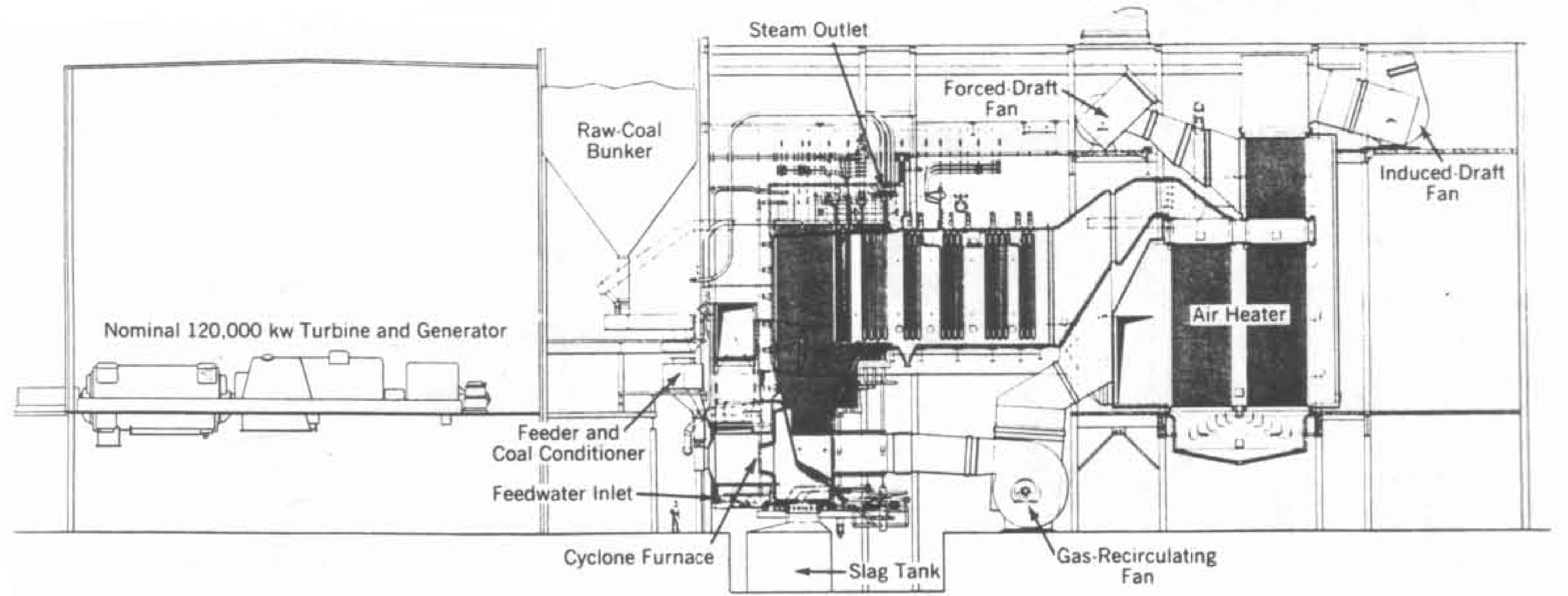
Industrial motivation

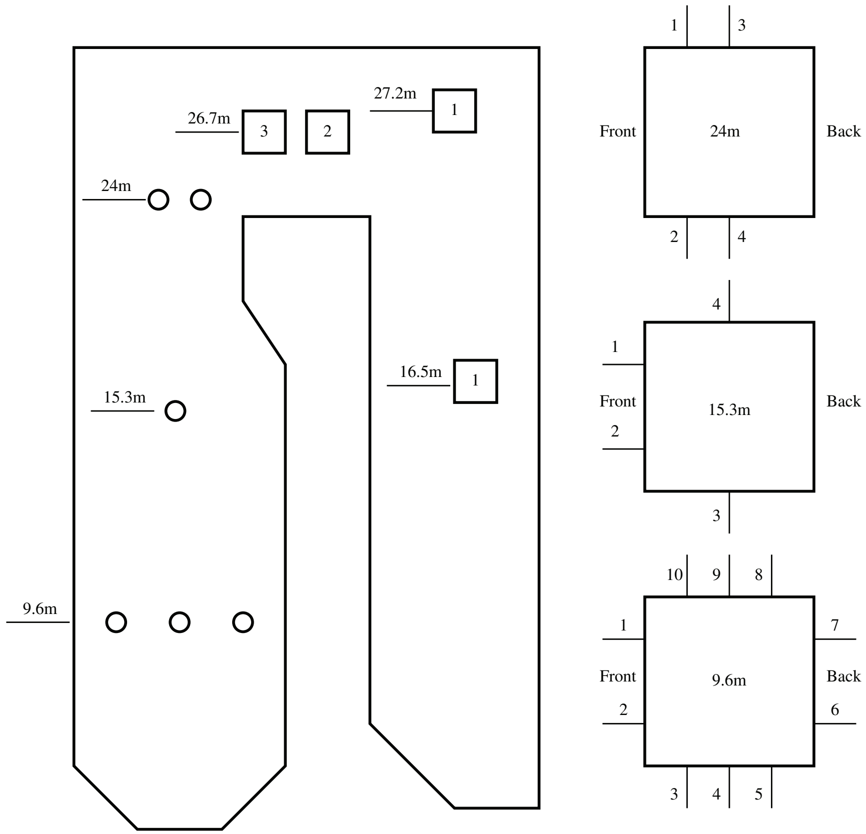


Steam generator in a power plant
S. C. Schultz. Steam, Its Generation and Use, 40th ed. Babcock & Wilcox Company, 1992

Industrial motivation

Important processes

- gas flow in the large scale burners
- combustion processes described by physical principles (burnout measured data)
- NOx chemistry
- energy release and transfer to water piping
- co-firing - simultaneous combustion of biofuel

