Transient CFD simulation of wood log stoves with heat storage devices

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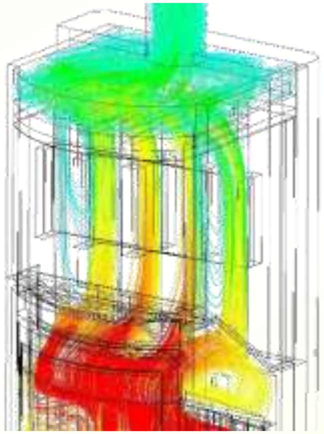

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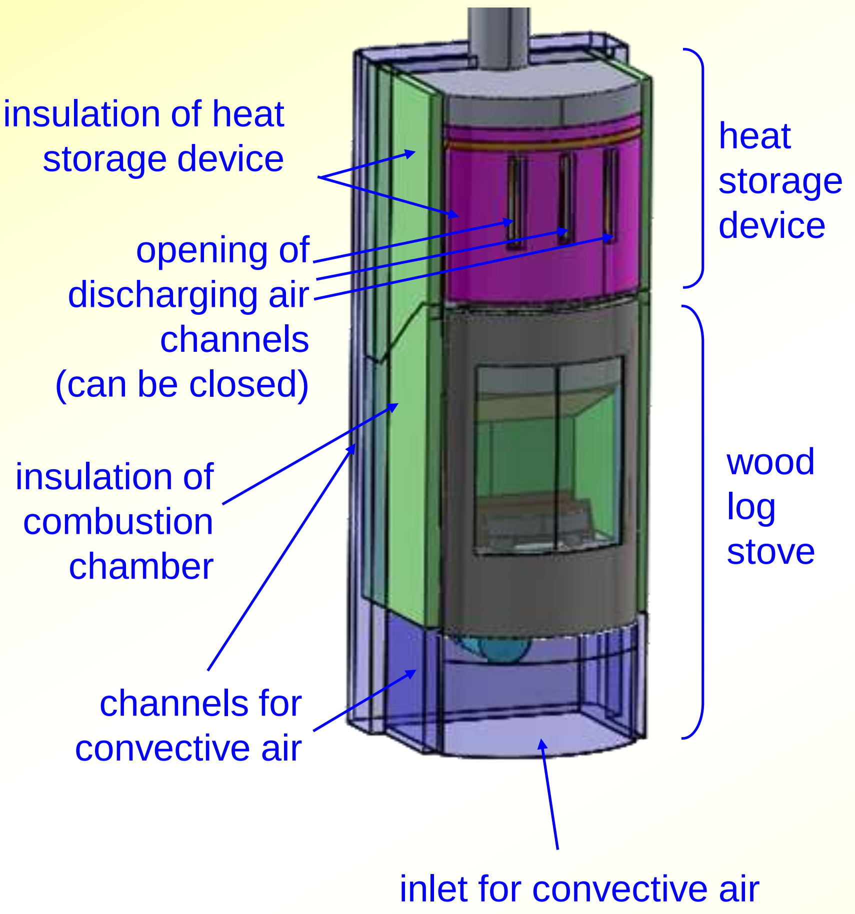
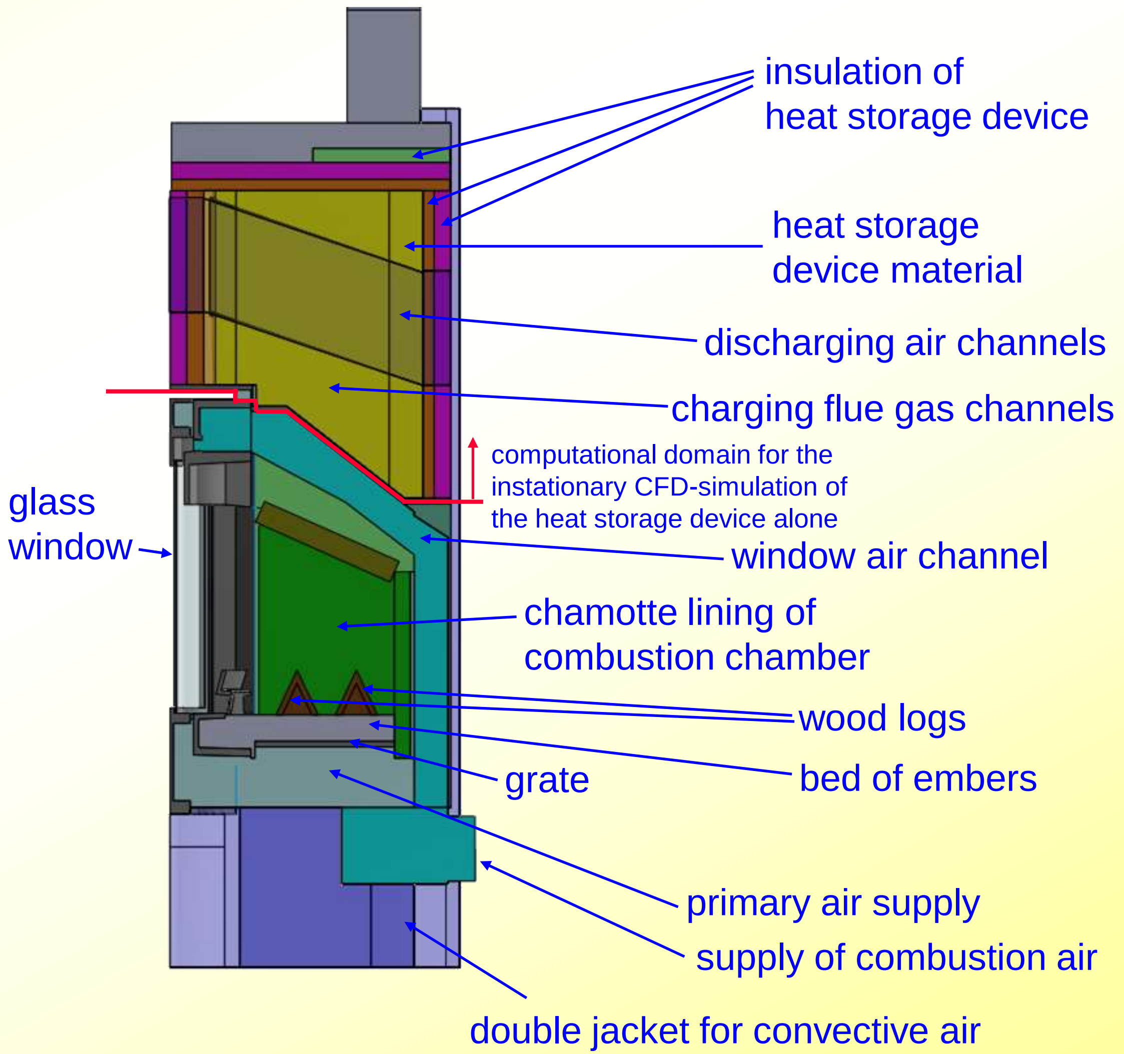
Scope of work

