The ultimate wood stove

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SINTEF Energy Research

SINTEF NTNU JØTUL Dovre morsø 1893 NORSK KLEBER

The ultimate wood stove

does not exist, and maybe never will

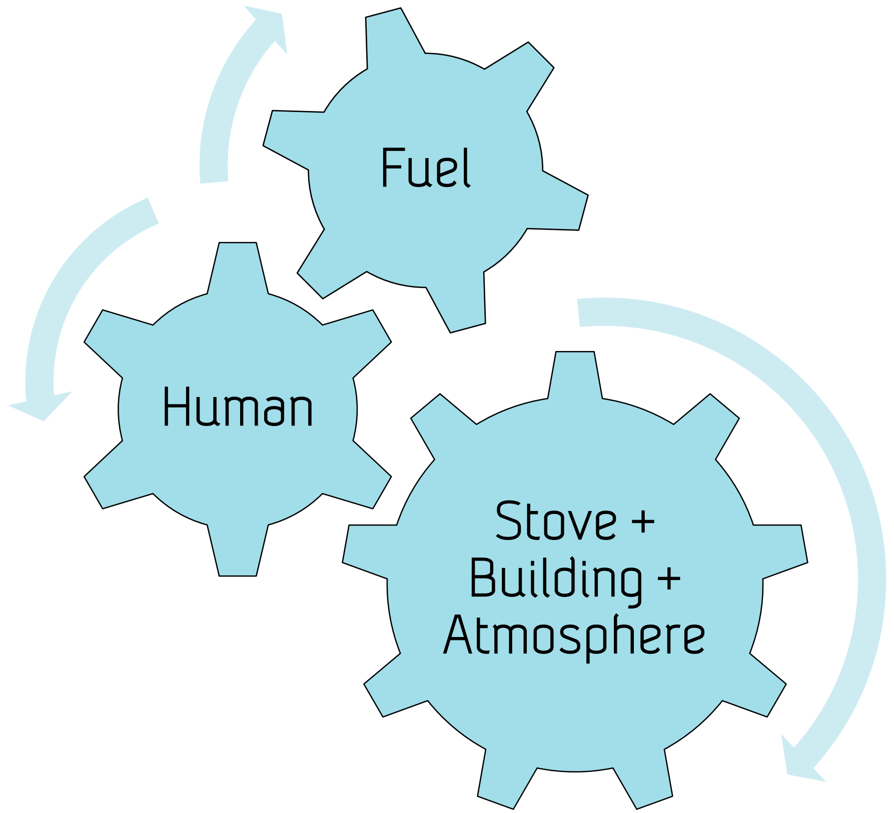
- High temperature
- Small volume flame
- Very good combustion
- Low radiation
- Not much "hygge"

- Much lower temperature
- Larger volume flame
- Poorer combustion
- High radiation
- "Hygge"

The ultimate wood stove

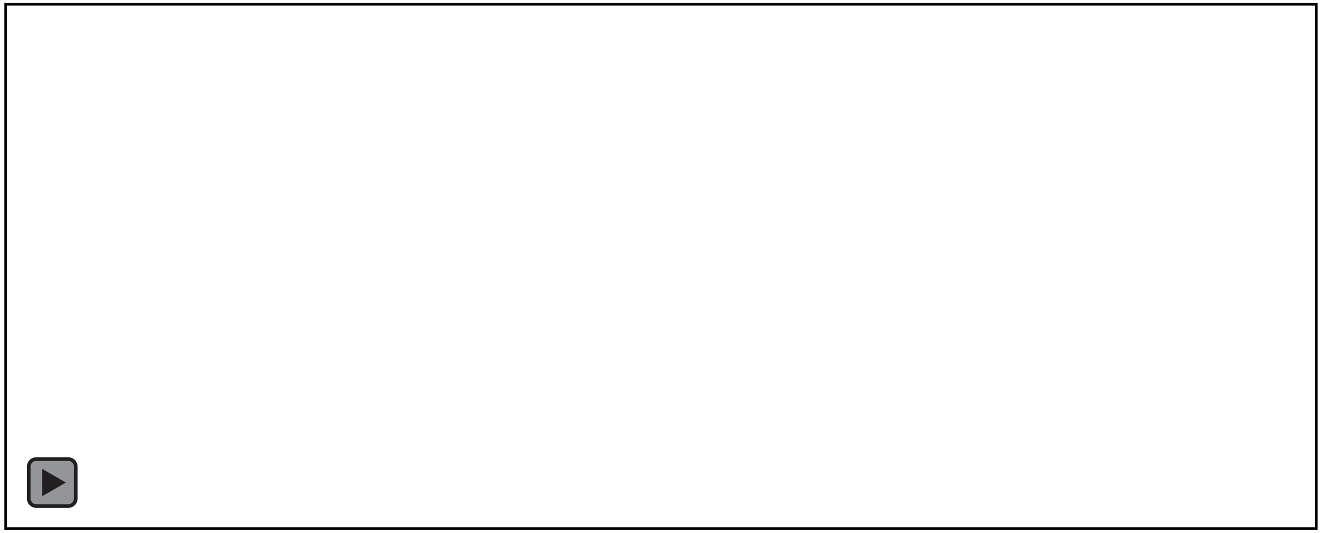
because it's not only about technology, and one technology does not serve all purposes

The ultimate wood stove



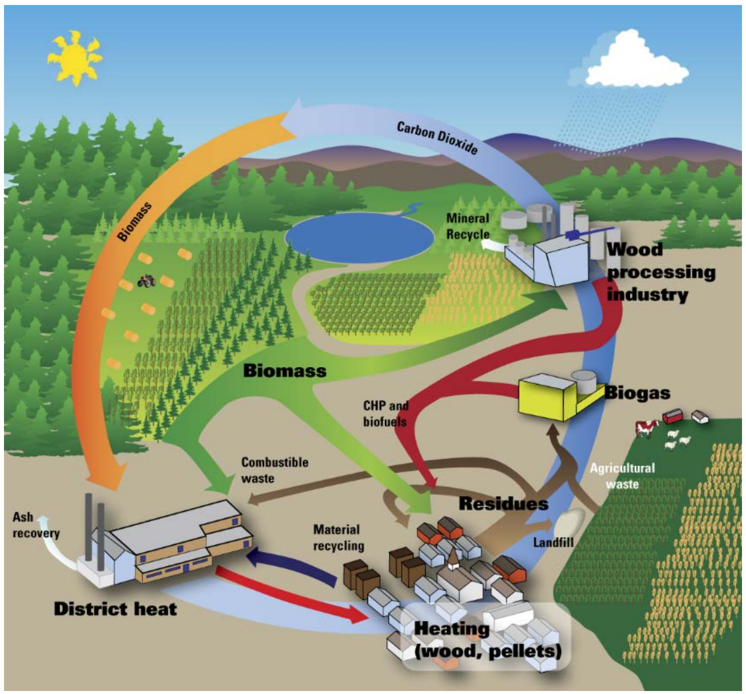
The ultimate wood stove

"Combustion of a batch of wood logs in a manually operated and controlled natural draft wood stove is the most complex combustion process there is."



The ultimate wood stove

In Norway, there has been and still is a large research momentum connected to wood stoves



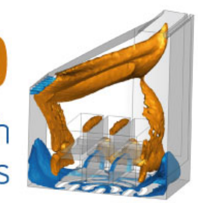
StableWood

New solutions and technologies for heating of buildings with low heating demand:
Stable heat release and distribution from batch combustion of wood

www.sintef.no/StableWood

WoodCFD

Clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches



AZEWS The One FME ZEB

The ultimate wood stove

The cooperation between CenBio, CenBio in-kind/spin-off projects and with links to other parallel running projects has been very valuable, and the efforts have been appreciated:

Edvard Karlsvik -

2011 Bioenergy innovation award (CenBio)

Morten Seljeskog –

2017 Årets ildsjel (Norsk Varme)

The ultimate wood stove

what 'we' want is
minimum emissions,
maximum energy efficiency,
maximum heat comfort
and 'hygge'
and not necessarily in that order...