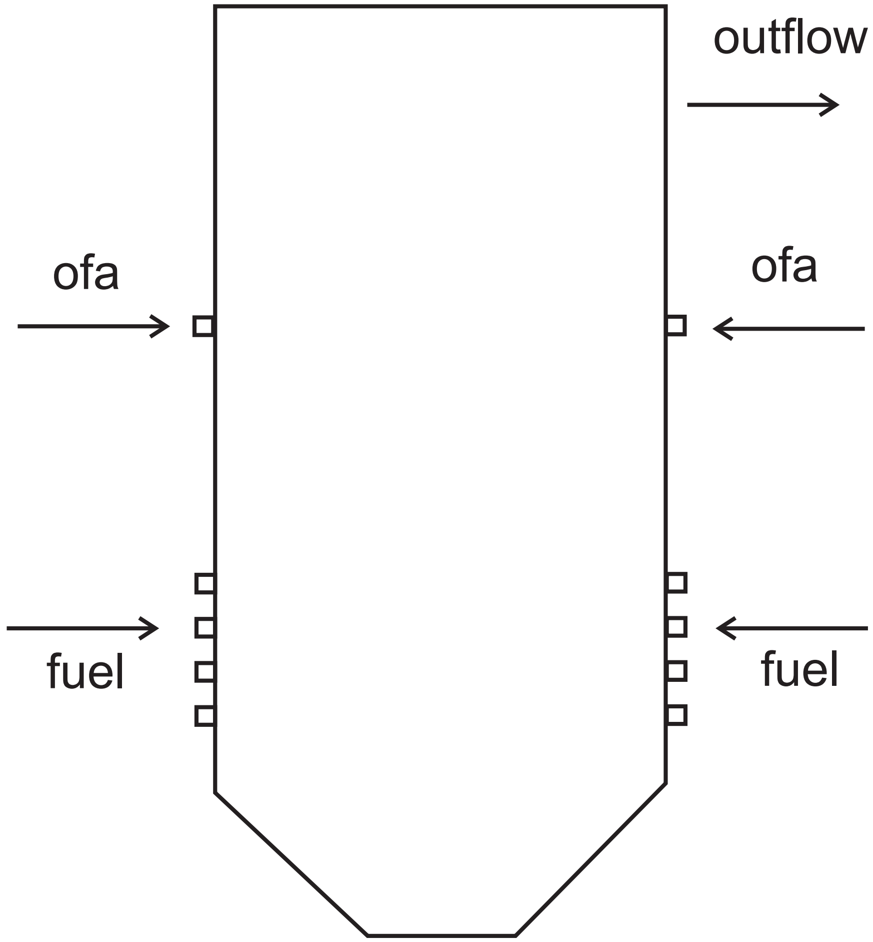


Measurement points in the burner

Geometry

Geometry

- inlet - burners - mixing
  - powderized coal
  - air
  - biofuel
- outlet - artificially underpressurized flue gas outflow
- walls transferring heat outwards
- over-fire air inlet (OFA)



Combustion chamber geometry

Mass conservation

Total-mass balance and chemical components balance laws

$$\begin{aligned} \frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_i)}{\partial x_i} &= 0 \\ \frac{\partial}{\partial t}(\rho Y_*) + \frac{\partial}{\partial x_i}(\rho Y_* v_i) &= \frac{\partial}{\partial x_i}\left(-\frac{\mu_T}{\mathrm{Sc}_t}\frac{\partial Y_*}{\partial x_i}\right) + \omega_* \end{aligned}$$

where * substitutes O_2, N_2, NO, HCN, NH_3, H_2O and CO_2

Char, volatiles and coal particle balance laws

$$\begin{aligned} \frac{\partial \rho_{\mathrm{char}}}{\partial t} + \frac{\partial(\rho_{\mathrm{char}} v_i)}{\partial x_i} &= R_{\mathrm{char}} \\ \frac{\partial \rho_{\mathrm{vol}}}{\partial t} + \frac{\partial(\rho_{\mathrm{vol}} v_i)}{\partial x_i} &= R_{\mathrm{vol}} \\ \frac{\partial n}{\partial t} + \frac{\partial(n v_i)}{\partial x_i} &= 0 \end{aligned}$$

Flow and heat transfer

Momentum and energy balance laws

$$
\begin{aligned}
\frac{\partial}{\partial t}(\rho v_i) + \frac{\partial}{\partial x_i}(p + \rho v_i^2) &= \frac{\partial}{\partial x_j}\left(\mu \frac{\partial v_i}{\partial x_j}\right) + \frac{1}{3}\frac{\partial}{\partial x_j}\left(\mu \frac{\partial v_j}{\partial x_i}\right) - \frac{2}{3}\frac{\partial}{\partial x_i}(\rho k) + \rho g_i \\
c_p\left[\frac{\partial}{\partial t}(\rho T) + \frac{\partial}{\partial x_i}(\rho T v_i)\right] &= -R_{\mathrm{char}} h_{\mathrm{char}} - R_{\mathrm{vol}} h_{\mathrm{vol}} - \nabla(\mathbf{q}_c + \mathbf{q}_r) + \frac{\partial}{\partial x_j}\left[\left(\mu_L + \frac{\mu_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]
\end{aligned}
$$

$k - \varepsilon$ model for turbulence

$$
\begin{aligned}
\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k v_i) &= \frac{\partial}{\partial x_j}\left[\left(\mu_L + \frac{\mu_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k - G_b - Y_m - \rho\varepsilon \\
\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon v_i) &= \frac{\partial}{\partial x_j}\left[\left(\mu_L + \frac{\mu_T}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}
\end{aligned}
$$

$$
p = \frac{\rho R T}{\bar{M}}, \quad \mu_T = \rho C_\mu \frac{k^2}{\varepsilon}, \quad \mu = \mu_L + \mu_T, \quad h_{\mathrm{char}} + h_{\mathrm{vol}} = LHV
$$

$$
G_k = \left(\frac{\partial v_1}{\partial x_2} + \frac{\partial v_2}{\partial x_1}\right)^2 + \frac{\partial v_1}{\partial x_1}\left[\frac{4}{3}\mu\frac{\partial v_1}{\partial x_1} - \frac{2}{3}\left(\rho k + \mu\frac{\partial v_2}{\partial x_2}\right)\right] + \frac{\partial v_2}{\partial x_2}\left[\frac{4}{3}\mu\frac{\partial v_2}{\partial x_2} - \frac{2}{3}\left(\rho k + \mu\frac{\partial v_1}{\partial x_1}\right)\right]
$$

