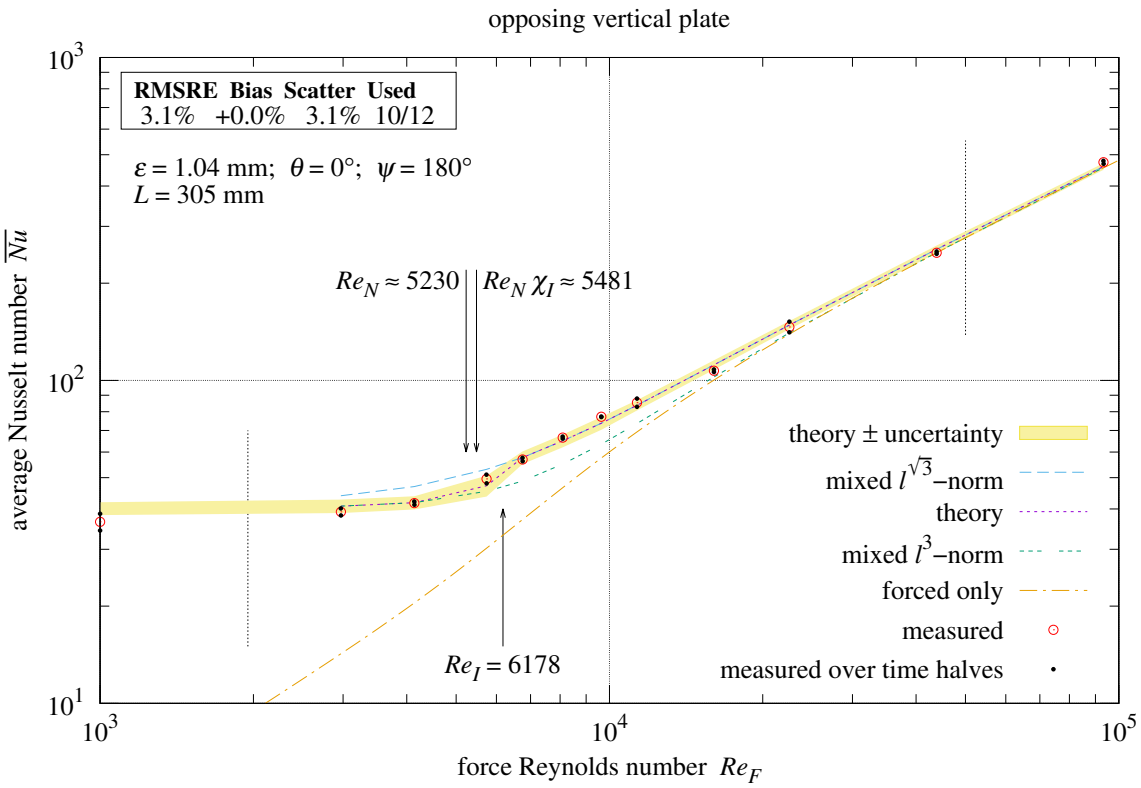
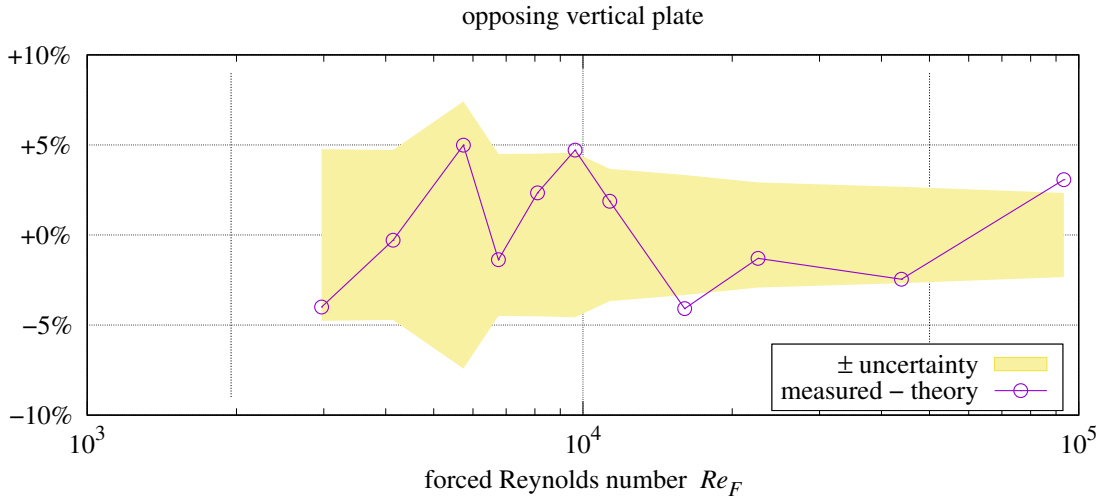
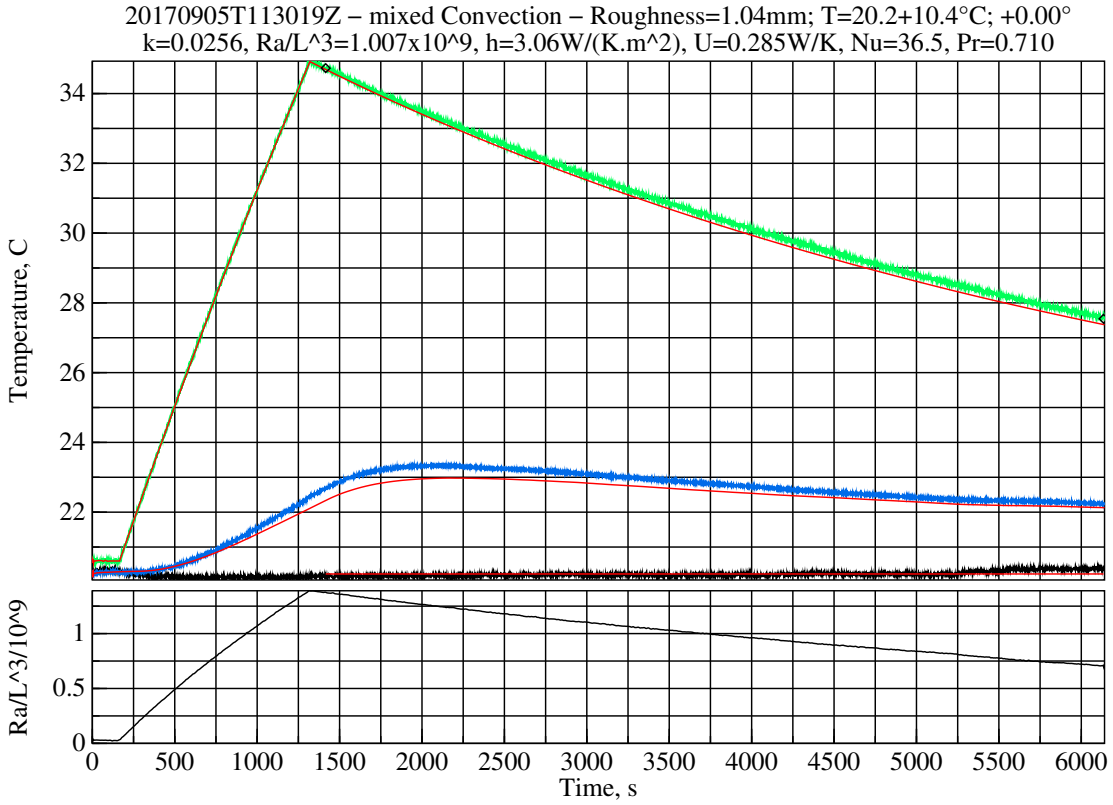
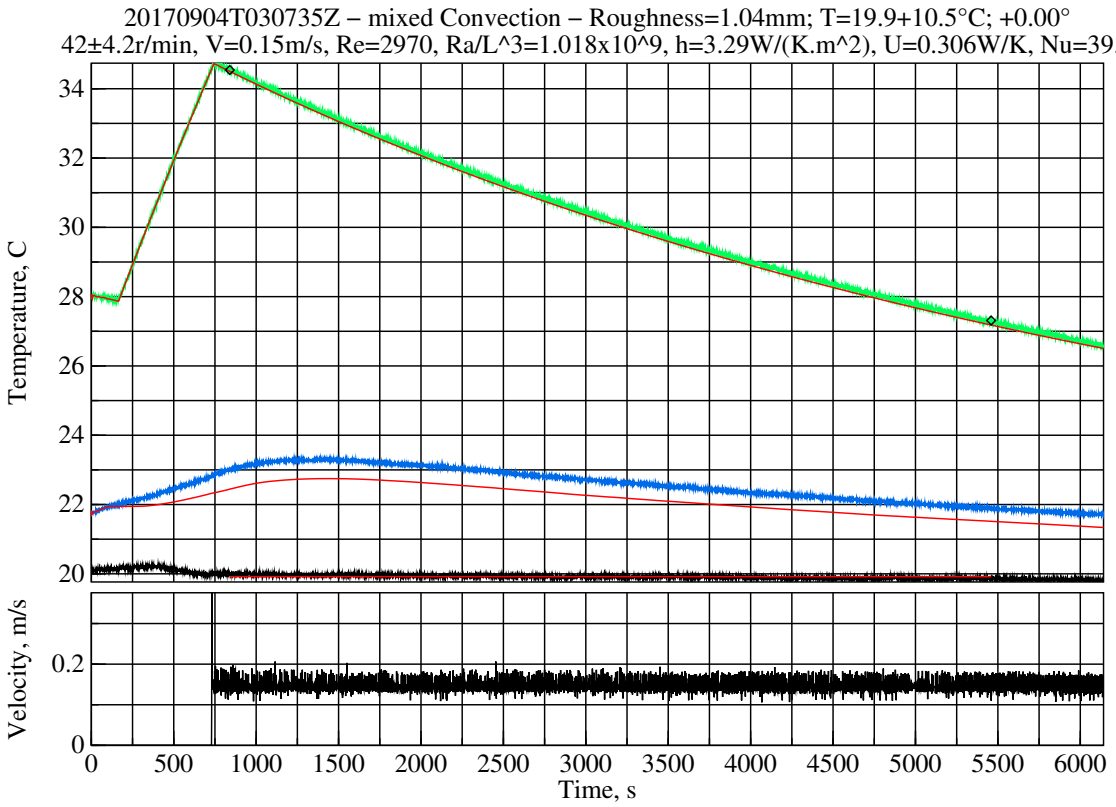

opposing vertical plate
RMSRE Bias Scatter Used
3.1% +0.0% 3.1% 10/12
ε = 1.04 mm; θ = 0°; ψ = 180°
L = 305 mm
Re_N ≈ 5230
Re_N χ_I ≈ 5481
Re_I = 6178
theory ± uncertainty
mixed l^√3–norm
theory
mixed l^3–norm
forced only
measured
measured over time halves
average Nusselt number Nu
force Reynolds number Re_F
10^3
10^2
10^1
10^4
10^5


opposing vertical plate
+10%
+5%
+0%
−5%
−10%
± uncertainty
measured − theory
forced Reynolds number Re_F
10^3
10^4
10^5



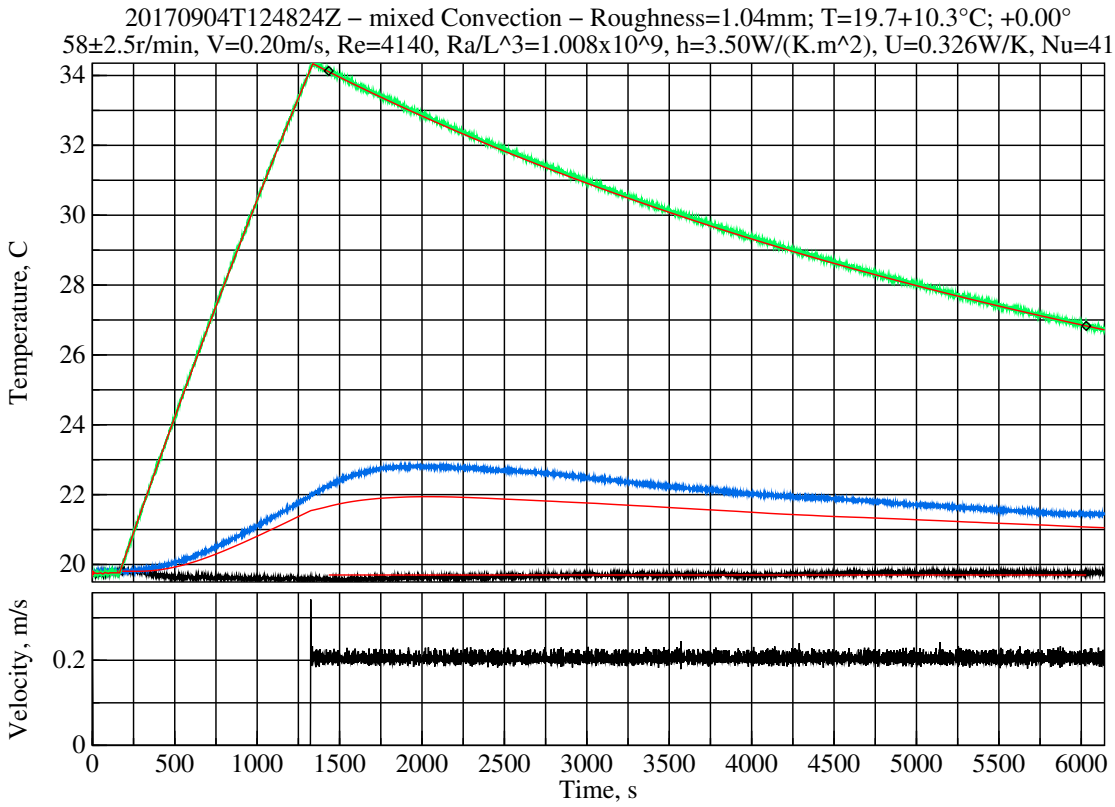
Estimated measurement uncertainties of natural convection at $\theta = 0.0$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+22.8%/K	0.10K	2.28%	LM35C differential