The ultimate wood stove

to approach this there is
a need for continuous
research, development
and public education

Key aspects and challenges

- The fuel
  - Moisture content
  - Size, stacking
  - Changing composition during a combustion cycle
- The stove
  - Overall design, combustion chamber design
  - Air addition, and leakages
  - Operation, control
- The building
  - Heating demand
  - Chimney, draft
  - Ventilation system
- The operator
  - Operation according to recommendations
  - Ignition, refill

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

What is their influence on the transient solid fuel conversion and heat production?

- **Combustion temperatures**
- Heat transfer mechanisms
- Heat storage
- Insulation
- Air preheating
- Fuel load
- Fuel consumption rate
- Moisture content in fuel
- Design
- Materials
- Glass area and properties
- Heat exchanging

Optimisation by modelling and experiments

- Heat distribution
- Radiation shields
- Fuel type
- Fuel composition
- **Excess air ratios**
- **Residence times**
- Draught
- **Air staging**
- Air distribution
- Fuel feeding
- Fuel distribution
- Regulation

Stable heat production and release, emission reduction and efficiency increase - at low heat output

Wood firing in the old days

Wood firing today

Low-energy buildings and passive houses

The future

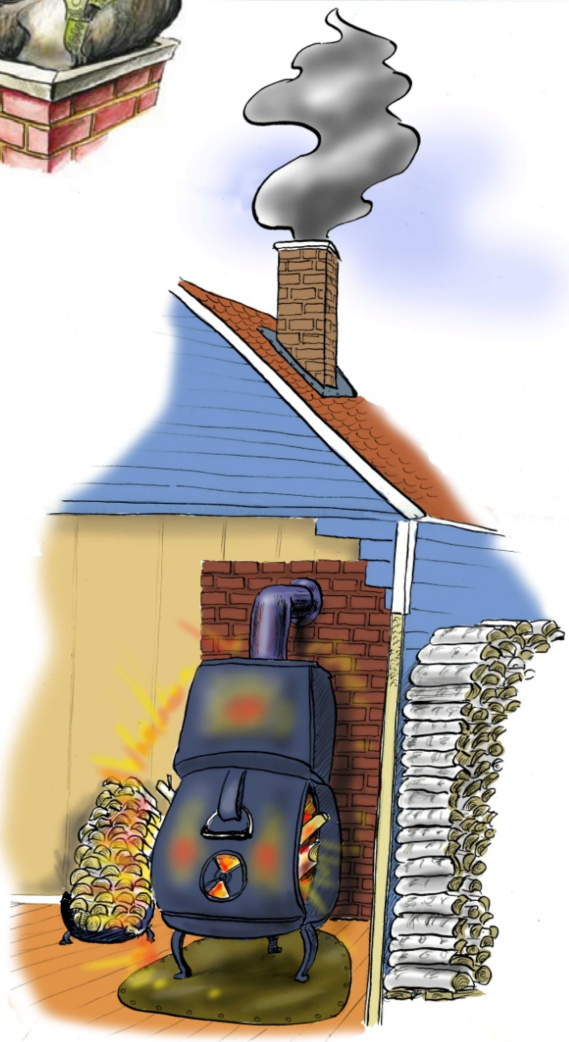
- Low-energy buildings have a lower annual heating demand than a standard building. E.g. the total annual energy demand for a low-energy building is less than 100 kWh/m^2 in Oslo, while a house built according to the current practice needs 170 kWh/m^2. Of this heating accounts for ca. **30 kWh/m^2** and 80 kWh/m^2, respectively
- The Passivhaus standard for central Europe requires that the building must be designed to have an annual heating demand as calculated with the Passivhaus Planning Package of not more than **15 kWh/m^2** per year in heating and 15 kWh/m^2 per year cooling energy OR to be designed with a peak heat load of 10 W/m^2

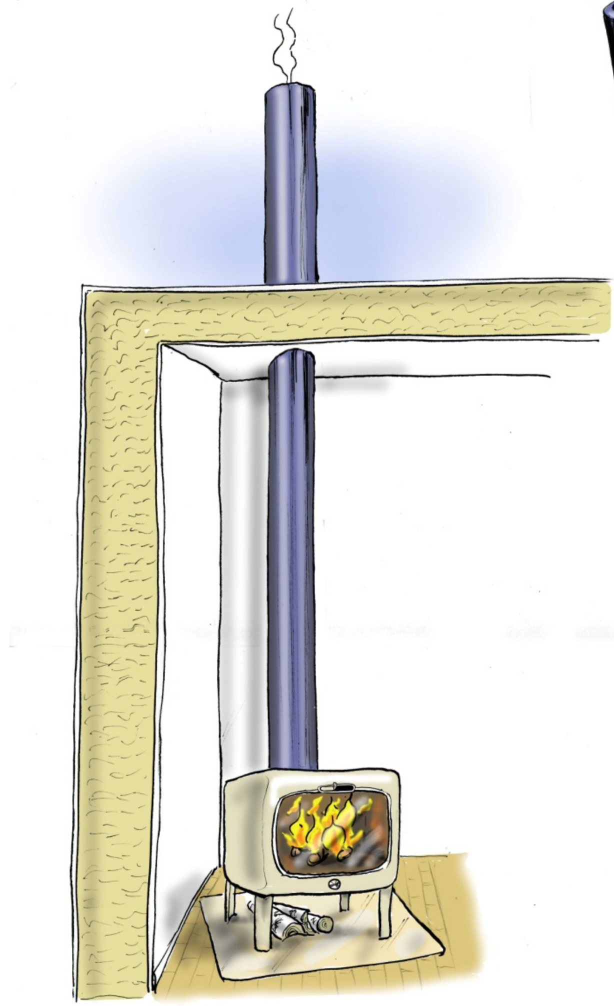
300-500 kWh/m^2 year

Less than 80 kWh/m^2 year **total** energy demand in a passive house (NS 3700), typically 60

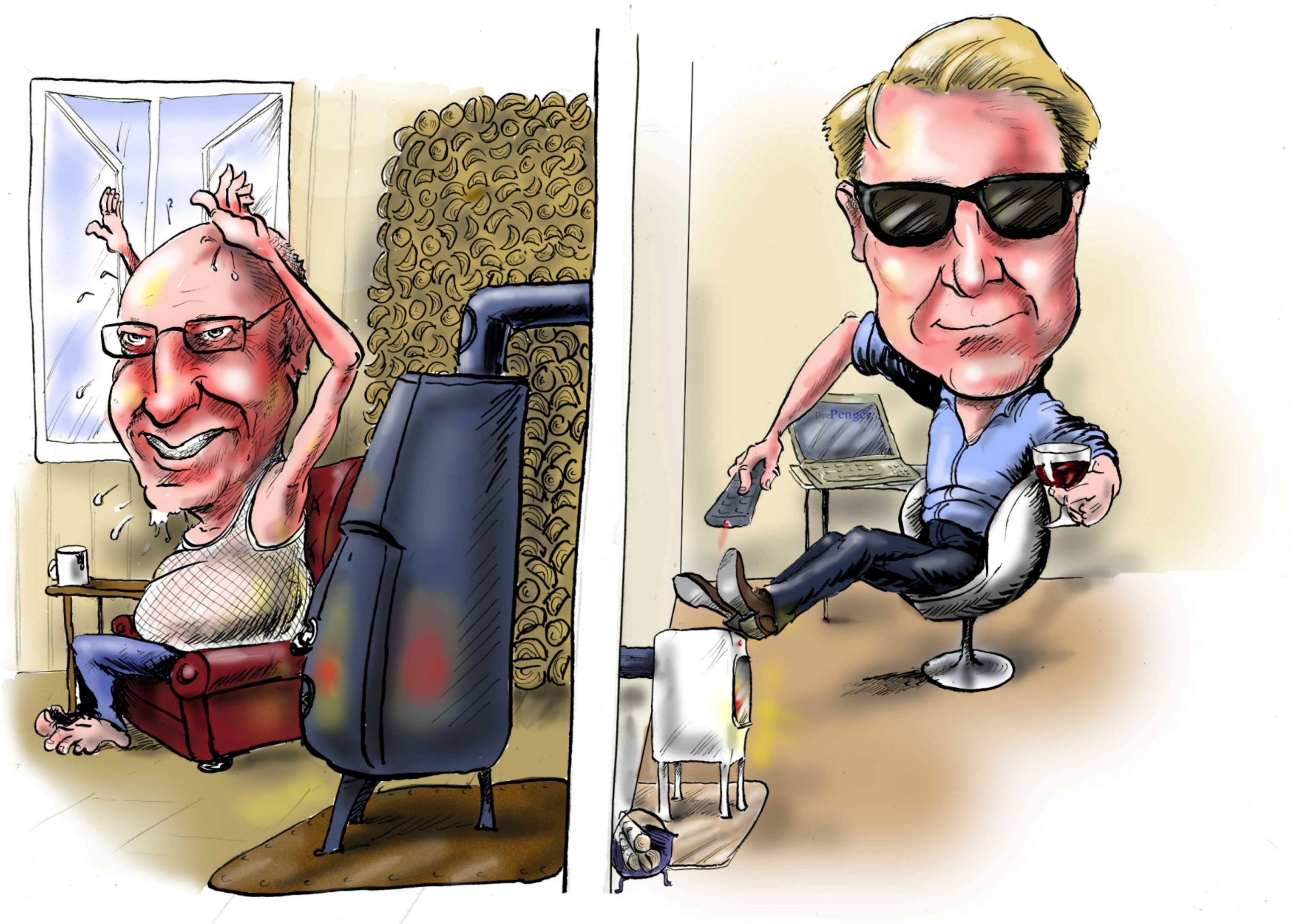
http://www.boligenok.no/teknisk-informasjon/passivhus/

