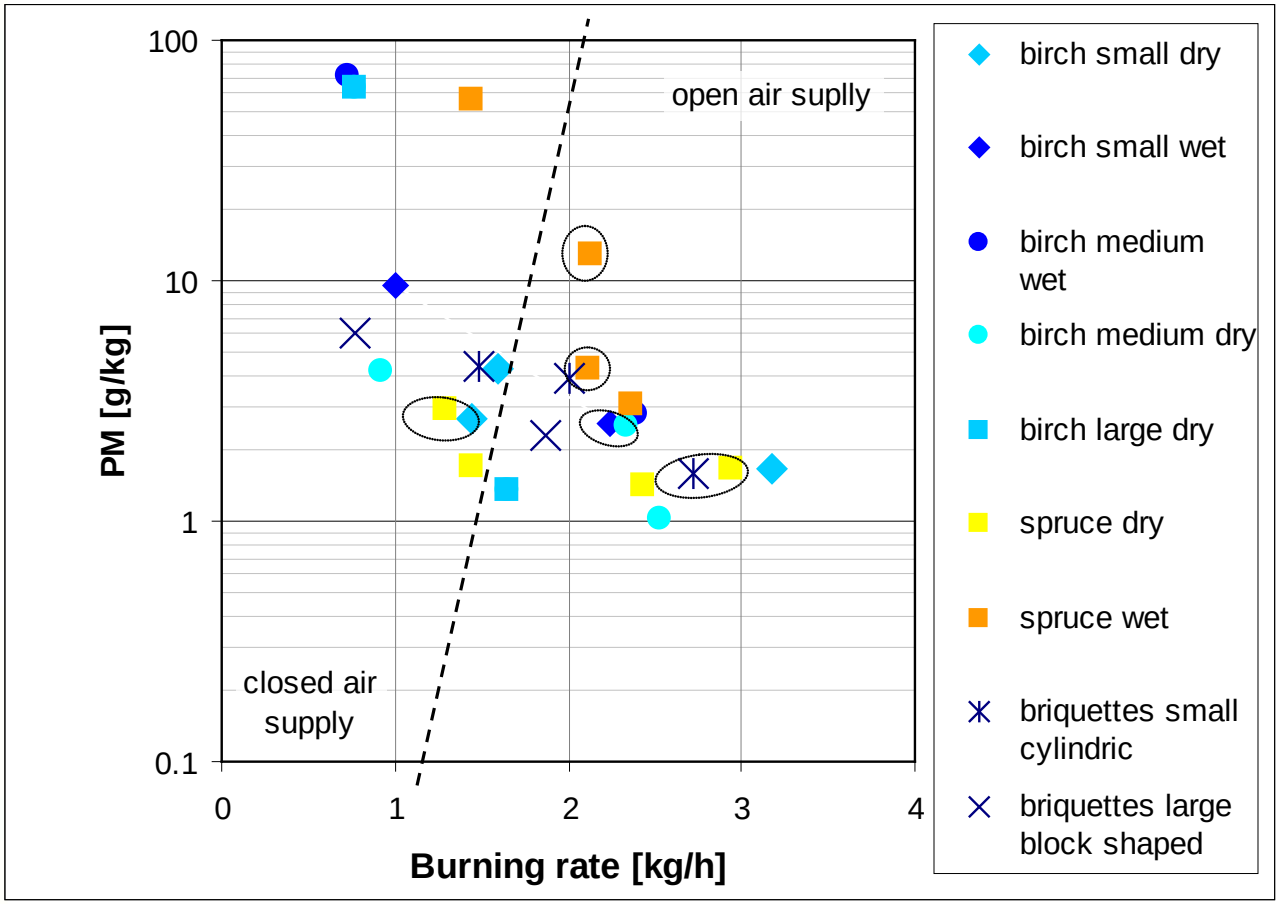
  PM < 4 g/kg

  (moisture→ 2x; size → conversion rate)

◌ Test runs in the cold stove

- - - separates experiments with open and closed air supply

Fuels



- fire starter better ignition help than newspaper and bark
- longer ignition → lower emissions (60%)
- briquettes give general low emission