P	100kPa	+0.0007%/Pa	1.5kPa	1.02%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.048%/(J/K)	42J/K	2.04%	plate thermal capacity
C_V	1.000	−14.1%	0.100	1.41%	vertical reuptake
L_c	0.305m	+616%/m	500um	0.31%	characteristic length
D_{PIR}	25.4mm	−541%/m	1.0mm	0.54%	insulation thickness
D_g	1.00mm	−548%/m	500um	0.27%	air gap
L_m	3.57mm	+1185%/m	500um	0.59%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.523\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.58%	PIR thermal conductivity
ϵ_{XPS}	0.515	+39.2%	0.010	0.39%	XPS emissivity
ϵ_{tp}	0.890	+46.9%	0.015	0.70%	tape emissivity
Ω_{tp}	0.540	+31.9%	0.020	0.64%	tape coverage
ϵ_{rs}	0.040	+161%	0.010	1.61%	test-surface emissivity
ϵ_{wt}	0.900	+76.9%	0.025	1.92%	wind-tunnel emissivity
				4.58%	combined bias uncertainty



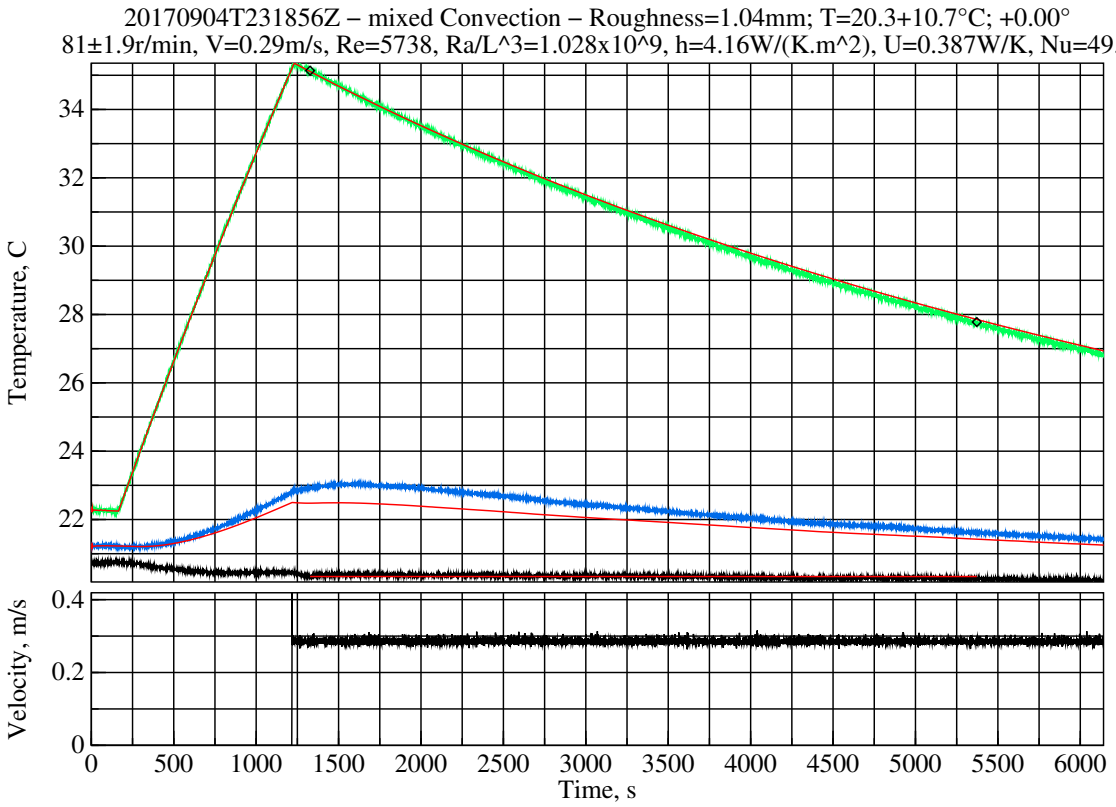
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 2970$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.5K	+22.4%/K	0.10K	2.24%	LM35C differential
P	100kPa	+0.0007%/Pa	1.5kPa	1.07%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.048%/(J/K)	42J/K	2.03%	plate thermal capacity
C_V	1.000	−13.9%	0.100	1.39%	vertical reuptake
L_c	0.305m	+605%/m	500um	0.30%	characteristic length
D_{PIR}	25.4mm	−532%/m	1.0mm	0.53%	insulation thickness
D_g	1.00mm	−539%/m	500um	0.27%	air gap
L_m	3.57mm	+1245%/m	500um	0.62%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.522\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.58%	PIR thermal conductivity