- Development of a CFD based methodology for the analysis and optimisation of wood log fired stoves and heat storage devices
- CFD aided development and optimisation of a wood log fired stove with heat storage device by applying the newly developed CFD methodology:
  - Stationary simulation of wood log stove and heat storage device for the basic evaluation and derivation of boundary conditions for transient CFD calculations
  - Transient simulation of the basic variant of the stove and the heat storage device
  - Transient simulation of the basic variant of the heat storage device alone
  - Parameter study with regard to the heat storage device geometry and the storage material properties (transient simulations of the heat storage device alone)

Scheme of stove and heat storage device geometry





Operating case and applied framework conditions

- **Nominal stove capacity: 10 kW**
- **fuel: 2 hard wood logs 33 cm long/ 2.77 kg per batch**
- **CFD simulations done with a steady-state operating case (at ~63% of batch time)**
- **Used also for transient simulations**

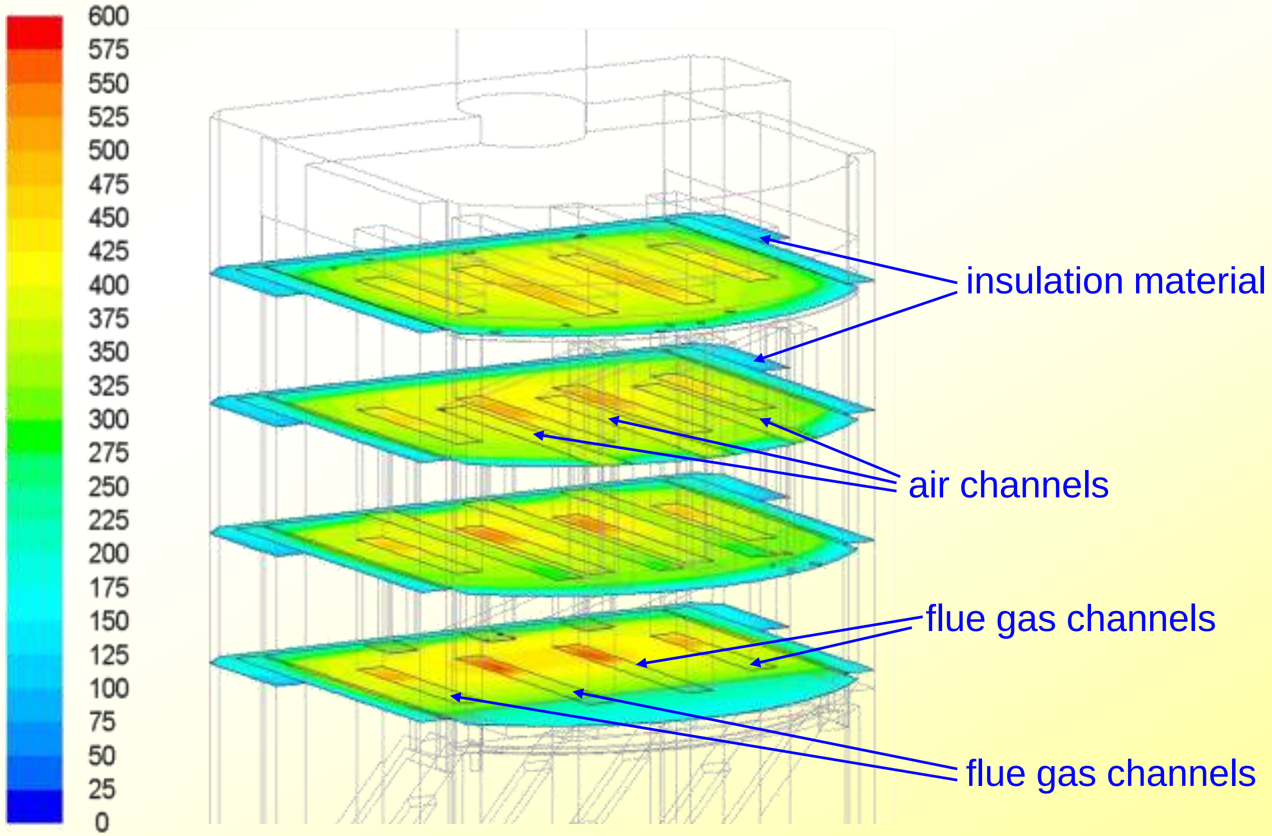
parameter	unit	
water	wt% w.b. ash-free	8.1
C	wt% d.b. ash-free	42.7
H	wt% d.b. ash-free	6.8
O	wt% d.b. ash-free	50.1
N	wt% d.b. ash-free	0.4
gross calorific value (GCV)	MJ/kg d.b.	17.7
net calorific value (NCV)	MJ/kg w.b.	14.7
fuel power related to NCV	kW	10.3
flue gas in combustion chamber - total	kg/h	26.34
flue gas released from fuel	kg/h	2.51
mass flow of air	kg/h	23.83
total air ratio	[ ]	2.03
O_2 fraction at stove outlet, dry	vol% d.b.	10.7

Model overview

- **Combustion of wood logs** — **Empirical wood log combustion model (in-house code)**
- **Turbulence** — **Realizable k-ε Model**
- **Gas phase combustion** — **Eddy Dissipation Model (A_{mag} = 0.8, B_{mag} = 0.5) / global methane 3-step mechanism (CH_4, CO, CO_2, H_2, H_2O und O_2) + additional reaction step for wood volatiles**
- **Radiation** — **Discrete Ordinates Model**
- **Shell conduction model** — **Heat transport in metal sheets**

Stationary simulation of wood log stove and heat storage device (1)

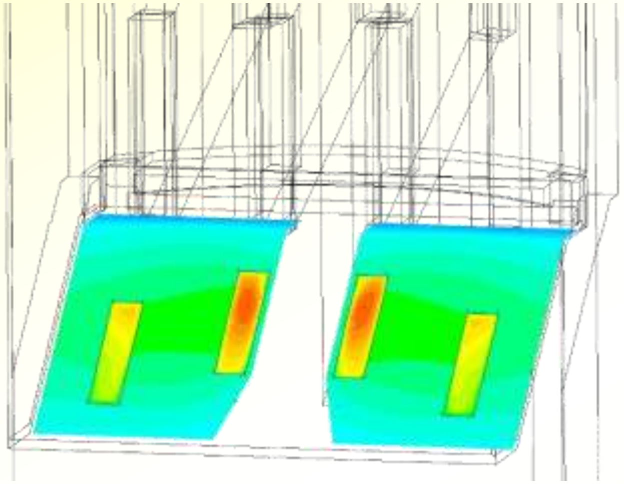
➢ Characterisation of basic variant of wood log stove and heat storage device



