SETCOM: Separate Effect Test for Condensation Modelling

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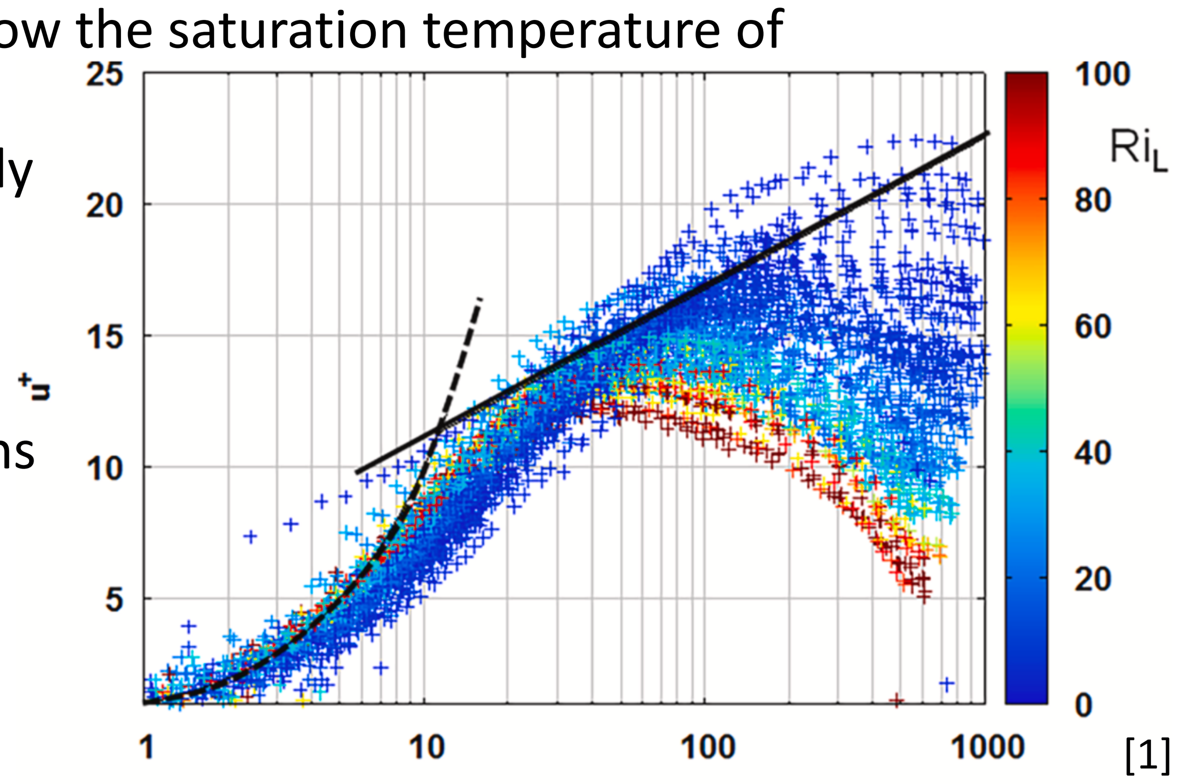
SETCOM test facility

Motivation:

- In case of fire, sprinkler and water mist systems are fire suppressions measures to extinguish the fire or at least to decelerate the fire spread and to reduce the heat release rate
- Sprinkler and water mist systems as extinguishing measures decreases the HRR and increases the H_2O mass fraction in the gas phase
- On structures, where the surface temperature is below the saturation temperature of steam this leads to wall condensation effects
- Additional buoyancy effects which are not sufficiently predicted by the standard wall functions