Change in effect needed





Change in effect needed



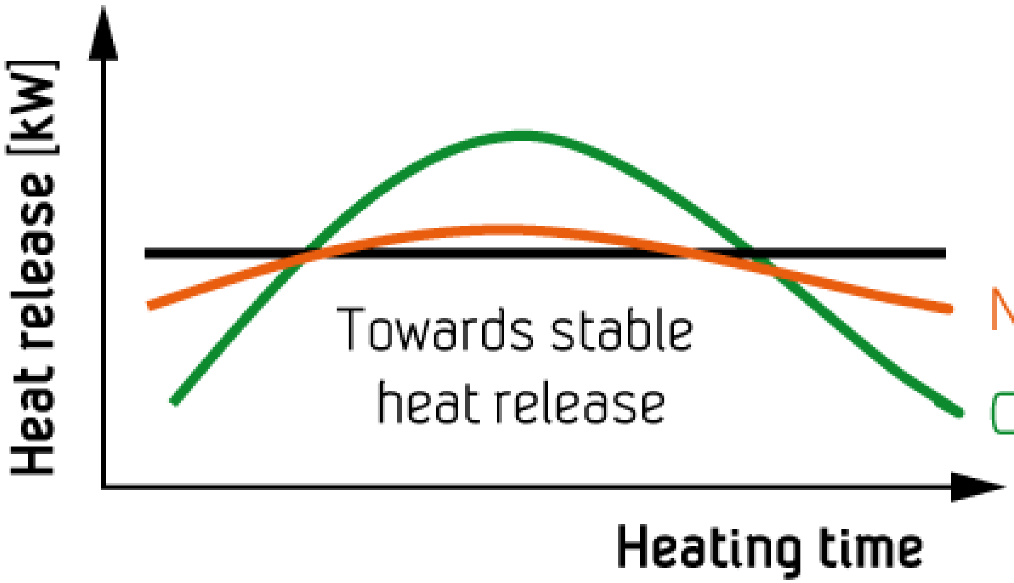
The future of wood firing in Norway

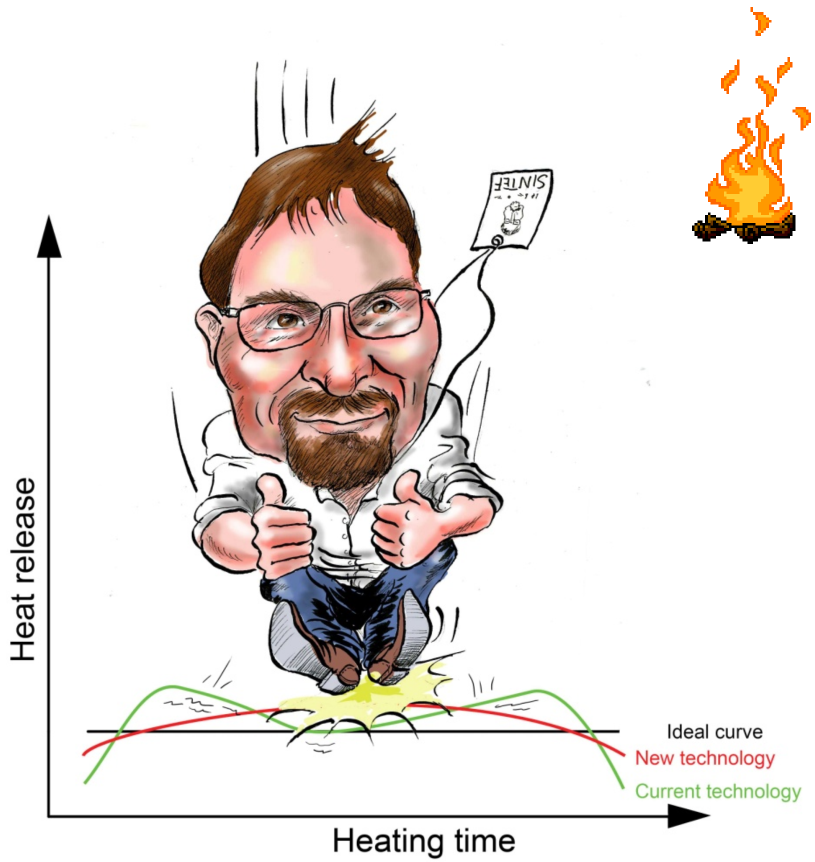
Old poorly insulated houses need a large effect, 10 – 15 kW