ϵ_{XPS}	0.515	+38.4%	0.010	0.38%	XPS emissivity
ϵ_{tp}	0.890	+45.9%	0.015	0.69%	tape emissivity
Ω_{tp}	0.540	+31.3%	0.020	0.63%	tape coverage
ϵ_{rs}	0.040	+158%	0.010	1.58%	test-surface emissivity
ϵ_{wt}	0.900	+75.3%	0.025	1.88%	wind-tunnel emissivity
				4.53%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	41.7r/min	+0.178%/(r/min)	4.2r/min	0.74%	fan rotation rate
				4.76%	RSS combined uncertainty



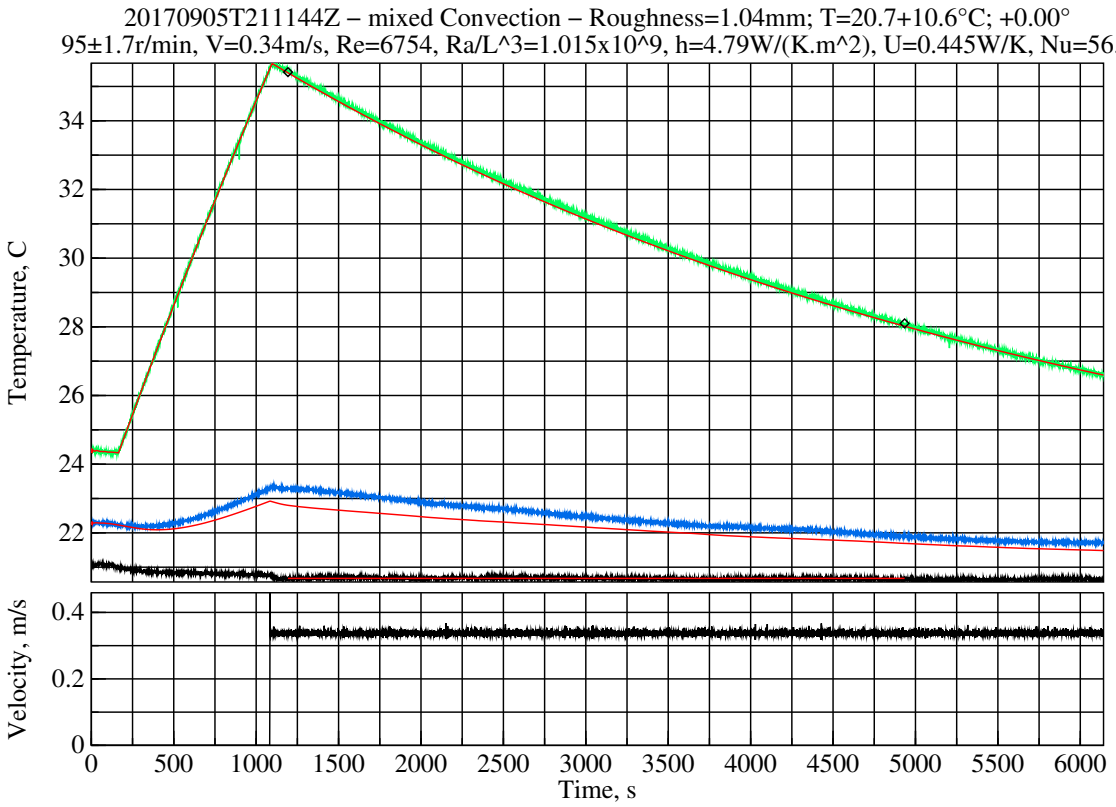
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 4140$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+22.4%/K	0.10K	2.24%	LM35C differential
P	100kPa	+0.0008%/Pa	1.5kPa	1.13%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.047%/(J/K)	42J/K	2.01%	plate thermal capacity