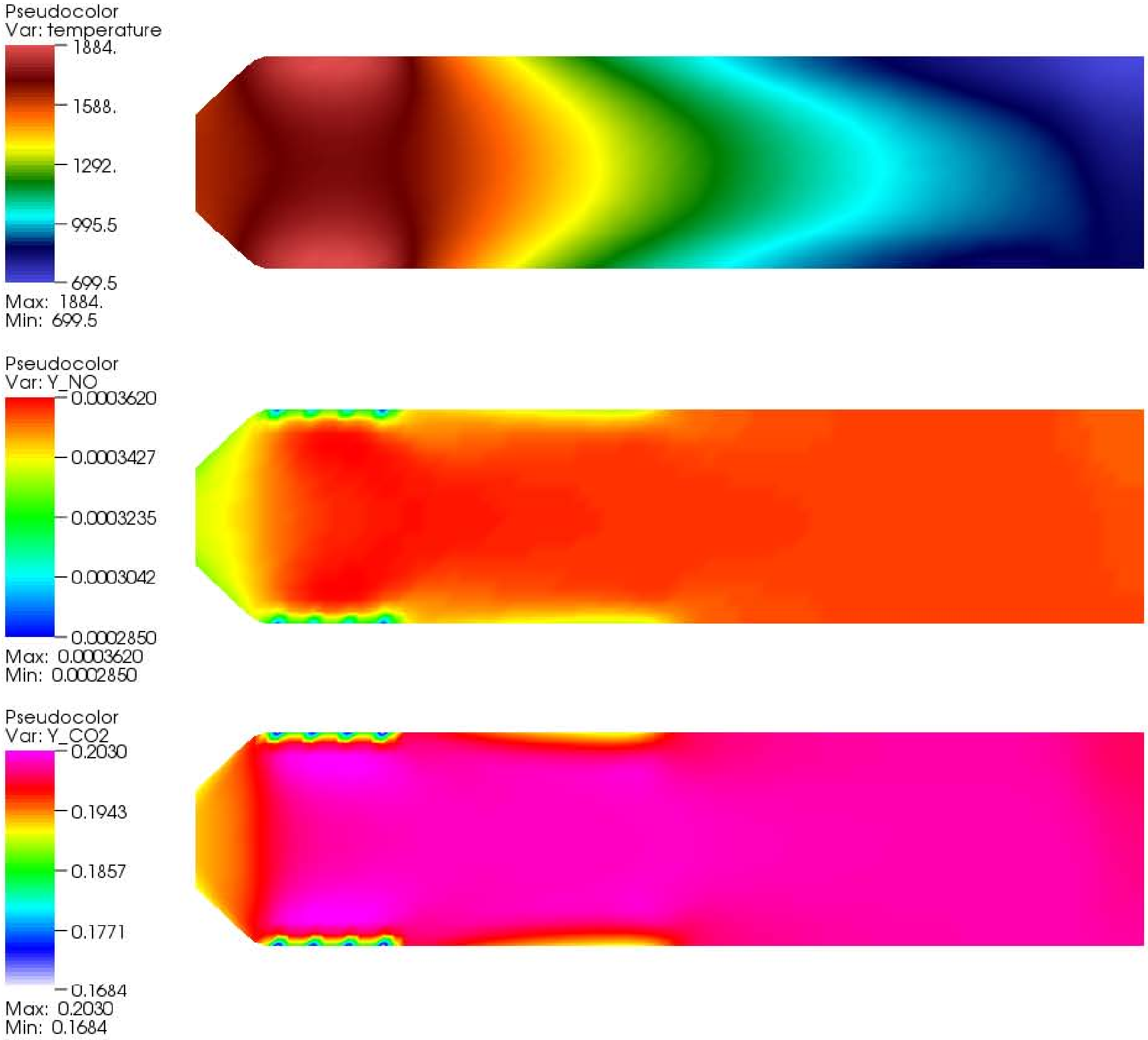
$$
G_b = -g_i \frac{\mu}{\rho \mathrm{Pr}_t}\frac{\partial \rho}{\partial x_i}, \quad C_{3\varepsilon} = \tanh\left|\frac{v_2}{v_1}\right|, \quad Y_m = 2\rho\varepsilon M_t^2, \quad M_t = \sqrt{\frac{k}{a^2}}, \quad a = \sqrt{\gamma R T}
$$

Simulation results

Case	Air distribution %				Fuel distribution %				Excess air coefficient				NO ppm	CO_2	O_2
	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4	B_1	B_2	B_3	B_4			
1	25	25	25	25	25	25	25	25	1.3	1.3	1.3	1.3	357	20%	1.9%
2	50	20	20	10	25	25	25	25	2.6	1.04	1.04	0.52	177	20%	1.9%
3	10	20	20	50	25	25	25	25	0.52	1.04	1.04	2.6	134	20%	2%
4	25	25	25	25	50	20	20	10	0.65	1.63	1.63	3.25	182	18%	4.5%

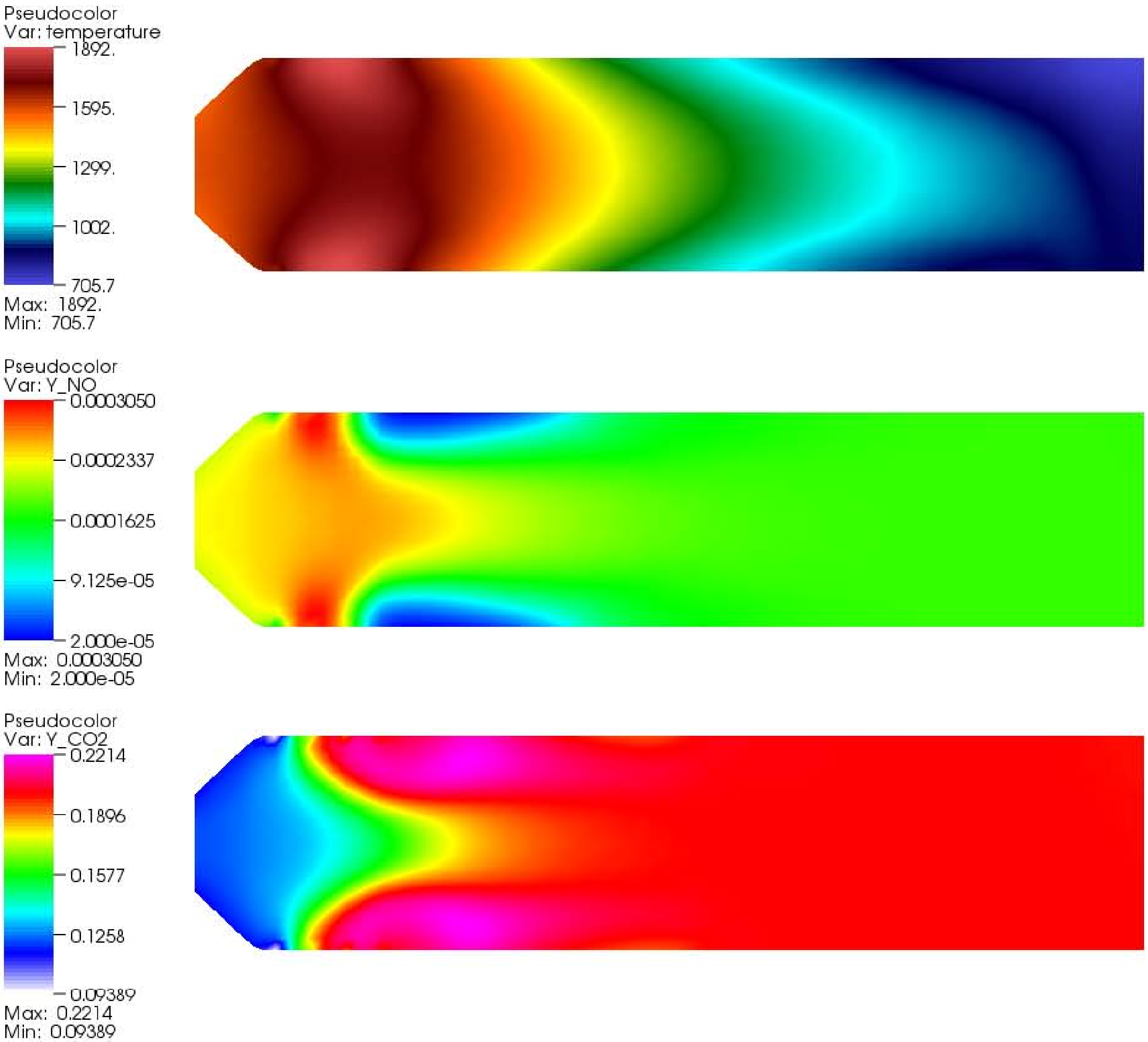
- **Case 1** - uniform air and coal distribution over 4 pairs of burners
- **Case 2** - decreasing air and uniform coal distribution over 4 pairs of burners (with consequent excess or missing air fraction in burners)
- **Case 3** - increasing air and uniform coal distribution over 4 pairs of burners (with consequent excess or missing air fraction in burners)
- **Case 4** - uniform air and decreasing coal distribution over 4 pairs of burners (with consequent excess or missing air fraction in burners)