Houses built after regulations from 2000 need an effect of 3 – 8 kW

Well insulated houses of today need an effect of 1 – 6 kW

Towards stable heat release in wood stoves and fireplaces



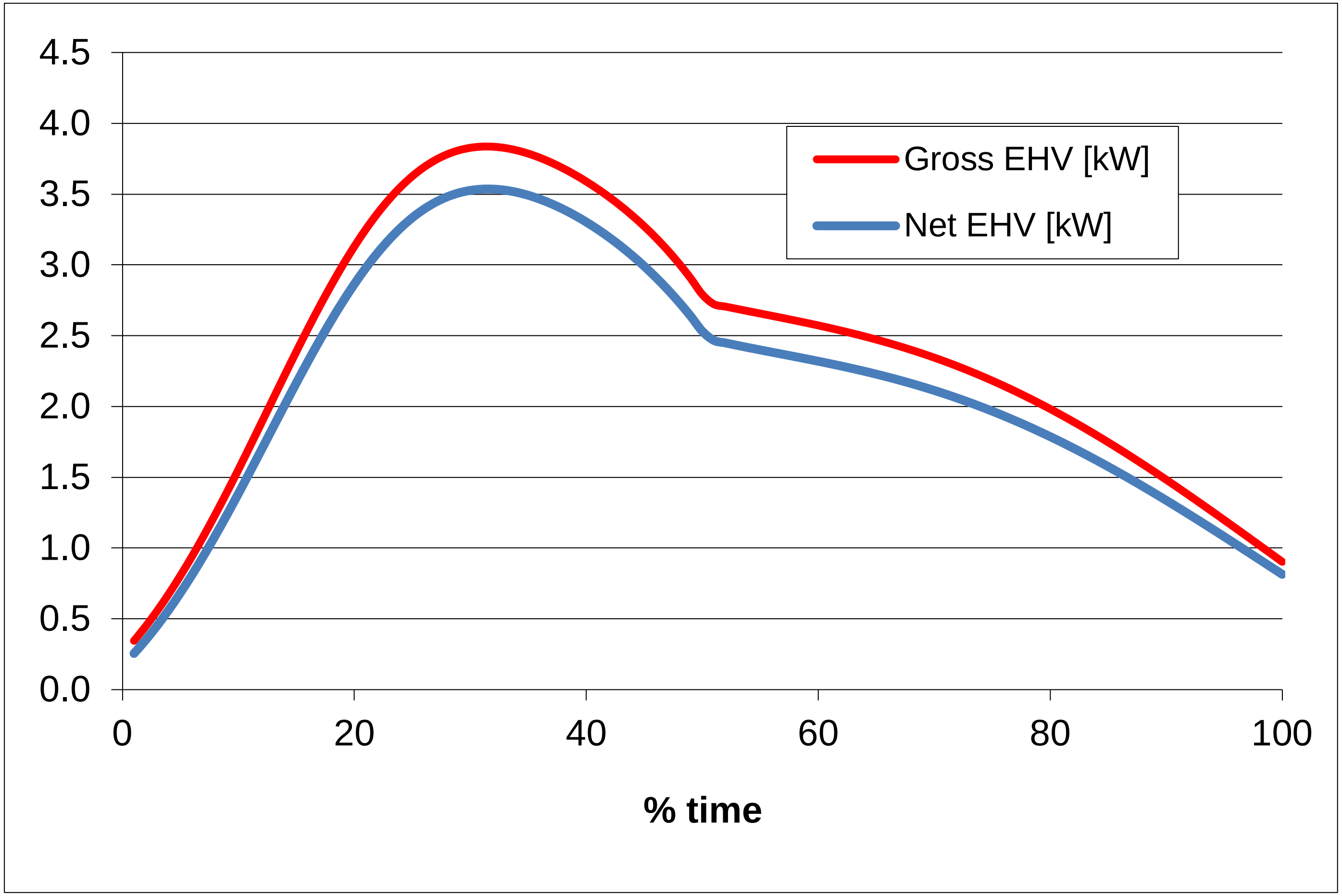


Research on down-scaled and low-load wood stoves

- A more continuous combustion process, including ignition principles - not activating all the wood at once
- A more constant heat release to a room/building - dampening the heat release peak to the room
- Reduced nominal effects - modern houses need less space heating, a fact
- Status quo or reduced total particle emission levels - increased emissions are not acceptable
- Black carbon emissions reduction - contributing to climate change, also from wood logs
- NOx emission reduction by optimized air staging - very possible in theory, challenging in practice
- Indoor air quality - preventing emissions into the room - balanced ventilation
- Increased efficiencies - very easy in principle, tougher in real life
- Transient modelling of wood log and wood stove combustion, including CFD modelling - stationary and transient - trial and error in the lab only works so far…
- Dynamics and thermal comfort of wood stoves in low-energy buildings, including CFD modelling - the influence of the transient heat release from a wood stove on your heat comfort
- Experimental verification of modelling work - because modelling is "just" a helpful tool
- Design solutions reducing possibilities for wrong operation - because people are not so good at it as they like to believe
- + User education - years of (mal)practice does not make you an expert

Improved combustion process control

This transient heat production profile is not beneficial!

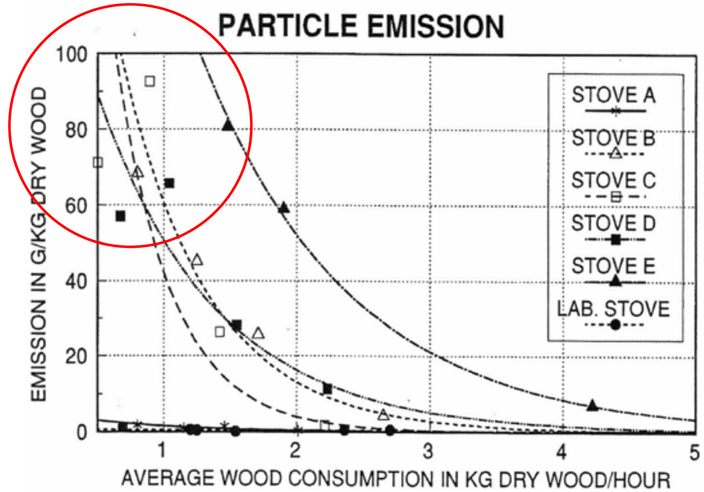


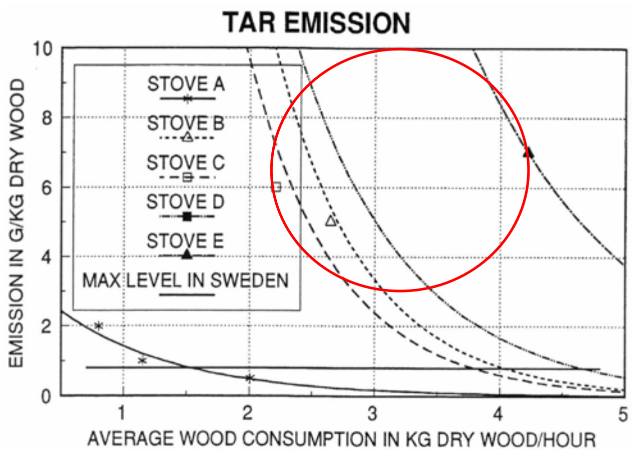
Improved combustion process control

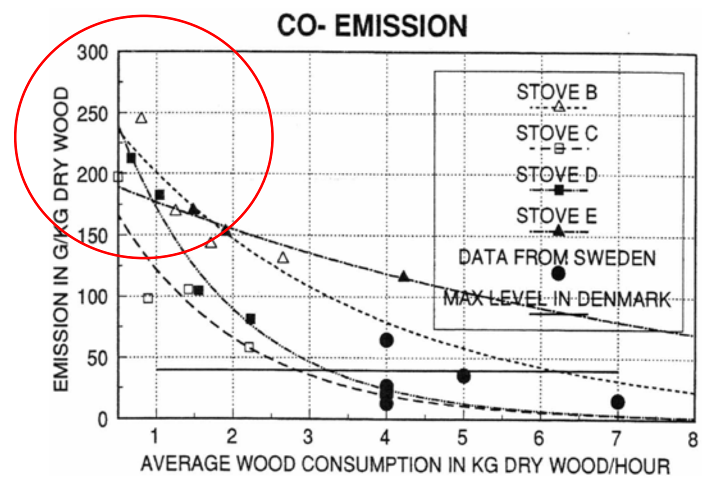
Emission control

Not so long ago...,
and in fact still happening today

Emissions increase with lower average wood consumption - part load operation





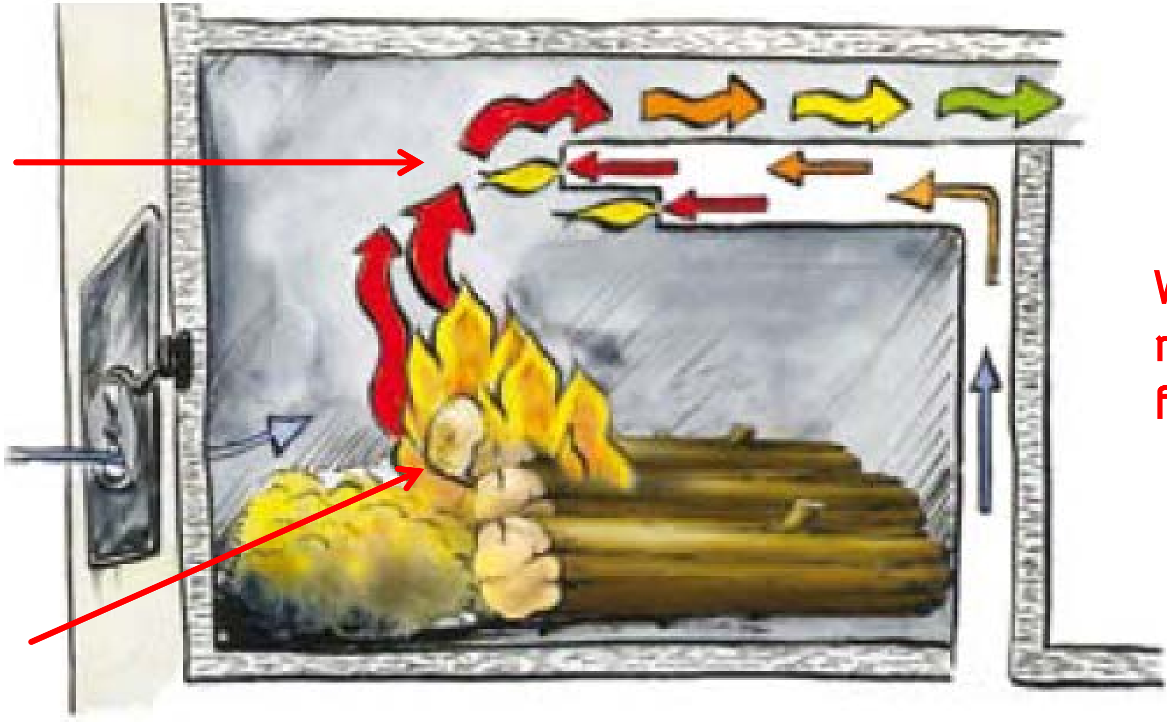


Improved combustion process control

Emission control

The revolution

High intensity gas phase combustion (even blue flames)