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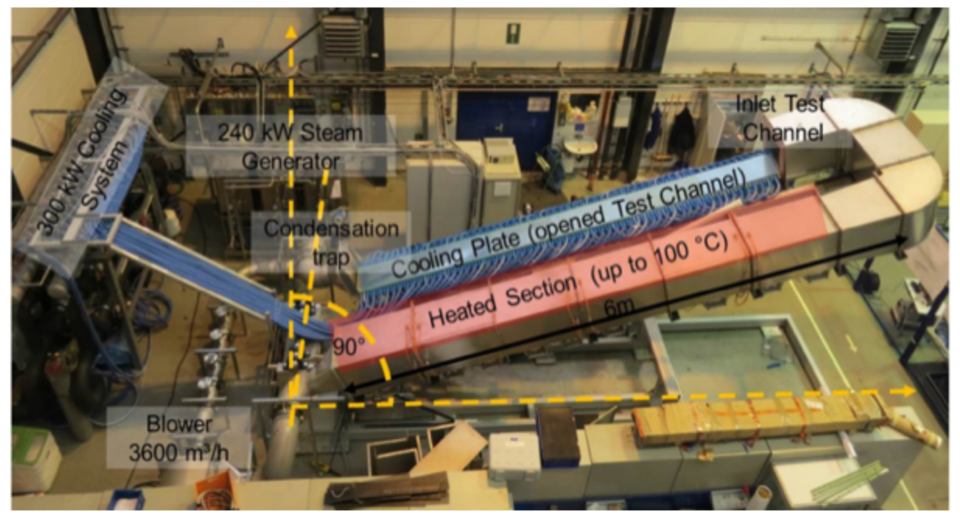
Goals:

- Investigation of model error on real scale applications
- Improvement of wall functions

Test facility

- Closed loop channel (rectangular cross section)
- Closed loop cooling system (20 Pumps)
- Coupled by counter current heat exchanger
- HTC: $\alpha_{cool} < 3500 W/m^2K$

Steady state, high reproducibility



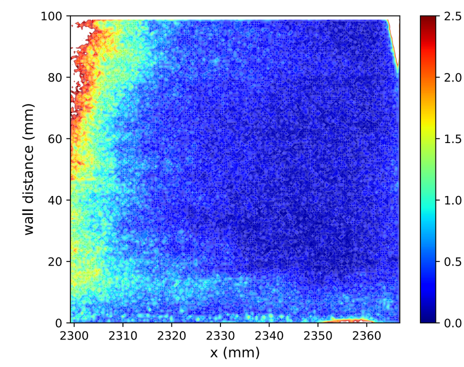
Boundary Conditions:

- Inlet velocity: $0.5 < u_{in} < 5\ m/s$
- Inlet temperature: $ambient < T_{in} < 100°C$
- Inclination : $0 < \phi < 90°$
- Relative humidity: ambient $< rH < 100\%$
- Pressure: $p = ambient$
- Cooling temperature: $8°C < T_{cool} < 50°C$

Optical Measurements:

- Particle Image Velocimetry (Stereo-PIV)
- Laser Doppler Velocimetry (2D-LDV)
- Profile Sensor (PS)

High resolution optical measurements for velocity boundary layer: 2D-3C-velocity fields, fluctuations



Well known boundary conditions

Measurements:

- 60 heat flux sensors (180 TC)
- Vane wheel and vortex anemometers (inlet)
- TC and PT100 (inlet)
- Capacitive humidity sensors

Condensation Model in FDS

Model:

$$Y_\alpha^+ = \frac{\rho u_\tau}{\dot{m}''_{dep,\alpha}}(Y_\alpha - Y_{\alpha,l})$$