Simulation results - Case 1



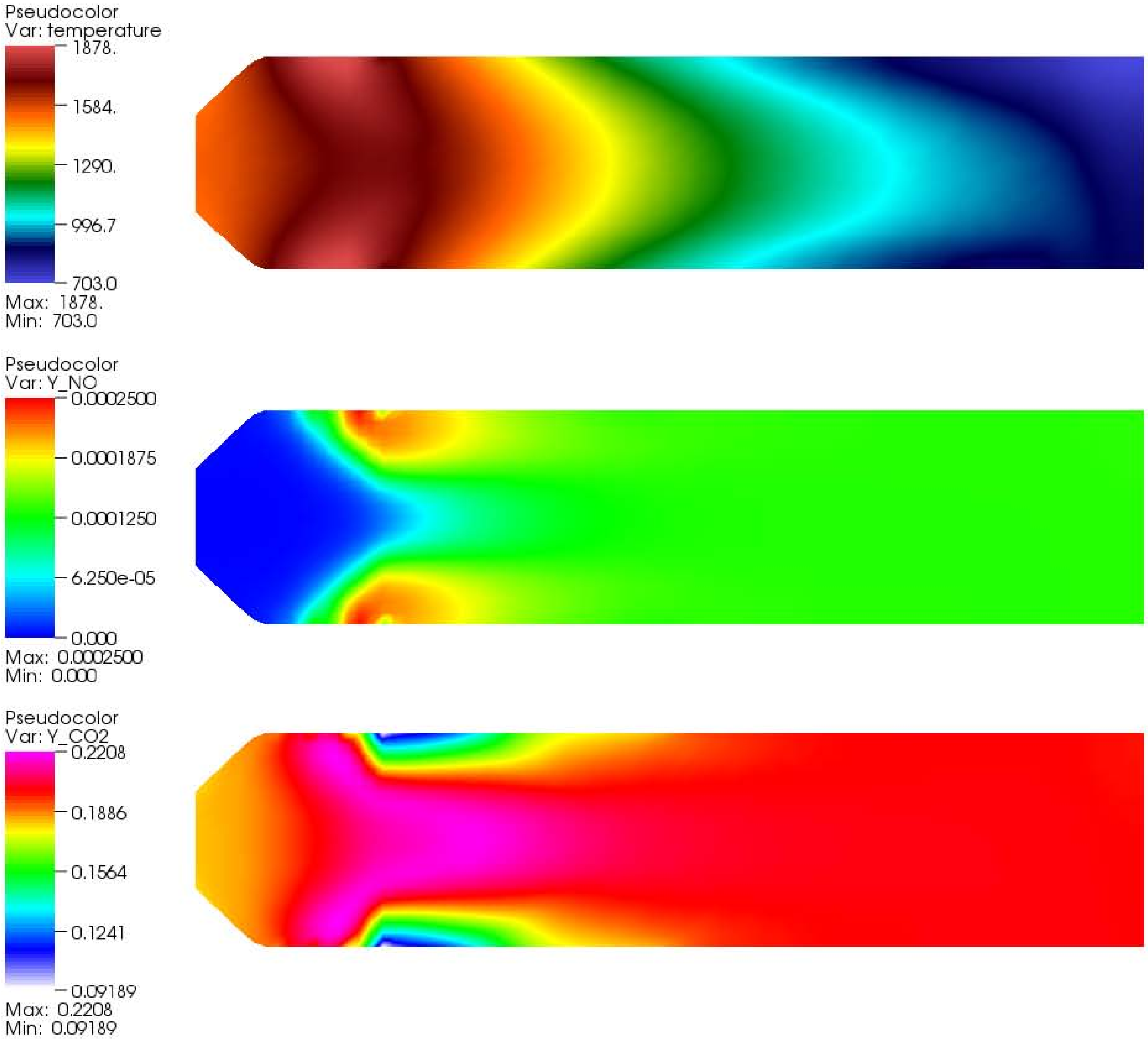
Case 1: Profiles of temperature (top), mass fraction of NO (middle) and mass fraction of CO_2 (bottom)