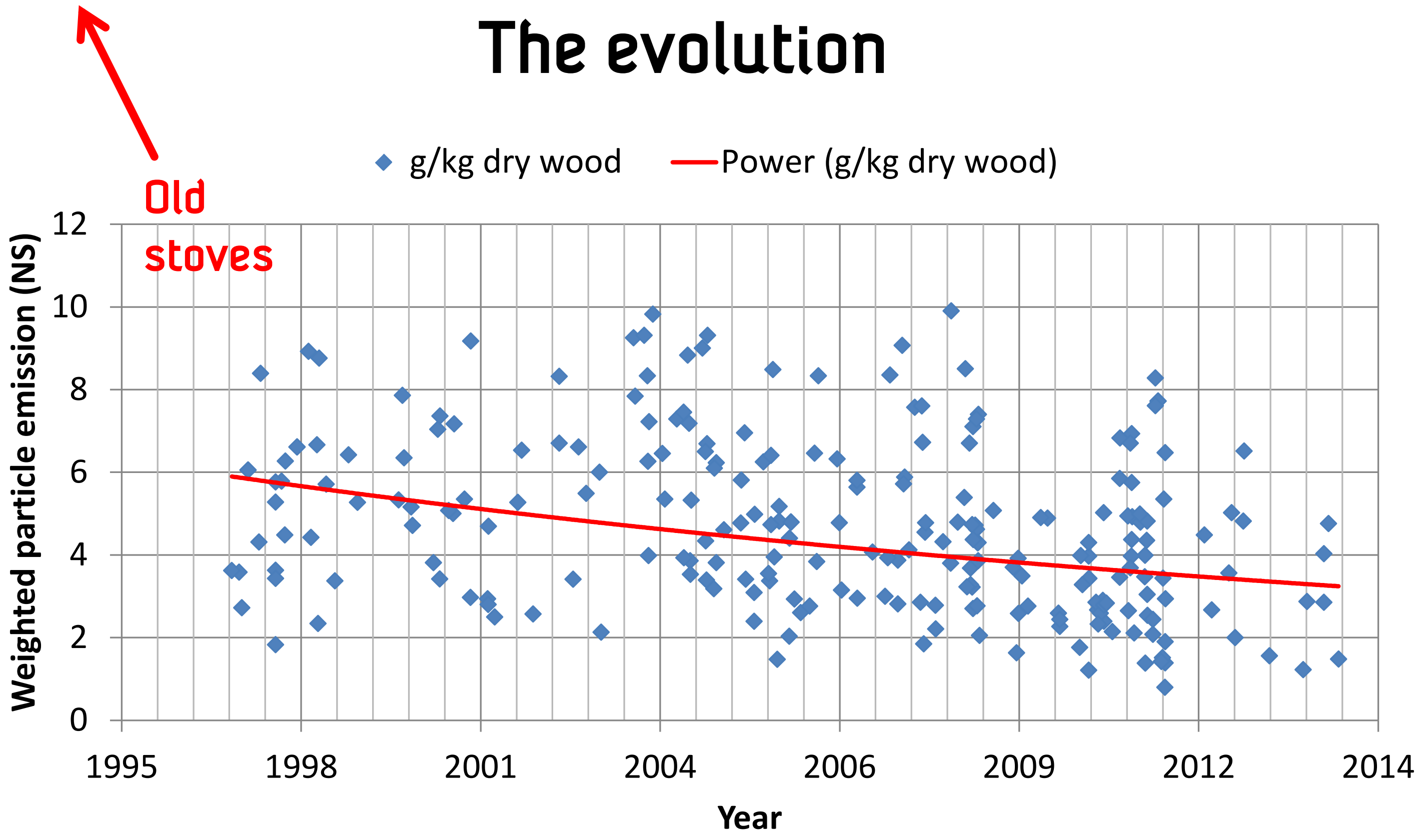
Controlled release of volatiles

Wood is not really a solid fuel!

+ insulated combustion chambers

Improved combustion process control

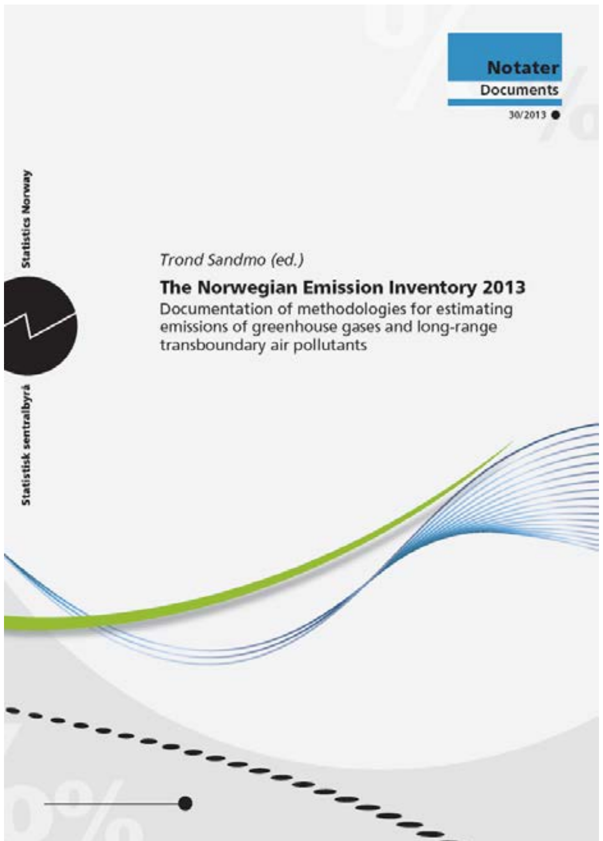
Emission control



Weighted particle emission levels as a function of year or development degree

Improved combustion process control

Emission control



	Emission inventory 2013			
	Fuel wood	Wood pellets	Charcoal	
PM10	17.43	1.1	2.4	g/kg
CO	101.2	2.6	100	g/kg
SO2	0.2			g/kg
NOx	0.986	1.1	1.4	g/kg
N2O	0.032	0.032	0.04	g/kg
CH4	5.3	5.3	8.4	g/kg
NMVOC	7	6.501	10	g/kg
Cd	0.1			g/tonn
PAH-total	25.41	38.8	39.9	g/tonn
PAH-6 (OSPAR)	4.13	6.8	18	g/tonn
PAH-4 (LRTAP)	1.42	2.5	2.6	g/tonn
NH3	0.066	0.066		g/kg
PM2.5	16.89	1.1	2.4	g/kg
TSP	17.78	1.1	2.4	g/kg
Dioxins	5.9	5.9	10	µg/tonn
Pb	0.05			g/tonn
Hg	0.010244			g/tonn
As	0.159			g/tonn
Cr	0.152			g/tonn
Cu	0.354			g/tonn

Wood logs are very far from the ideal fuel - **large particles** combined with **batch combustion** makes a challenging starting point