Pathlines of combustion air and flue gas coloured by oxygen concentration [m³ O_2/m³ wet flue gas] – side view (left); iso-surfaces of flue gas, air and material temperatures in the heat storage device (right)

Stationary simulation of wood log stove and heat storage device (2)

- **Derivation of the boundary conditions for transient simulations of the storage device alone**
  - **average temperatures at the bottom of the storage device**
  - **mass fluxes and temperatures of the flue gas at the entrance to the charging channels**



Iso-surfaces of the flue gas and material temperatures [°C] at the entrance to the storage device

		Bottom of storage device	Flue gas channel left	Flue gas channel center-left	Flue gas channel center-right	Flue gas channel right
parameter	unit					
mass flow of flue gas	g/s	-	1.58	2.08	2.08	1.57
mean temperature	°C	388	512	574	574	511

Transient simulation of wood log stove and heat storage device (1)

Operating mode of heat storage device (24 hour cycle):

- Heating of wood log fired stove in a batch mode in order to charge the heat storage device (duration: 5 h, approximately 5 batches)
- Heat storage/standstill (duration: 10 h/over night)
- Discharge of heat storage via natural convection (duration: 9 h)

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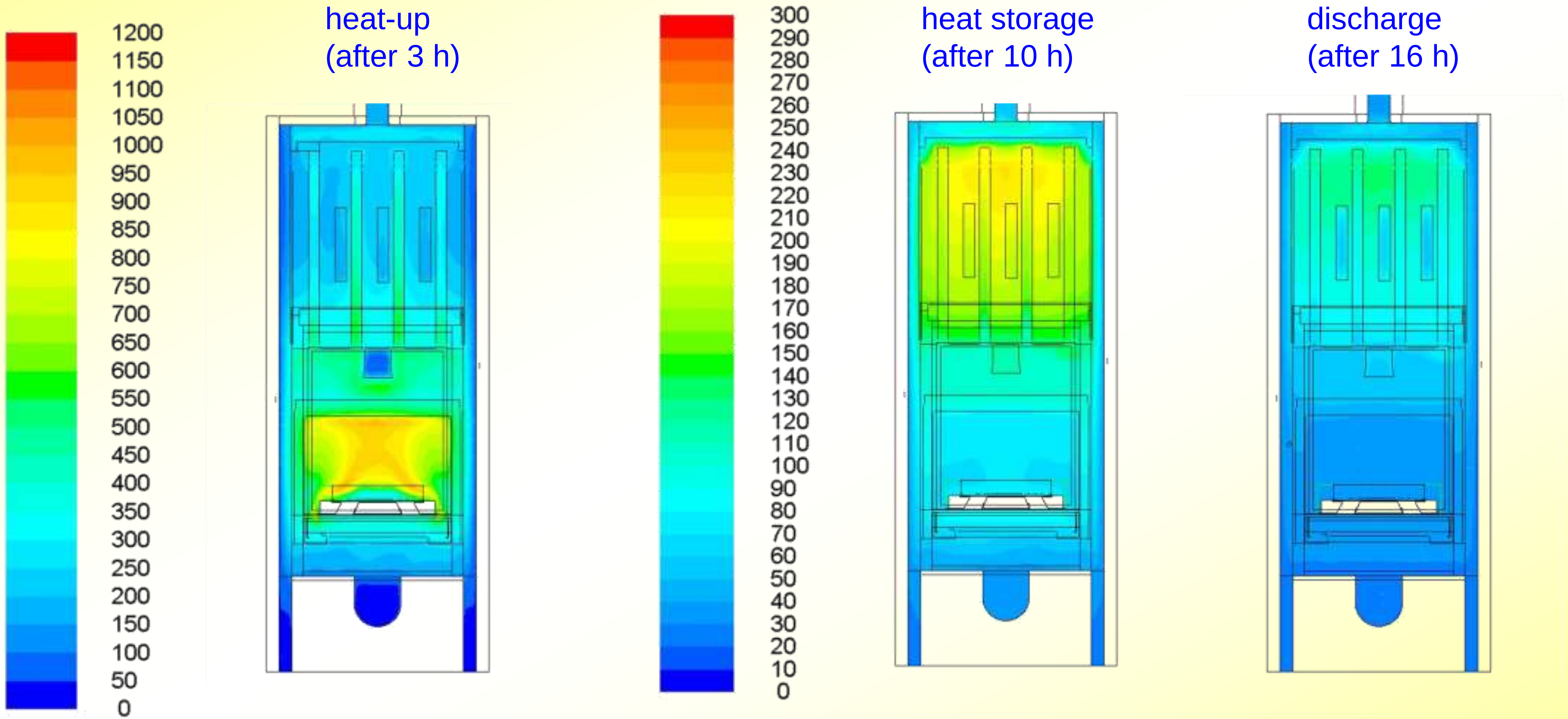
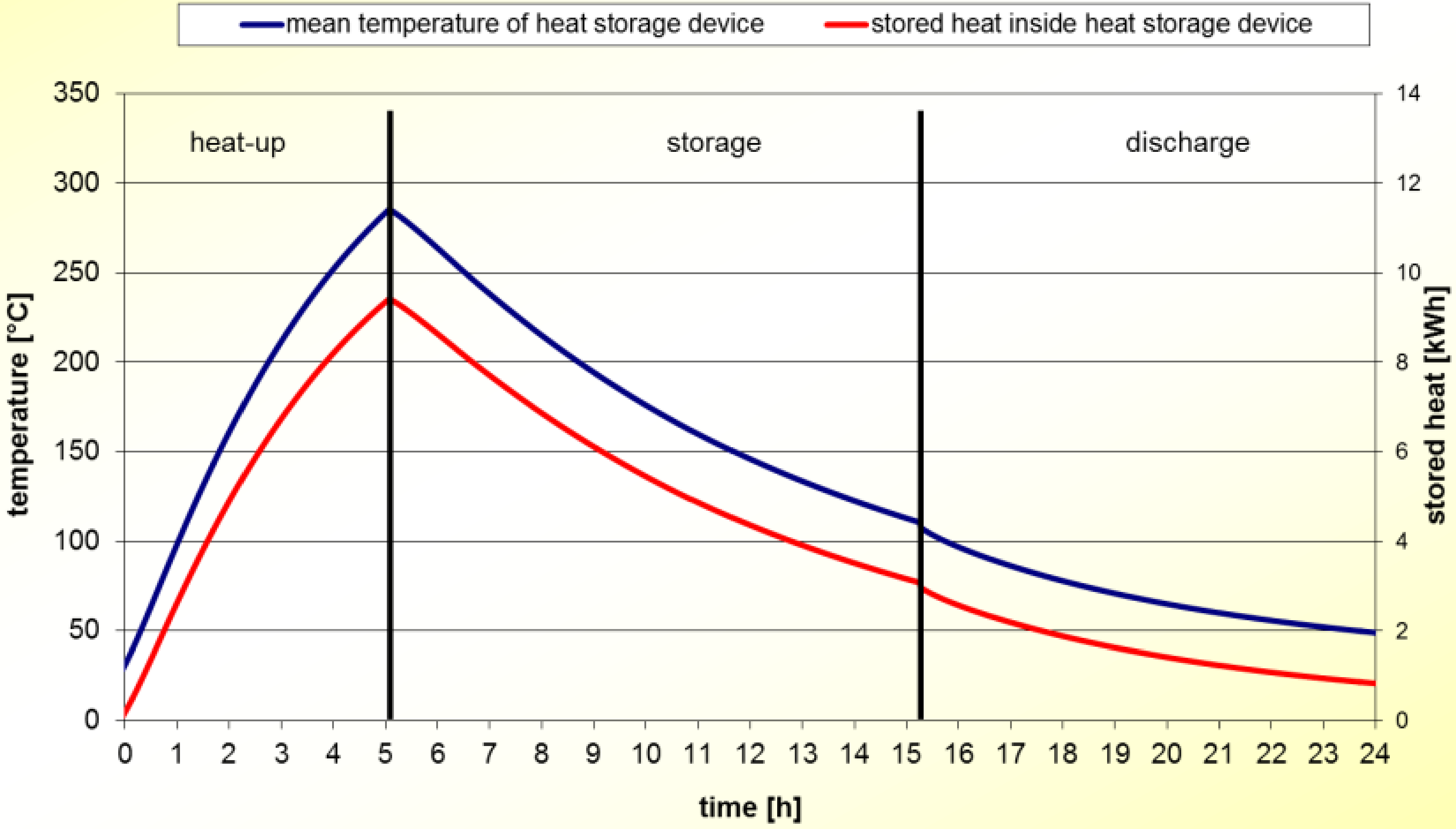
Transient simulation of wood log stove and heat storage device (2)