$$y^+ = \frac{\rho u_\tau \delta n/2}{\eta}$$

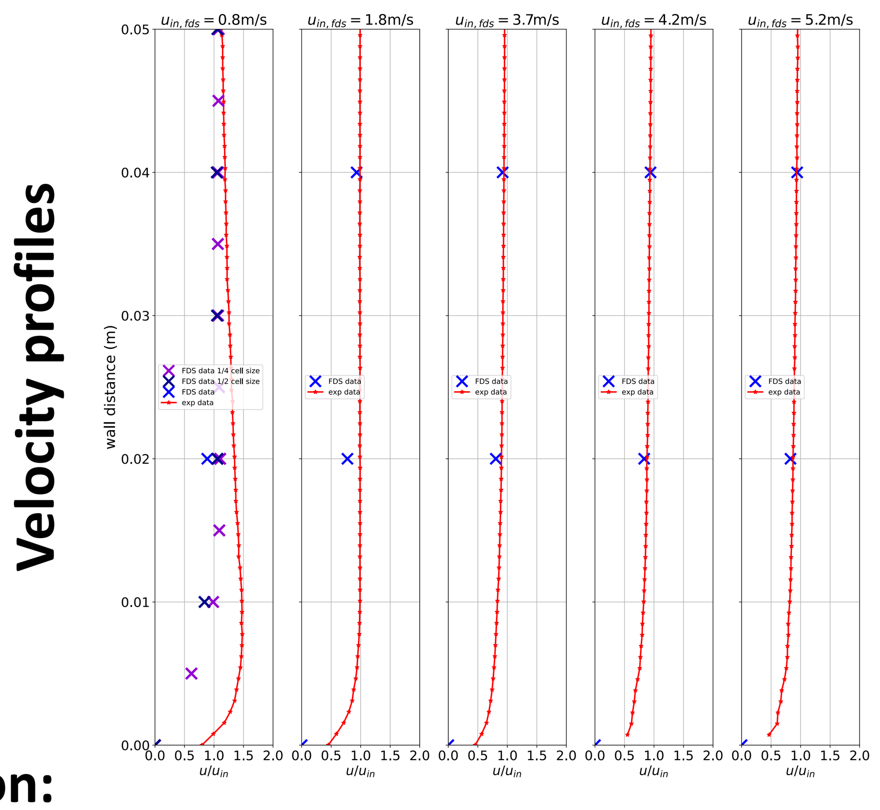
$$Y_\alpha^+ = Scy^+e^{-\Gamma} + \left(2.12\ln(y^+) + \left(3.85Sc^{\frac{1}{3}} - 1.3\right)^2 + 2.12\ln(Sc)\right)e^{-\frac{1}{\Gamma}}$$

$$\Gamma = \frac{(0.01Scy^+)^4}{1 + 5Sc^3y^+}$$

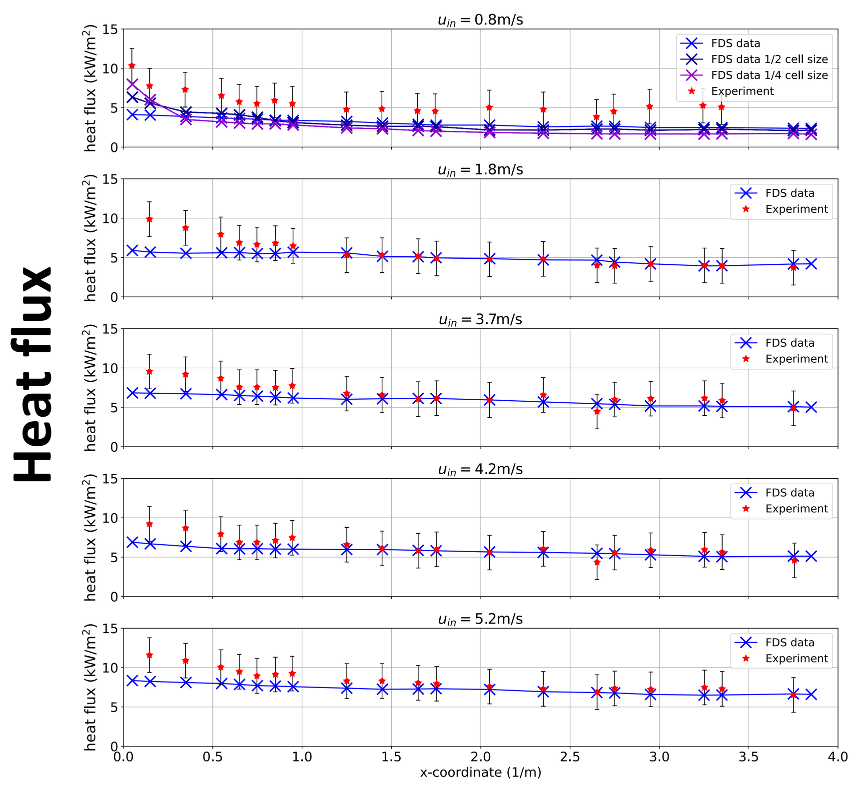
$$\dot{q}''_{dep,\alpha} = \dot{m}''_{dep,\alpha}(h_v(T_w) + h_{s,\alpha}(T_g) - h_{s,\alpha}(T_w)) \qquad [2]$$