Simulation results - Case 2



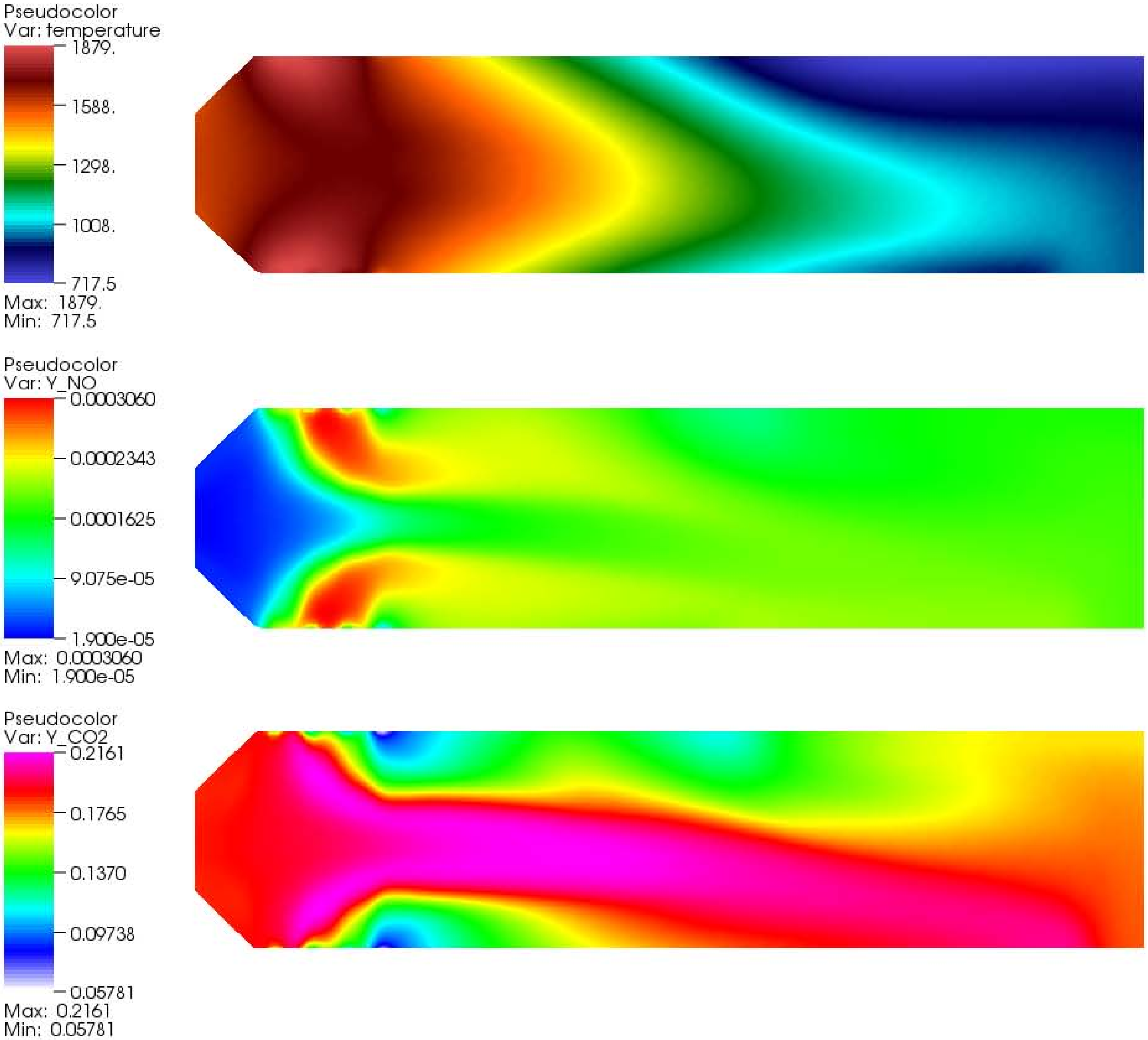
Case 2: Profiles of temperature (top), mass fraction of NO (middle) and mass fraction of CO_2 (bottom)

Simulation results - Case 3



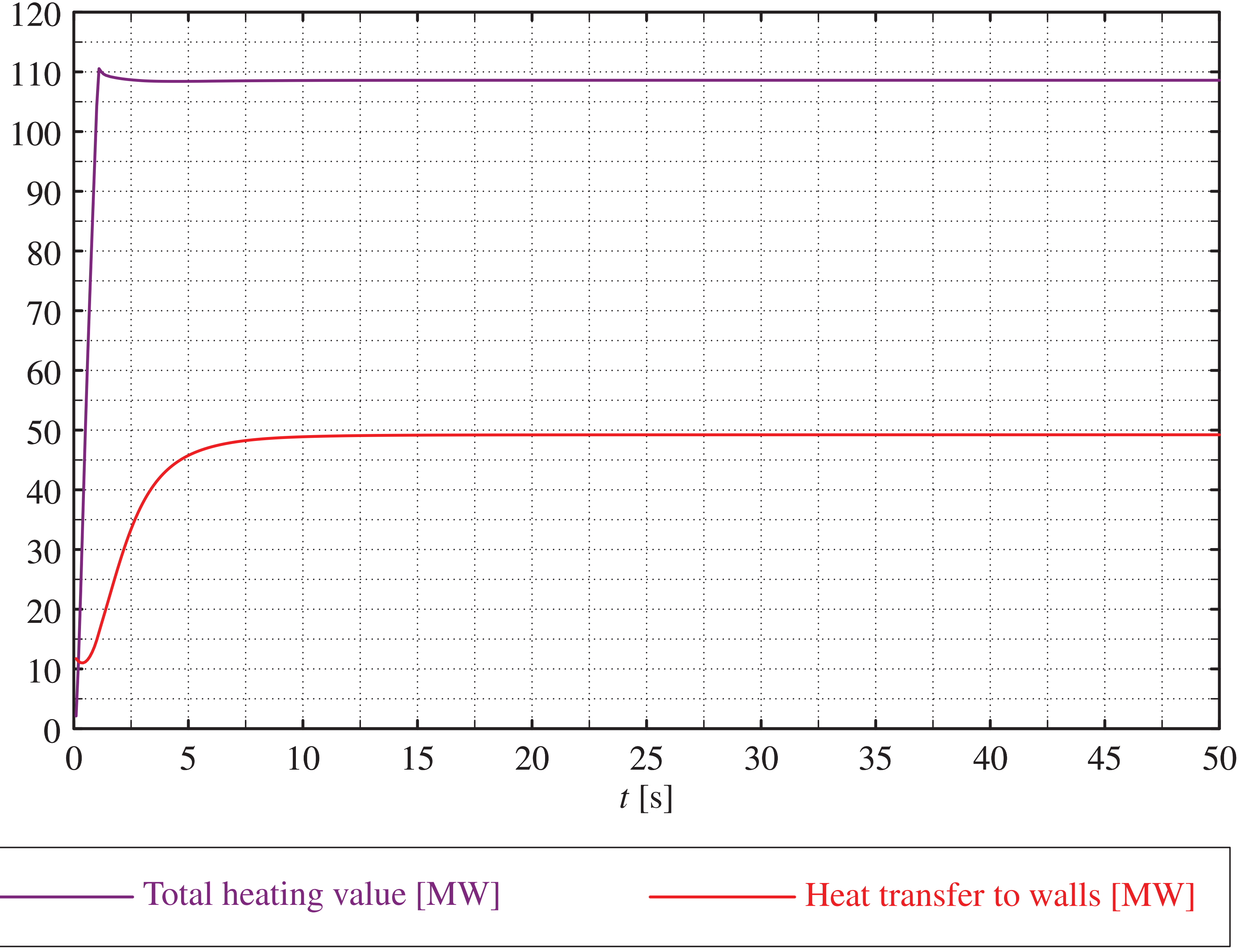
Case 3: Profiles of temperature (top), mass fraction of NO (middle) and mass fraction of CO_2 (bottom)