Iso-surfaces of flue gas, air, and material temperatures [°C] in a vertical cross section through the rear part of the flue gas channels

Transient simulation of wood log stove and heat storage device (3)

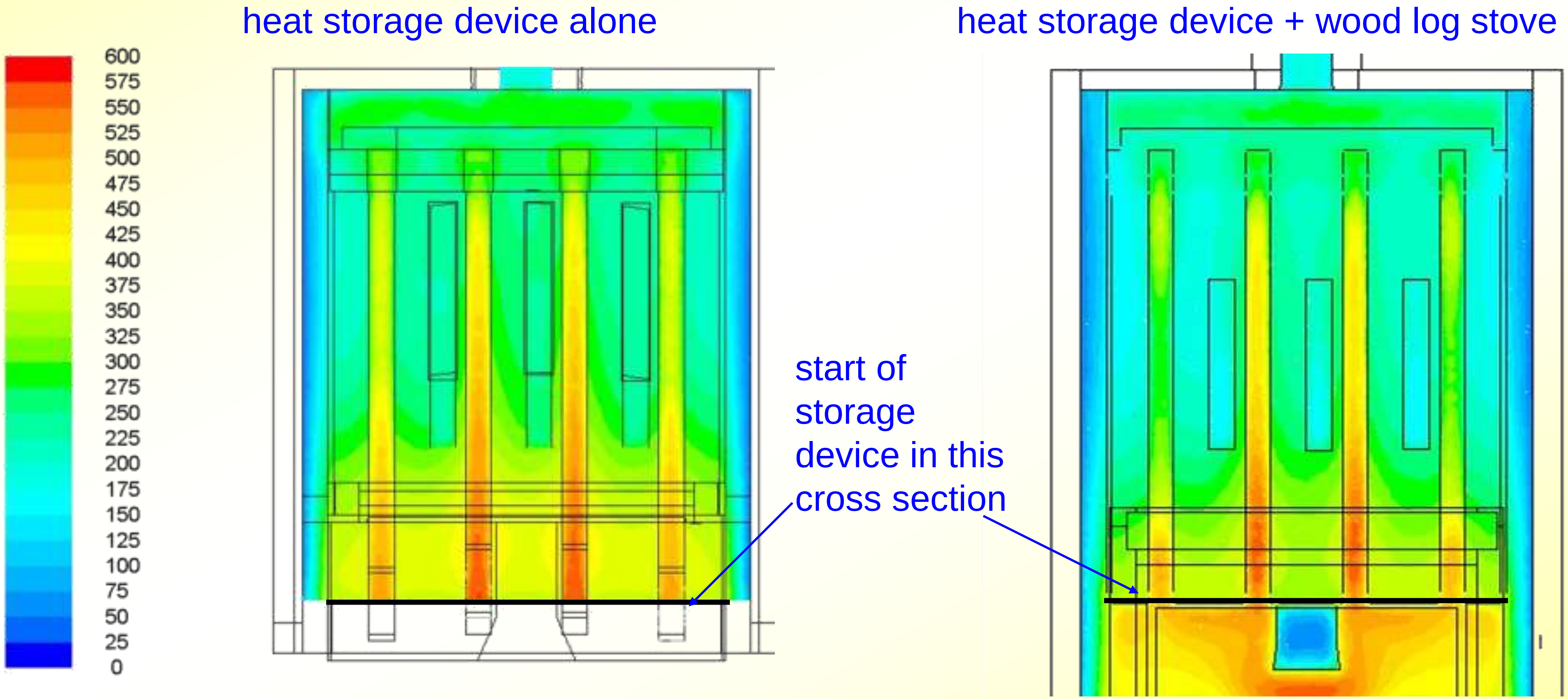
➢ Total heating cycle of heat storage device + wood log stove



Profile of the mean temperature of the heat storage device and the stored heat inside the heat storage device

Transient simulation of heat storage device alone (1)

- **Comparison of transient simulation results of total and reduced system (heat-up phase after 3 h):**