Fireplace, old and new stove
PM: Also night firing and only day firing

5

CenBio Bioenergy Innovation Centre

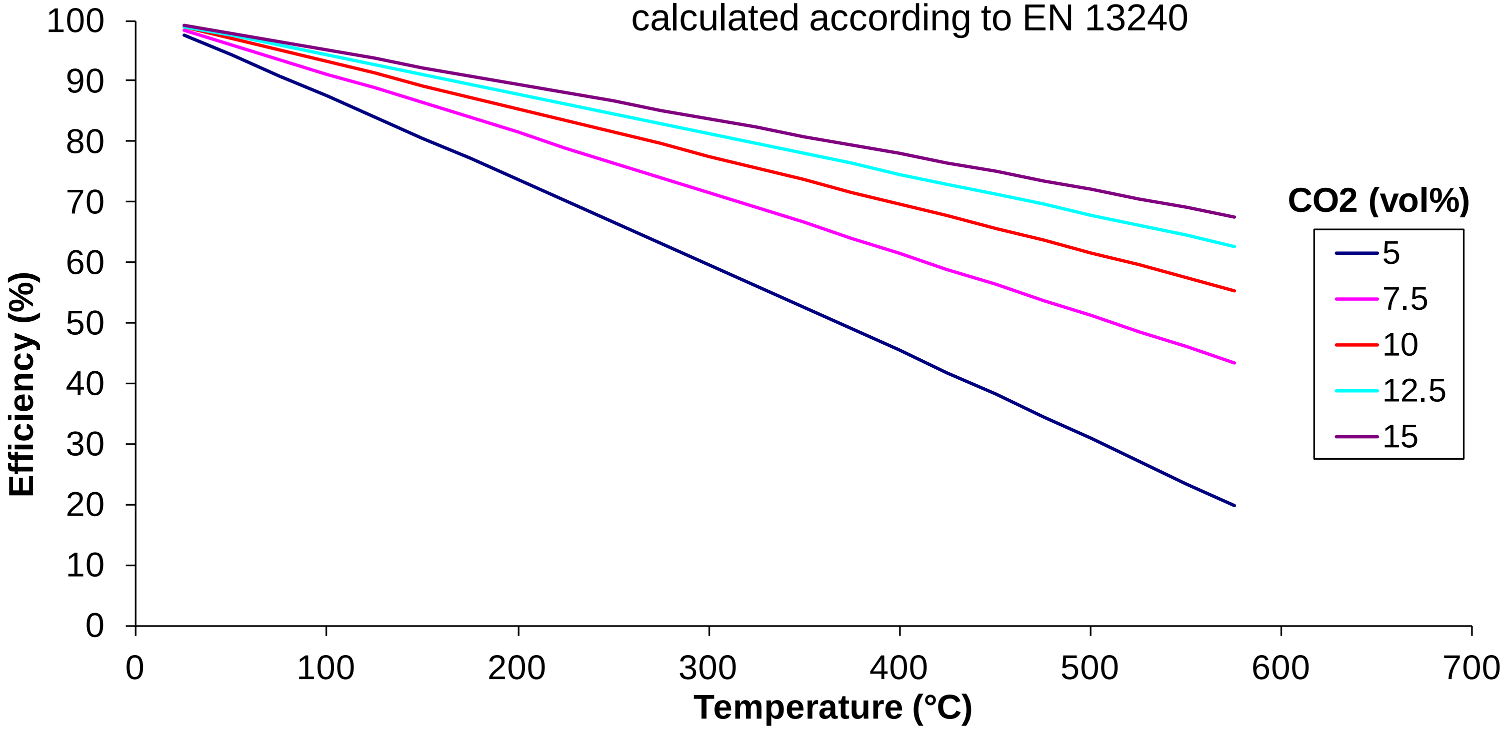
ıat about black carbon (BC)?

Improved combustion process control

Energetic performance

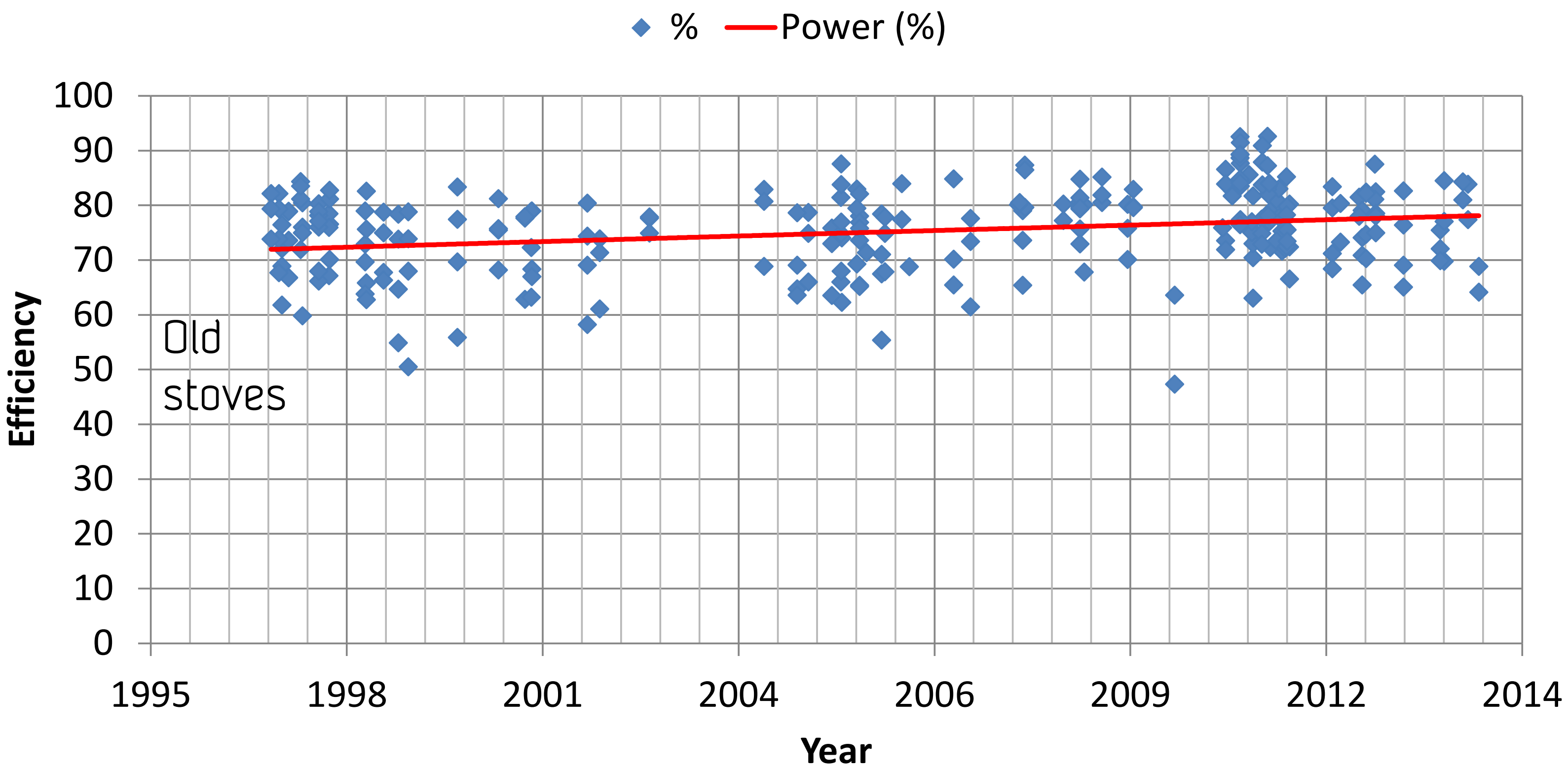
- **Chimney inlet temperature**
- **Excess air ratio**
- Moisture content

Stove thermal efficiency as a function of chimney inlet temperature and vol% CO_2 in dry flue gas, calculated according to EN 13240