C_V	1.000	−13.5%	0.100	1.35%	vertical reuptake
L_c	0.305m	+596%/m	500um	0.30%	characteristic length
D_{PIR}	25.4mm	−562%/m	1.0mm	0.56%	insulation thickness
D_g	1.00mm	−570%/m	500um	0.29%	air gap
L_m	3.57mm	+1267%/m	500um	0.63%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.555\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.62%	PIR thermal conductivity
ϵ_{XPS}	0.515	+37.2%	0.010	0.37%	XPS emissivity
ϵ_{tp}	0.890	+44.6%	0.015	0.67%	tape emissivity
Ω_{tp}	0.540	+30.3%	0.020	0.61%	tape coverage
ϵ_{rs}	0.040	+154%	0.010	1.54%	test-surface emissivity
ϵ_{wt}	0.900	+72.8%	0.025	1.82%	wind-tunnel emissivity
				4.49%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	57.8r/min	+0.285%/(r/min)	2.5r/min	0.71%	fan rotation rate
				4.71%	RSS combined uncertainty



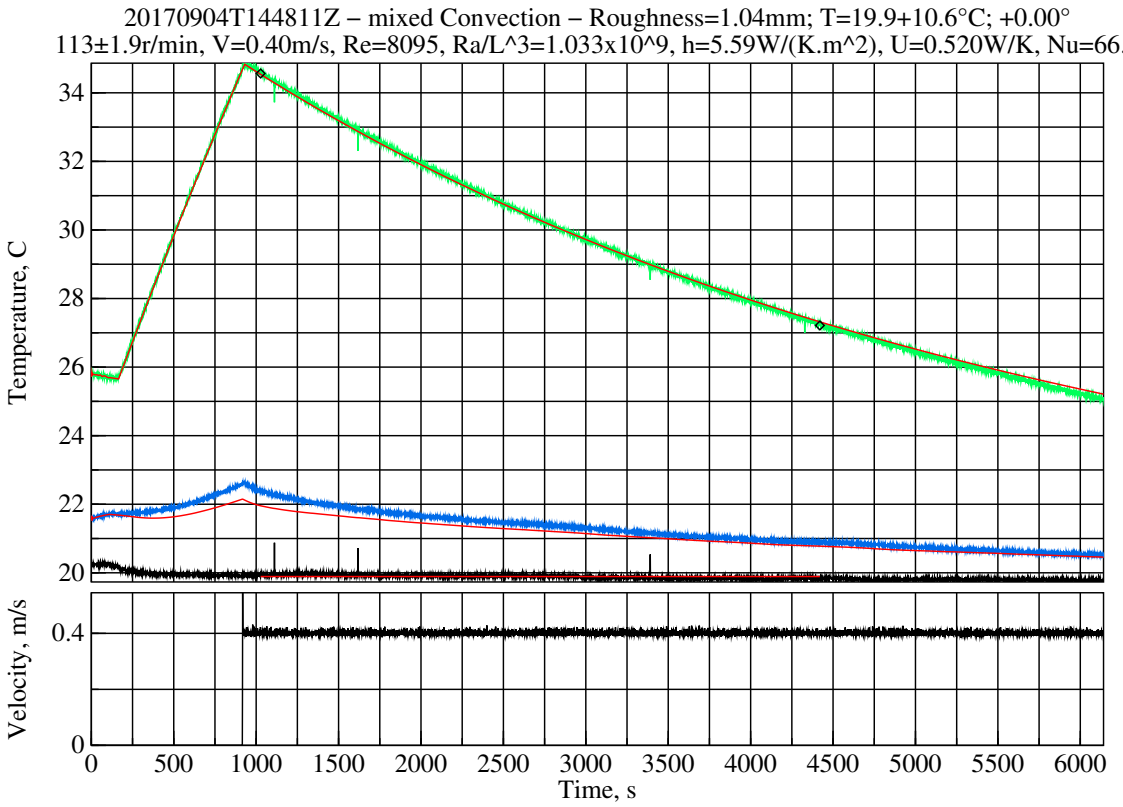
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 5738$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.7K	+18.6%/K	0.10K	1.86%	LM35C differential
P	100kPa	+0.0013%/Pa	1.5kPa	1.88%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.045%/(J/K)	42J/K	1.91%	plate thermal capacity
η	0.400	+300%	0.004	1.20%	anemometer calibration
C_V	1.000	−12.0%	0.100	1.20%	vertical reuptake
L_c	0.305m	+758%/m	500um	0.38%	characteristic length
ς	2.00mm	−11635%/m	100um	1.16%	post height
D_{PIR}	25.4mm	−532%/m	1.0mm	0.53%	insulation thickness
D_g	1.00mm	−540%/m	500um	0.27%	air gap
L_m	3.57mm	+1260%/m	500um	0.63%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.533\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.59%	PIR thermal conductivity