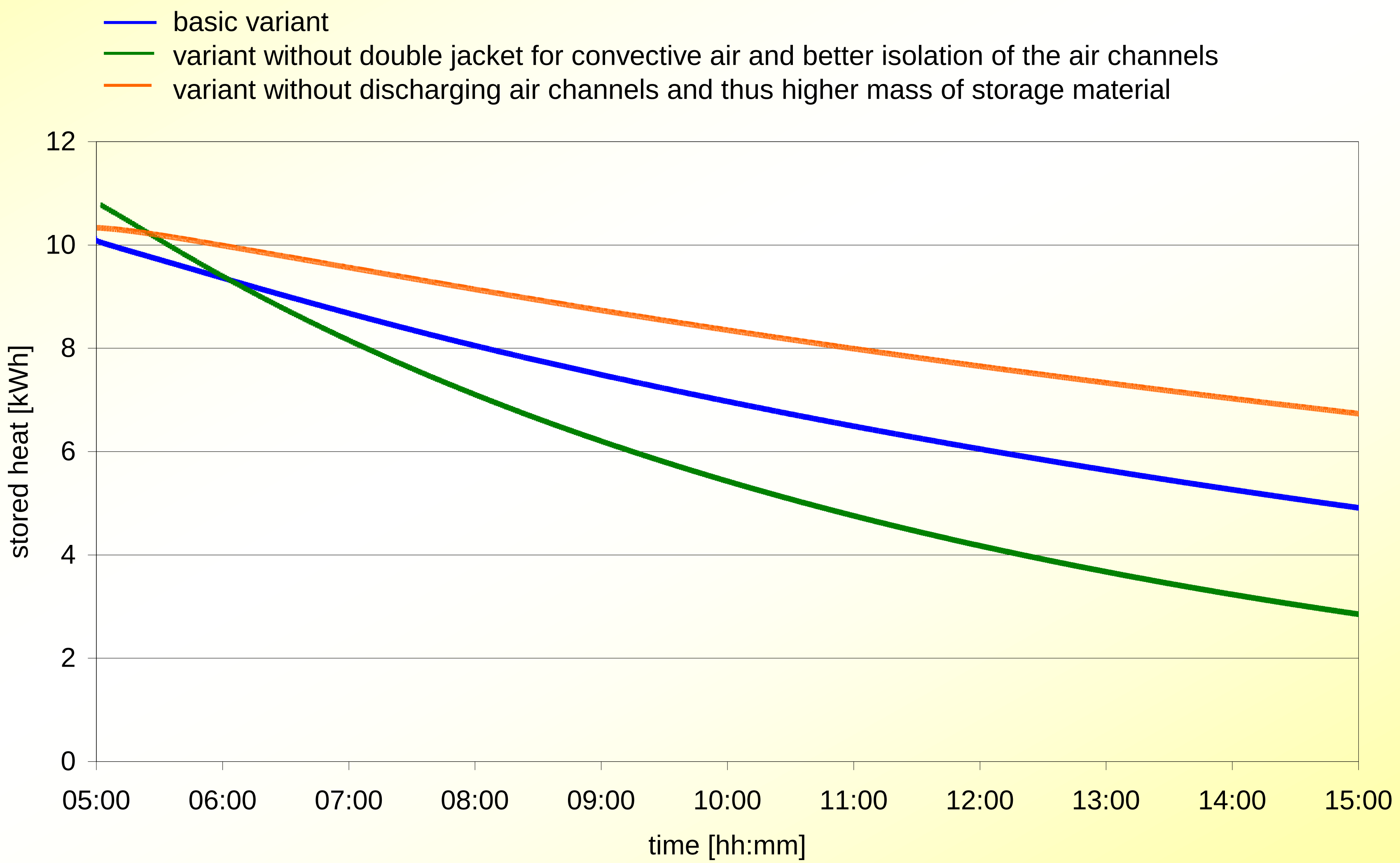
Iso-surfaces of flue gas-, air- and material temperatures [°C] in a vertical cross section through the rear part of the flue gas channels

Design study for system optimisation (1)

- **Geometric variations (selection):**
  - removal/enlargement of double jacket for convective air
  - reduction of the cross-section of the flue gas exit from the storage device
  - steeper inclination of the air channels/removal of air channels
  - smaller air channels (increase of mass of heat storage material)
  - better insulation of the heat storage device
- **Material property variations:**
  - increased heat conductivity (2x)
  - increased density (2x)
  - both increased heat conductivity and density (2x)