Simulation results - Case 4



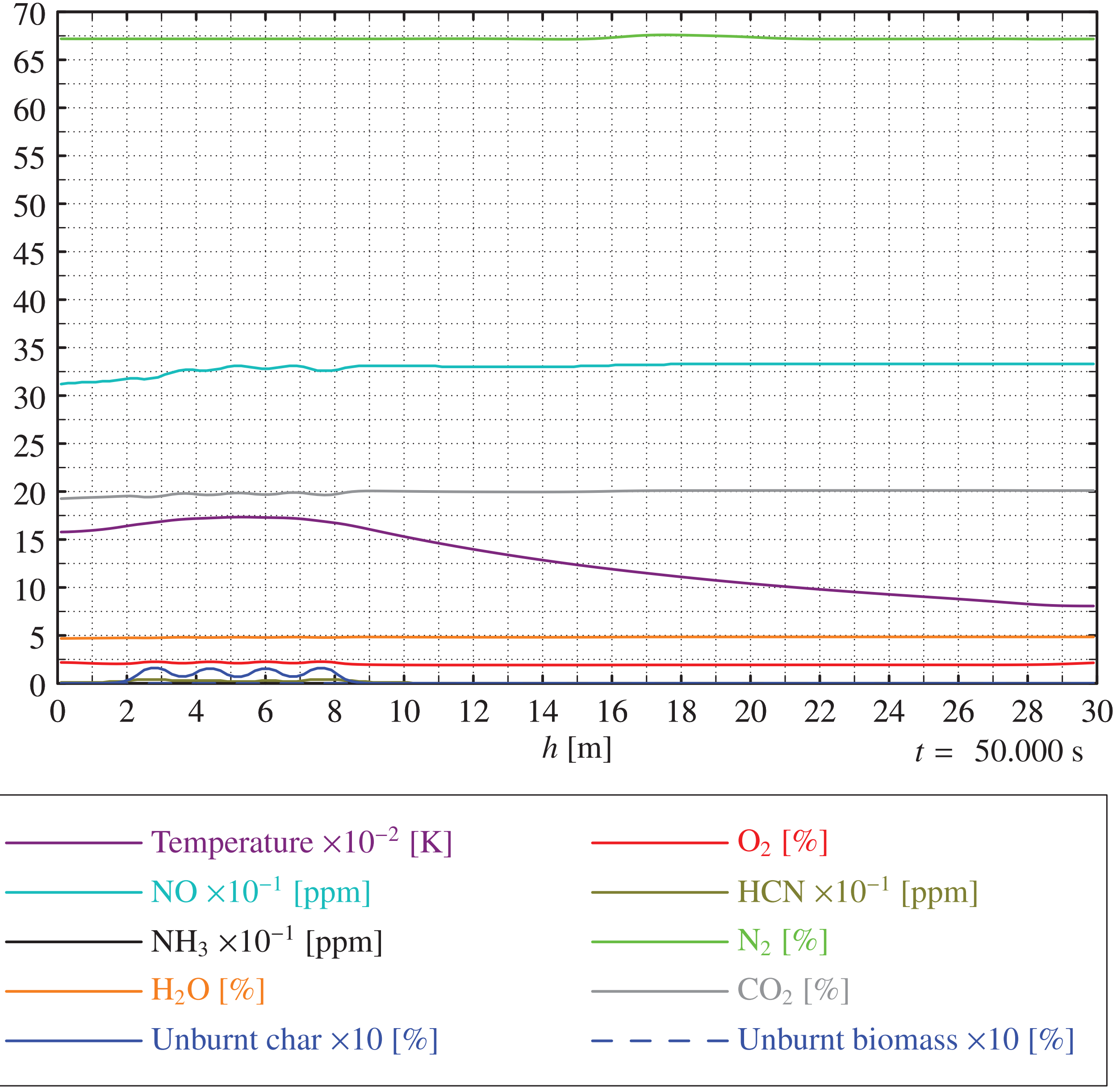
Case 4: Profiles of temperature (top), mass fraction of NO (middle) and mass fraction of CO_2 (bottom)

Simulation results - uniform burner composition



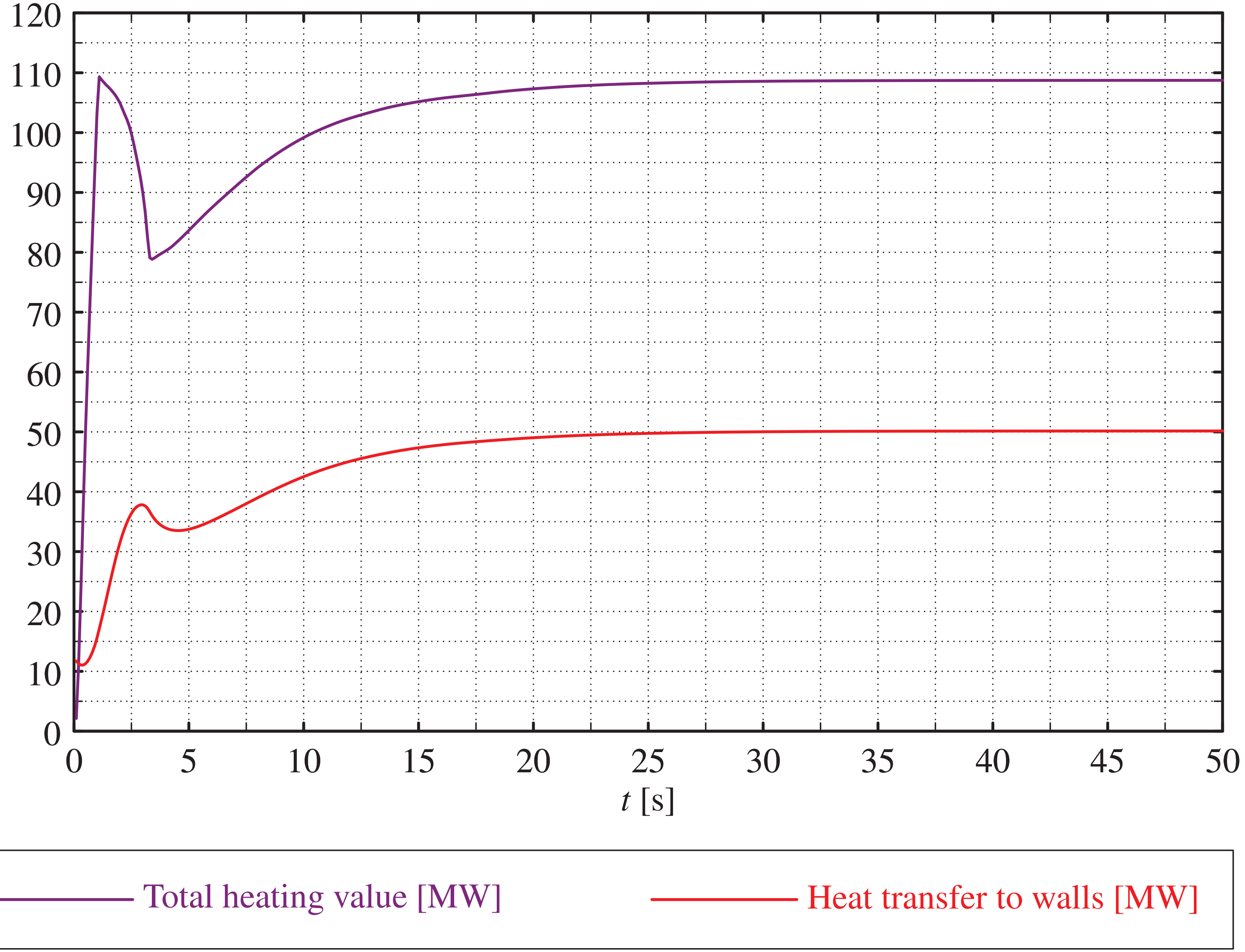
Time evolution of energy release and wall transfer