◌ Test runs in the cold stove

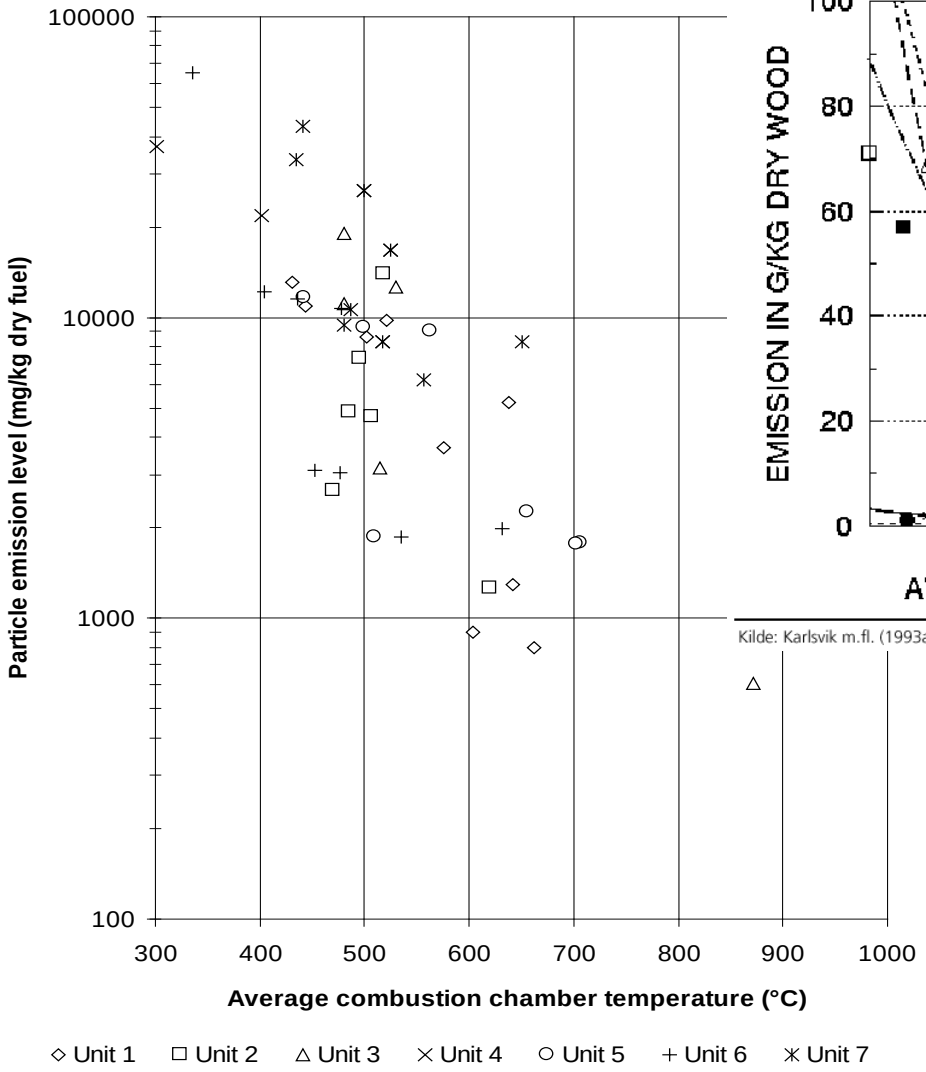
- - - separates experiments with open and closed air supply

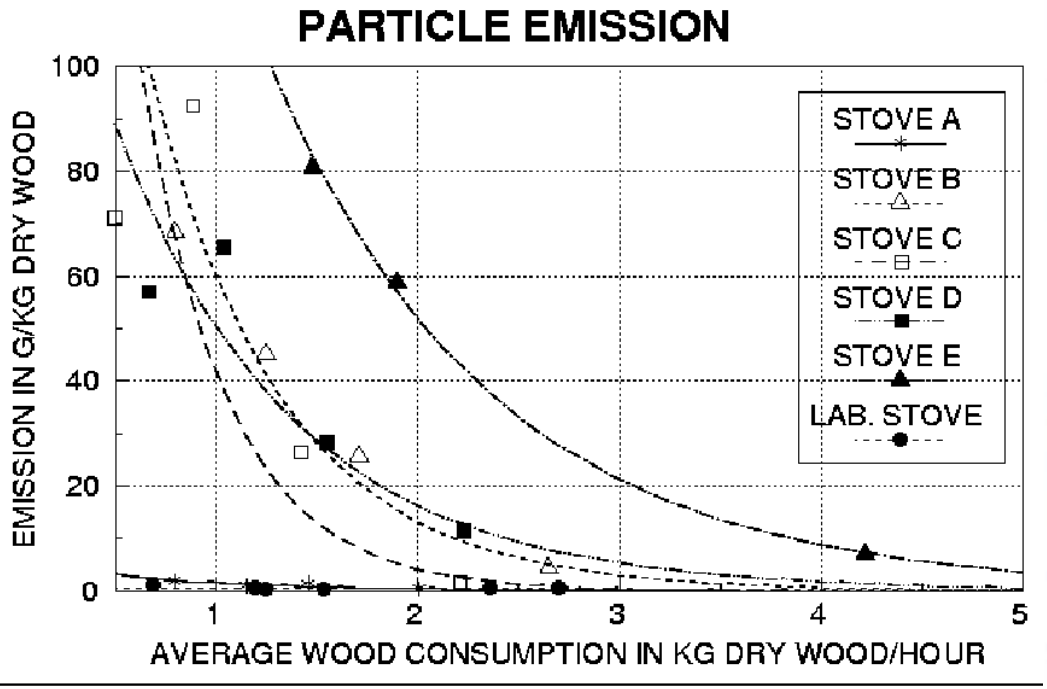
Different ways of arranging the test fuel

Experiments

- Wood stove development and testing
- Emissions, e.g. particles, CO, hydrocarbons, NOx
- Efficiencies
- Moisture content effects
- Fuel composition effects
- Air distribution effects
- Wood log size and distribution effects
- Ignition method effects
- Transient effects