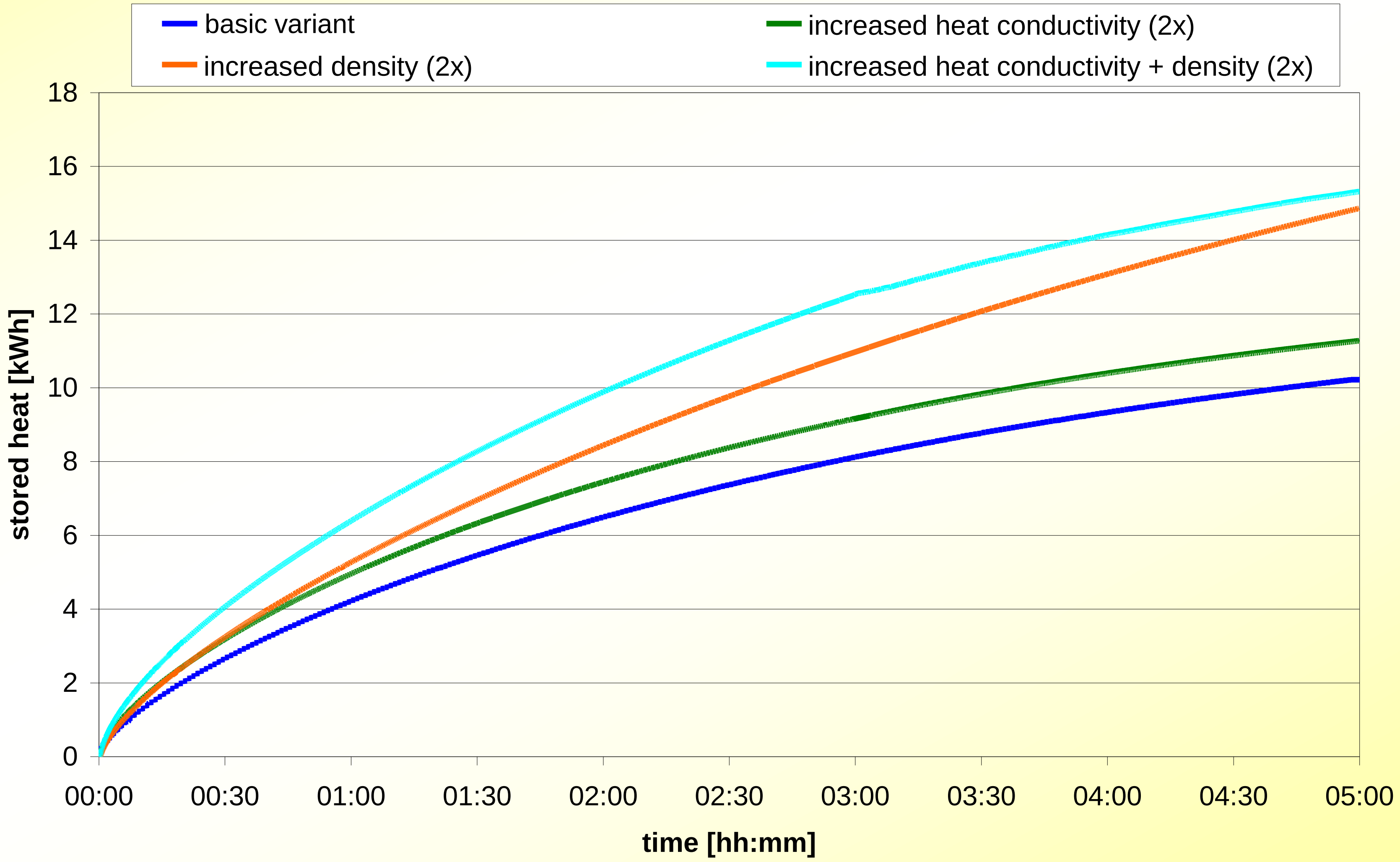
Design Study (2) geometric variations

➢ **Heat release during storage phase for the basic variant and two geometrical variants:**



Design Study (2)
variation of material properties

- **Heat storage during charging phase for the basic variant and three material variants:**



Summary and conclusions

- A CFD based methodology for the analysis and optimisation of a wood log stove with heat storage device was successfully developed and applied.
- Main results are:
  - The heat-up, heat storage and discharge behaviour of a stove + heat storage unit can be realistically evaluated.
  - The influence of air flow in the discharging channels and of flue gas flow in the charging channels can be identified.
  - The influence of geometry and material properties on the charging/discharging processes can be shown and assessed.
- Transient CFD simulations of wood log fired stoves constitute an efficient process analysis and design tool.
- They allow a target-oriented and time saving method for the optimisation of wood log fired stoves + heat storage devices

Thank you for your attention

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