Simulation results - uniform burner composition



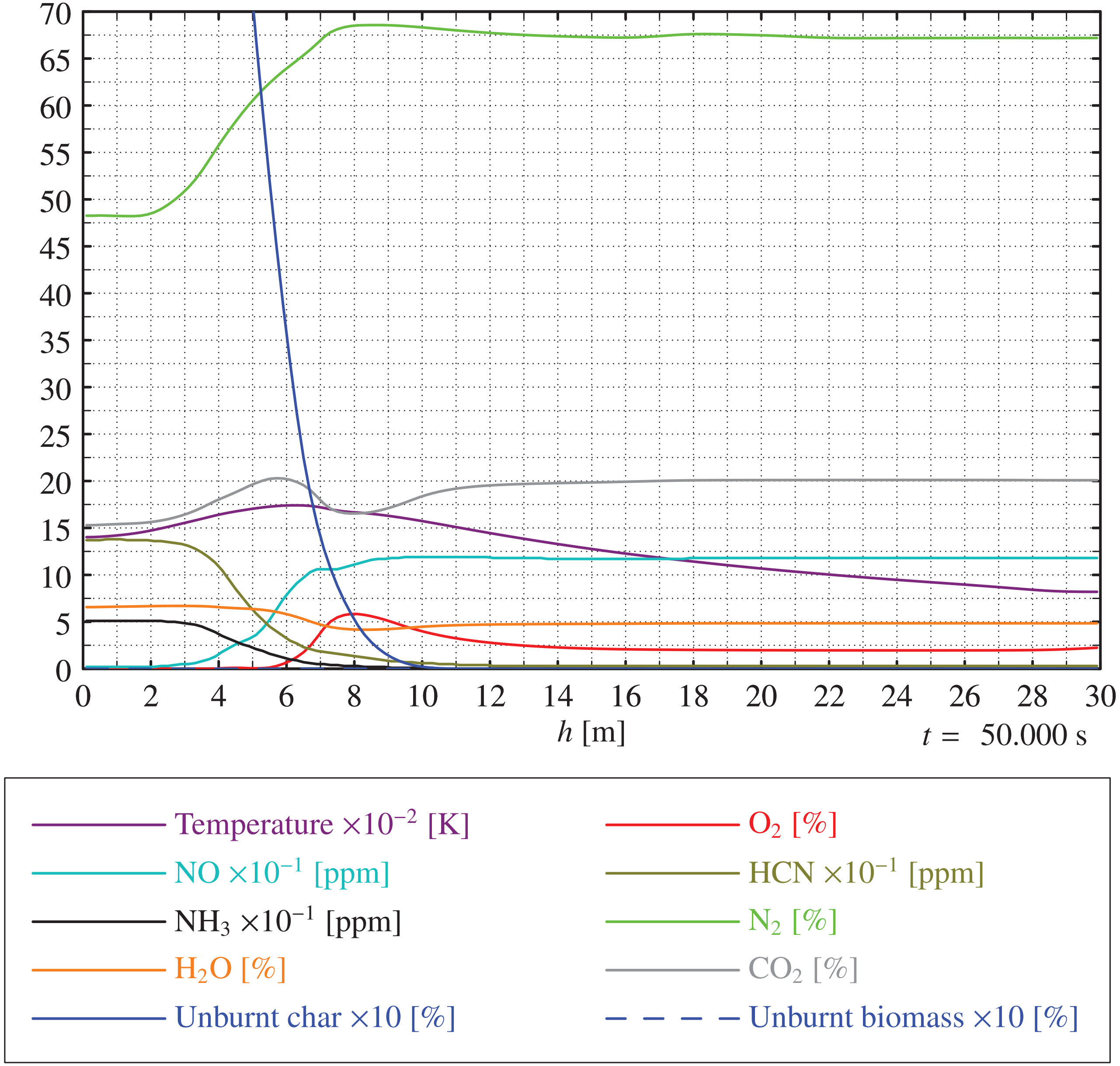
Vertical distribution of key system variables at a given time