Results: Qualitative Comparison FDS vs Experiments - velocity profiles and heat flux profiles

Velocity profiles

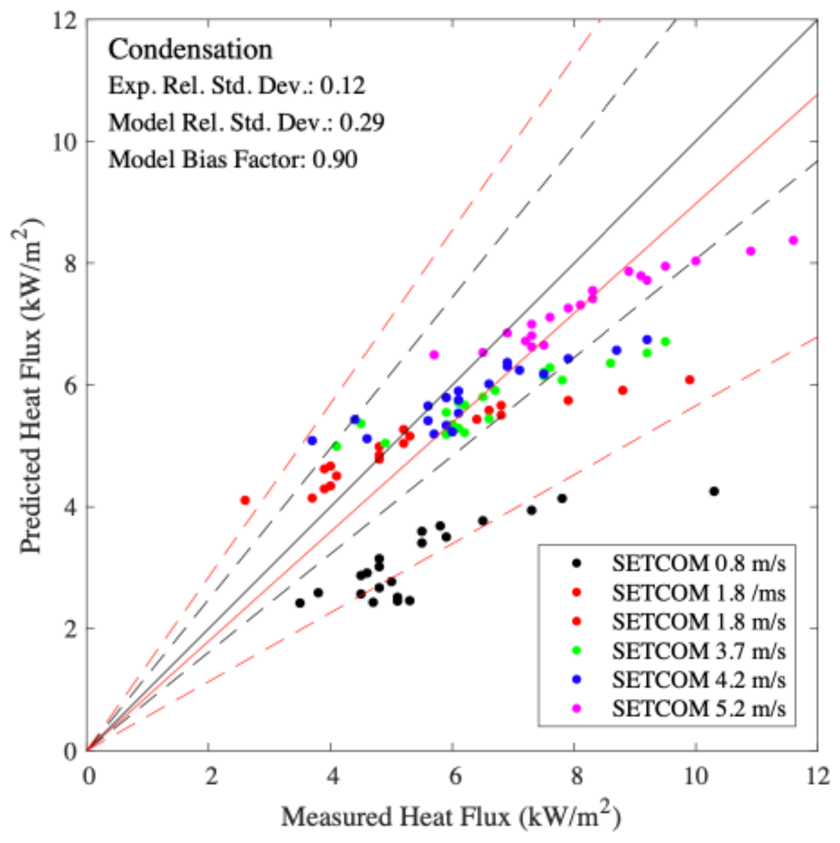


Heat flux



Conclusion:

- Pre section + inlet turbulence intensity in model → fully developed flow conditions at inlet (incomparable to experimental point data)
- Normalized velocity profiles are in reasonable agreement for forced and mixed convection (Ri<10)
- Deviations in the velocity profile increase with buoyancy
- Heat flux results in sufficient agreement, but for increasing buoyancy deviations increase as well, deviations increase to the inlet



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Outlook:

- Grid sensitivity analysis
- Conduction experimental test series for buoyancy dominated (Richardson Numbers) test cases ($10 < Ri$)
- Experimental investigation of 3D velocity, temperature and concentration conditions at inlet of test section

References:

[1] Kelm - 2019 - Development of multi-dimensional wall-funtion approach for wall condensation - Nuclear Engineering and Design

[2] Kader - 1981 - Temperature and concentration profiles in fully turbulent boundary layer - Int. J. Heat Mass Transfer

[3] McGrattan - 2021 – Fire Dynamics Simulator: Validation Guide - https://pages.nist.gov/fds-smv/manuals.html