Improved combustion process control

Energetic performance



Stove efficiency as a function of year or development degree

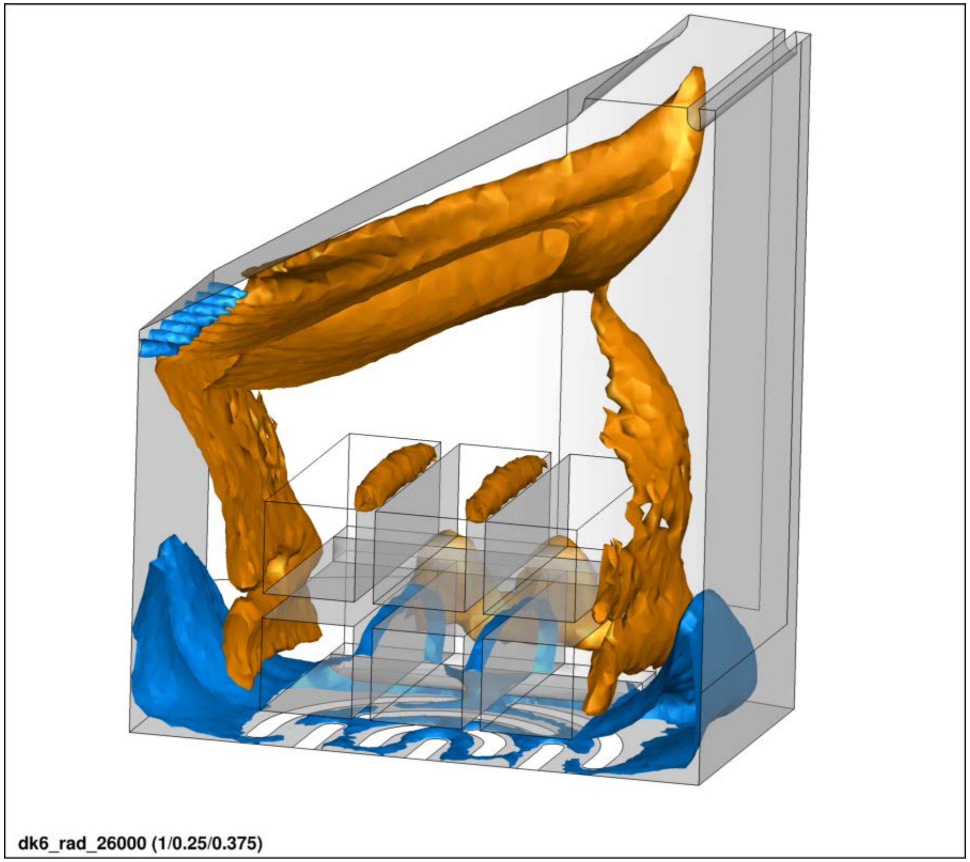
Use of heat storage materials (incl. phase change materials)

- Thermal inertia - increased heat storage capacity
- Phase change materials - much higher heat storage capacity, and heat uptake and release at a constant temperature

- Challenges:
  - Efficient heat transfer to and distribution in the PCM
  - Proper PCM positioning and dimensioning
  - Avoiding PCM overheating and permanent degradation
    - **Must be possible to reduce the heat transfer if danger of overheating**

Wood stove modelling

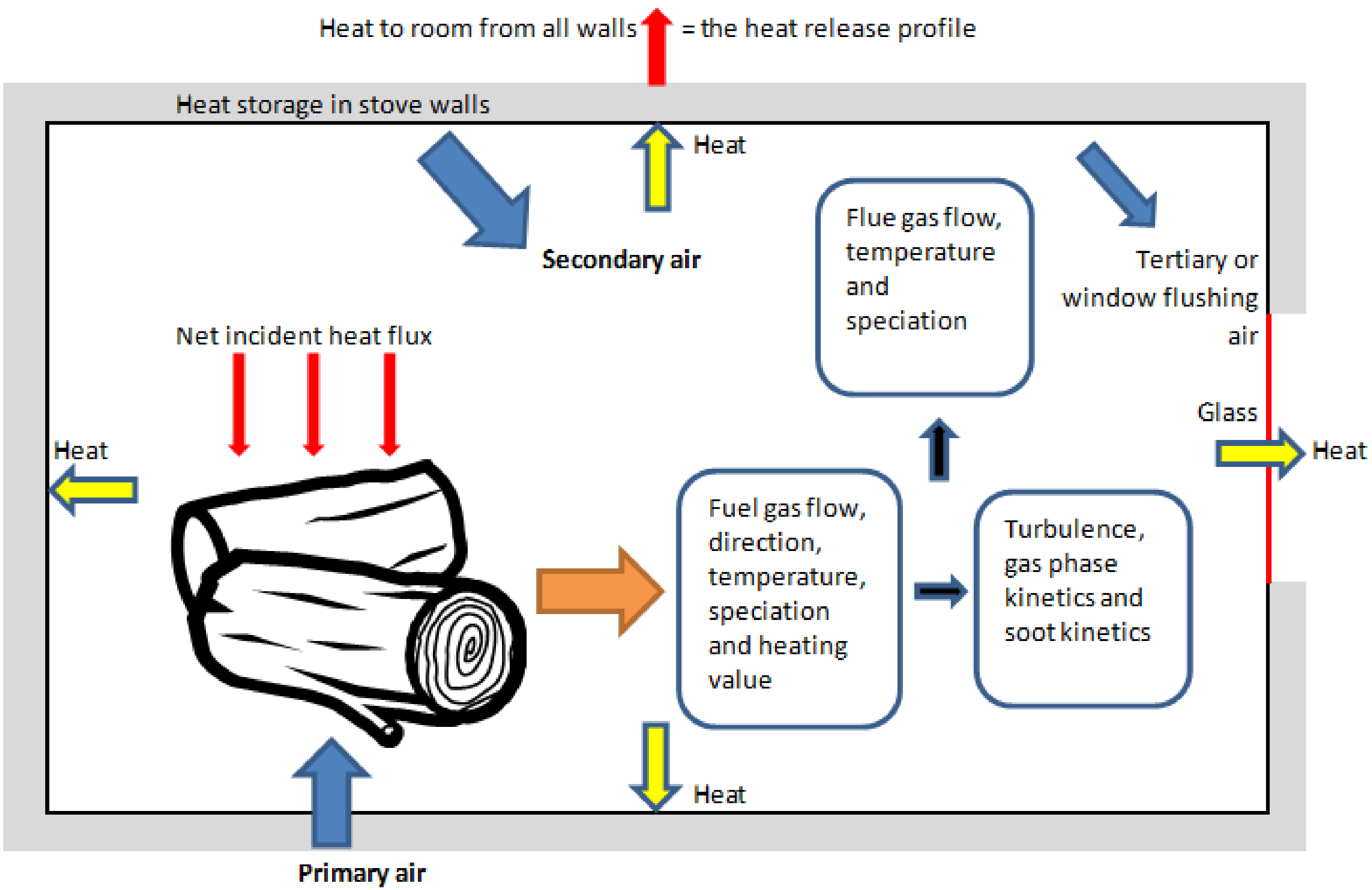
Computational fluid dynamics - CFD



- Symmetry boundary
- kε - realizable turbulence model
- Radiation: Discrete ordinates method
- Soot: Moss & Brookes model
- EDC-model with finite rate chemistry
- 3 different chemical reaction mechanisms developed for biomass combustion (Løvås et al. 2013)
  - **81 species**
  - **49 species**
  - **36 species**

Wood stove modelling

CFD + sub models



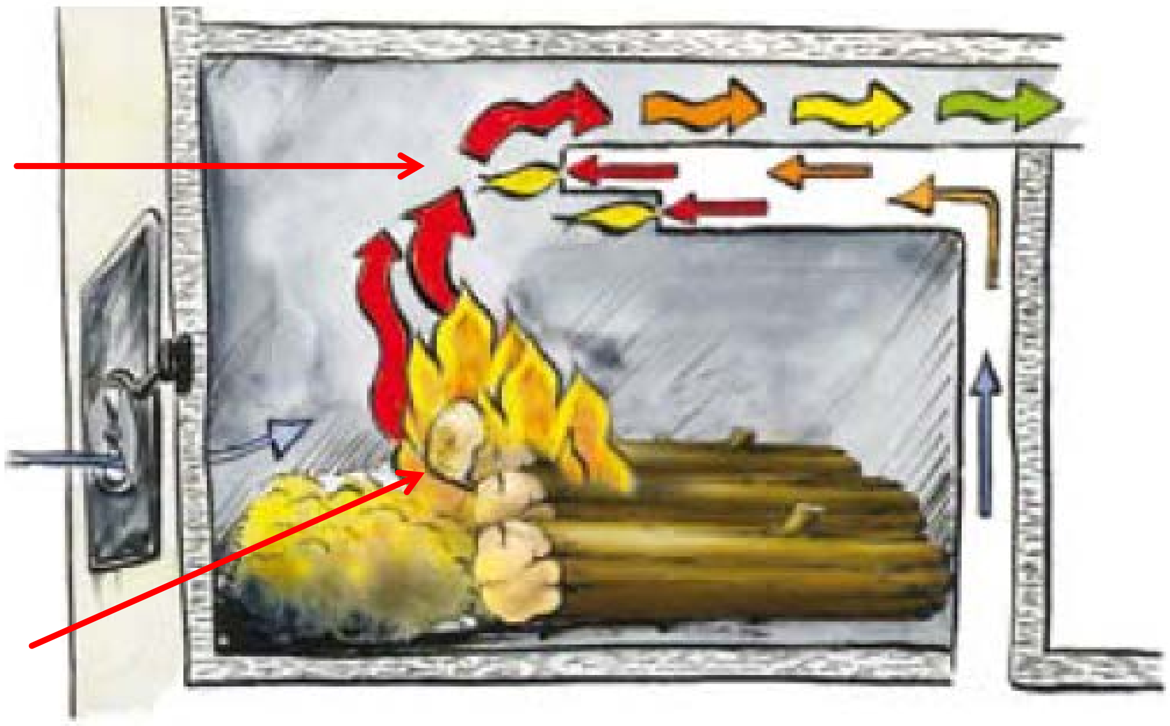
The ultimate wood stove

Emissions:
Optimum/maximum gas phase combustion: time, temperature and turbulence
Air addition control and preheating, leakage control
Crack the tars (forming OC) and burn out the soot (BC) and CO
Keep the temperature high and control the excess air in the char combustion phase
Keep flames away from walls and cold zones