Simulation results - staging $10, 20, 20, 50\%$ air x coal



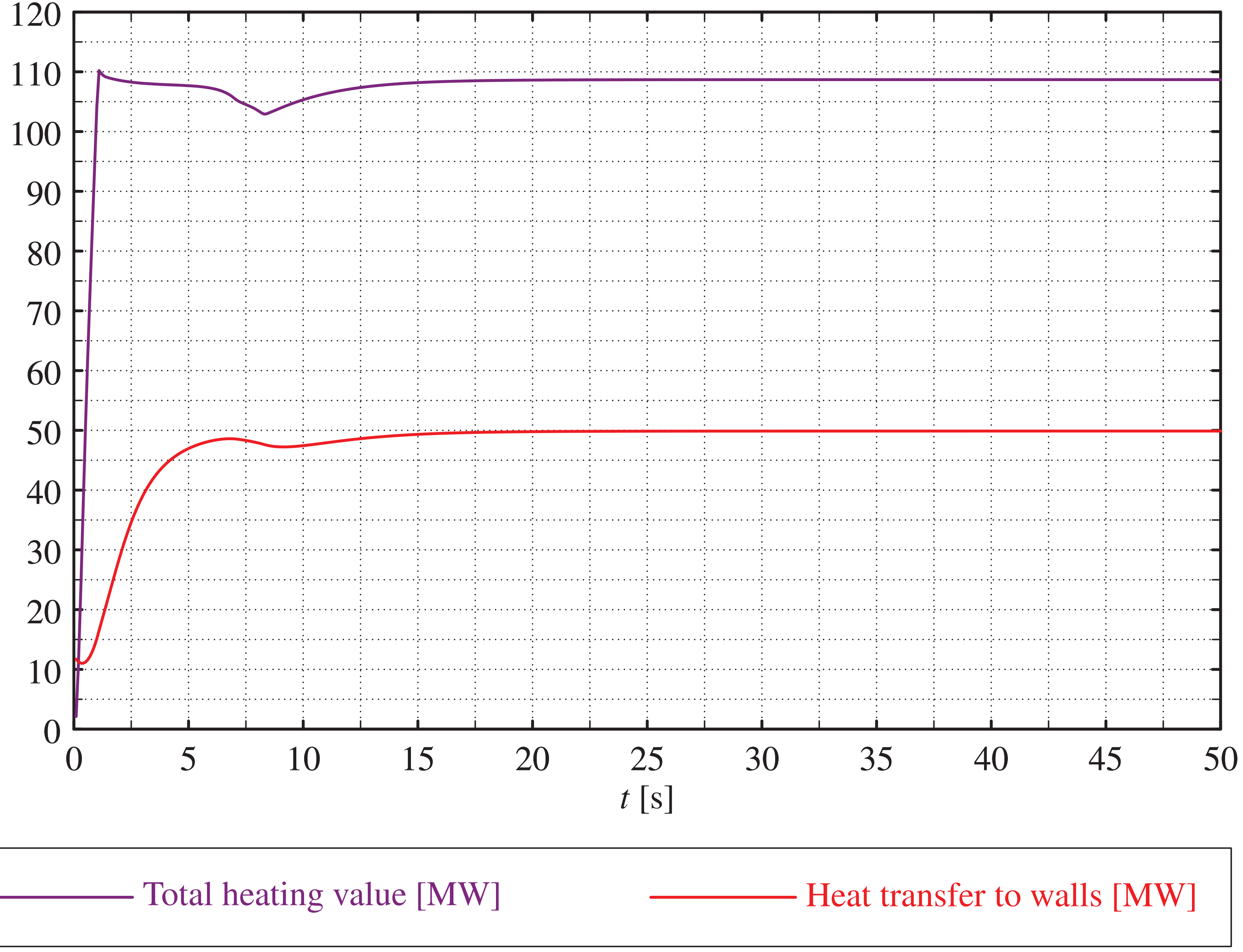
Time evolution of energy release and wall transfer

Simulation results - staging



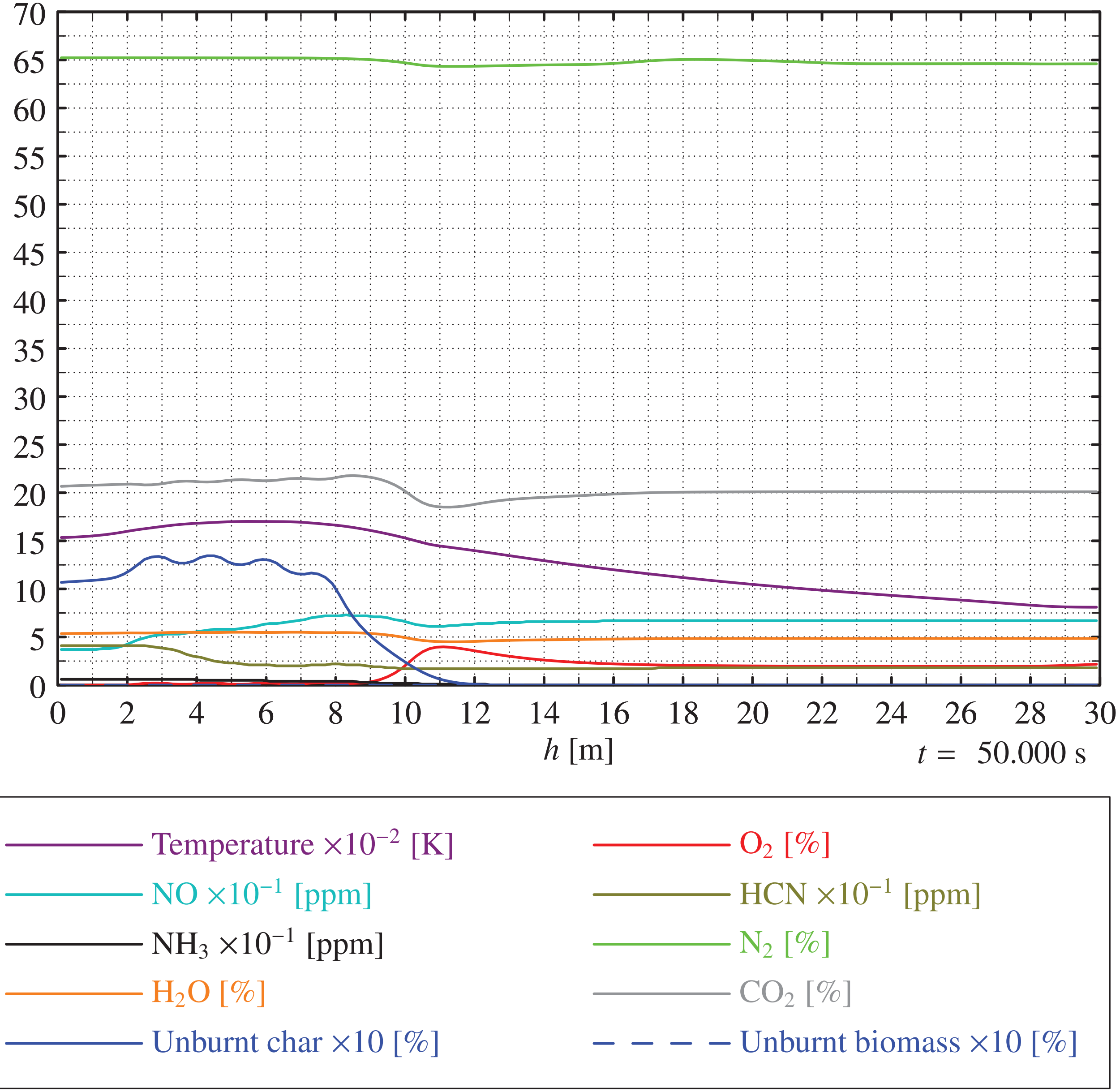
Vertical distribution of key system variables at a given time

Simulation results - OFA



Time evolution of energy release and wall transfer

Simulation results - OFA



Vertical distribution of key system variables at a given time