Examples of results

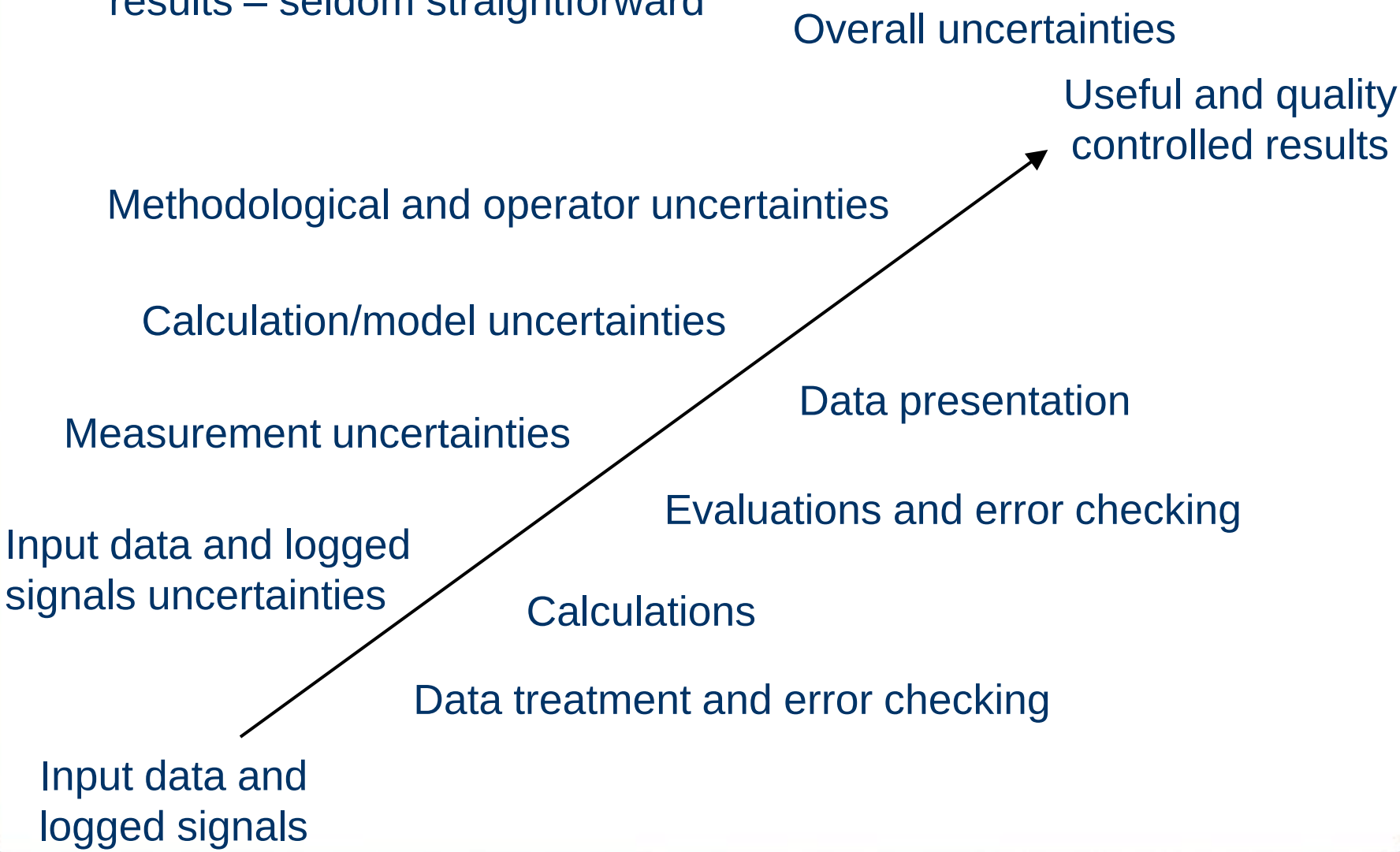




Kilde: Karlsvik m.fl. (1993a).

Data treatment

- From input data and logged signals to useful and quality controlled results – seldom straightforward



Experiments to be run in the biofuelsGS course

- Combustion of NS test fuel
- Relatively high burning rate experiment, with preheating test
- Spruce and birch
- Gas analysis, in flue gas channel, with conventional analyzers (CO and CO2, + O2)
- Particle sampling according to NS 3058 (dilution tunnel, cold filter)
- Wood stove temperatures and chimney inlet temperature

Data treatment of biofuelsGS experiments

- Convert the raw data into useful and quality controlled results using pre-prepared Excel worksheet (explanation/theory and demonstration on Thursday)

- Extract the following key data for each fuel
  - Average and transient burning rate
  - Weighted and transient thermal efficiency
  - Weighted and transient combustion efficiency
  - Weighted and transient total efficiency
  - Average particle emission level in g/kg dry fuel (calculate)
  - Transient temperatures and draft

- Compare the above data for the two fuels

- Suggest explanations for differences in the results

- Discuss within your group: How would you design an experimental setup revealing transient “input data”?