High intensity gas phase combustion (**even blue flames**)

Health: IAQ

Controlled release of volatiles



Efficiency:
Heat transfer
Low excess air

Advanced control system

Catalytic converter

ESP

Chimney fan

Minimum user influence

+ insulated combustion chambers

Heat comfort: smaller stoves, heat storage, ignition from the top

The way forward

Experiments

+

simulations

+

time, and patience

StableWood

New solutions and technologies for heating of buildings with low heating demand:
Stable heat release and distribution from batch combustion of wood

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Publications

This section will contain information about material published by StableWood.

StableWood handbook

- Newsletter 2-2014
- Newsletter 1-2014
- Newsletter 2-2013
- Newsletter 1-2013
- Newsletter 2-2012
- Newsletter 1-2012
- Newsletter 2-2011
- Newsletter 1-2011

Øyvind Skreiberg, Morten Seljeskog, Laurent Georges (2015). Solutions and technologies for wood stoves in future's energy efficient residential buildings. Oral presentation at 23rd European Biomass Conference and Exhibition, 1-4 June 2015, Vienna, Austria. (Co-presentation with ZEB).

Mette Bugge, Øyvind Skreiberg, Nils E. L. Haugen, Per Carlsson, Morten Seljeskog (2015). Predicting NOx emissions from wood stoves using detailed chemistry and computational fluid dynamics. Energy Procedia 75(August):1740-1745.

Øyvind Skreiberg, Morten Seljeskog, Laurent Georges (2015). The process of batch combustion of logs in wood stoves – Transient modelling for generation of input to CFD modelling of stoves and thermal comfort simulations. Chemical Engineering Transactions 43:433-438. (Co-publication with ZEB).

Merethe Ruud, Øyvind Skreiberg (2015). Hvordan oppnår du optimal trekk og riktig fyring i vedovnen? TU.no. Reprodusert på Gemini.no.

Øyvind Skreiberg, Laurent Georges, Morten Seljeskog (2015). Bioenergy and buildings. Pan European Networks Government 13, February 2015, pp. 96-97. (Co-publication with ZEB).

Mario Ditaranto, Morten Seljeskog, Øyvind Skreiberg (2015). Hyttetur og klimakur. Dagens Næringsliv, 13. februar 2015. Reprodusert på Gemini.no.

Laurent Georges, Øyvind Skreiberg (2014). Modeling of the Indoor Thermal Comfort in Passive Houses heated by Wood Stoves. Proceedings of System Simulation in Buildings 2014 (SSB2014), 10-12 December, Liege, Belgium. (Co-publication with ZEB).

Lars Martin Hjorthol, Øyvind Skreiberg (2014). Peiskos på sparebluss. Gemini.no.

Ricardo Luís Teles de Carvalho, Ole M. Jensen, Morten Seljeskog, Øyvind Skreiberg, Laurent Georges, Franziska Goile (2014). Proper indoor climate by the adoption of advanced wood-burning stoves? Proceedings of ROOMVENT 2014, 19-22 October 2014, Sao Paulo, Brazil, pp. 66-73.

Øyvind Skreiberg (2014). Biofuels of the future, and modelling implications. Keynote presentation at the 1st International Workshop on CFD and Biomass Thermochemical Conversion, 30th September, 2014, DBFZ, Leipzig, Germany. (Co-presentation with CenBio).

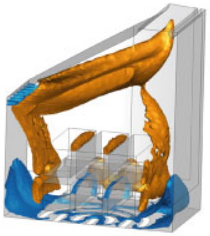
Mette Bugge, Nils E. L. Haugen, Øyvind Skreiberg, Morten Seljeskog (2014). CFD modelling of NOx emissions from wood stoves. 1st International Workshop on CFD and Biomass Thermochemical Conversion, 30th September, 2014, DBFZ, Leipzig, Germany, pp. 51-56.

Morten Seljeskog, Øyvind Skreiberg (2014). Batch combustion of logs in wood stoves – Transient fuel models and modelling of the fuel decomposition and products composition as input to CFD gas phase calculations. 1st International Workshop on CFD and Biomass Thermochemical Conversion, 30th September, 2014, DBFZ, Leipzig, Germany, pp. 39-44.

http://www.sintef.no/stablewood

WoodCFD

Clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches



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Publications

WoodCFD publications:

- Newsletter 2-2016
- Newsletter 1-2016
- Newsletter 2-2015
- Newsletter 1-2015

Mette Bugge, Nils E. L. Haugen, Øyvind Skreiberg. Transient CFD simulations of wood log combustion in a wood stove. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

Inge Haberle, Øyvind Skreiberg, Nils Erland L. Haugen. Numerical simulation of devolatilization of wood logs and pressure generation in the wood log center. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

Alexis Sevault, Roger Khalil, Bjørn Christian Enger, Øyvind Skreiberg, Franziska Goile, Liang Wang, Morten Seljeskog, Rajesh Kempegowda. Performance evaluation of a modern wood stove when using charcoal. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

A. Cablé, L. Georges, P. Peigné, Ø. Skreiberg, K. Chetehouna. Coupled ventilation system and wood logs-stove for use in low energy dwellings: an investigation using dynamic energy simulations. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

Thalfeldt M., Georges L., Skreiberg Ø. Measurement of plumes created by wood stoves. Accepted for presentation at Healthy Buildings Europe 2017, 2-5 July 2017, Lublin, Poland.

Morten Seljeskog, Alexis Sevault, Asbjørn Østnor, Øyvind Skreiberg. Variables affecting emission measurements from domestic wood combustion. Accepted for publication in Energy Procedia.

Morten Seljeskog, Franziska Goile, Øyvind Skreiberg. Recommended revisions of Norwegian emission factors for wood stoves. Accepted for publication in Energy Procedia.

Øivind Lie, Simen Gjølsjø, Øyvind Skreiberg (2017). Maks varme av veden. Hytteliv 1/2017:46-48.

Kolbeinn Kristjansson, Erling Næss, Øyvind Skreiberg (2016). Dampening of wood batch combustion heat release using a phase change material heat storage: Material selection and heat storage property optimization. Energy 115:378-385.

Jacob Hadler-Jacobsen (2016). A model for pyrolysis of thermally thick wood particles. SINTEF Summer Job Project report. Supervisors: Nils Erland L. Haugen, Øyvind Skreiberg

Eivin Dyvik Sellevold (2016). Modeling of indoor environment of building heated using wood stoves. NTNU Master thesis. Main supervisor: Laurent Georges, Co-supervisor: Øyvind Skreiberg

Guangyu Cao, Laurent Georges, Øyvind Skreiberg, Morten Seljeskog (2016). An experimental study on how a wood stove affects the indoor air quality when used as the main source of heating in two representative Norwegian dwellings, one modern and one old. Indoor Air 2016, 3-8 July 2016, Ghent, Belgium.

Morten Seljeskog, Alexis Sevault, Birger Rønning, Magnus Rishaug, Asbjørn Østnor, Øyvind Skreiberg (2016). Variables affecting particulate emissions from residential wood combustion – simultaneous

http://www.sintef.no/woodcfd

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Thank you for your attention!

The Research Council of Norway

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