ϵ_{XPS}	0.515	+33.0%	0.010	0.33%	XPS emissivity
ϵ_{tp}	0.890	+39.6%	0.015	0.59%	tape emissivity
Ω_{tp}	0.540	+26.9%	0.020	0.54%	tape coverage
ϵ_{rs}	0.040	+137%	0.010	1.37%	test-surface emissivity
ϵ_{wt}	0.900	+64.4%	0.025	1.61%	wind-tunnel emissivity
θ	50.0m°	+2.15%/°	0.50°	1.08%	plate angle
				4.75%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	80.6r/min	+1.49%/(r/min)	1.9r/min	2.84%	fan rotation rate
				7.41%	RSS combined uncertainty



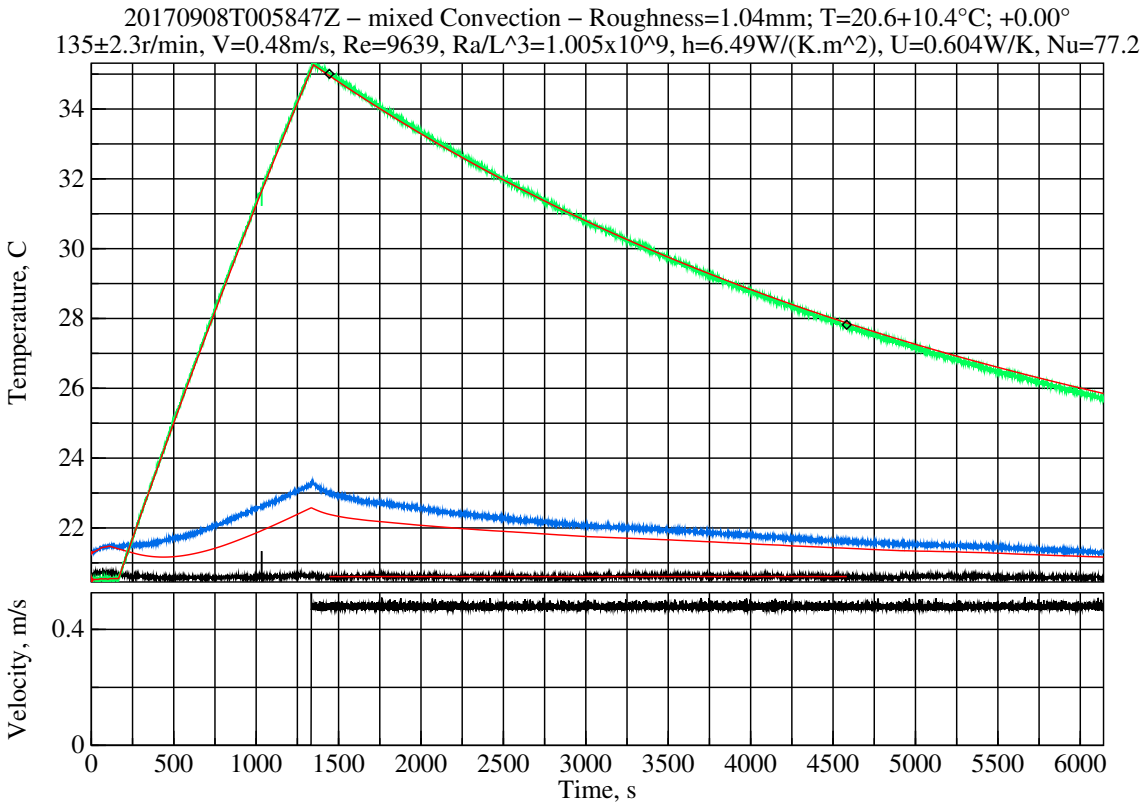
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 6753$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.6K	+18.4%/K	0.10K	1.84%	LM35C differential
P	100.0kPa	+0.0010%/Pa	1.5kPa	1.48%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.041%/(J/K)	42J/K	1.76%	plate thermal capacity
η	0.400	+156%	0.004	0.62%	anemometer calibration
C_V	1.000	−9.82%	0.100	0.98%	vertical reuptake
L_c	0.305m	+559%/m	500um	0.28%	characteristic length
L_T	8.34mm	+3123%/m	100um	0.31%	post length
ς	2.00mm	−8295%/m	100um	0.83%	post height
D_{PIR}	25.4mm	−449%/m	1.0mm	0.45%	insulation thickness
D_g	1.00mm	−455%/m	500um	0.23%	air gap
L_m	3.57mm	+1127%/m	500um	0.56%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.454\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.50%	PIR thermal conductivity
ϵ_{XPS}	0.515	+26.9%	0.010	0.27%	XPS emissivity
ϵ_{tp}	0.890	+32.3%	0.015	0.48%	tape emissivity
Ω_{tp}	0.540	+22.0%	0.020	0.44%	tape coverage
ϵ_{rs}	0.040	+113%	0.010	1.13%	test-surface emissivity
ϵ_{wt}	0.900	+52.6%	0.025	1.31%	wind-tunnel emissivity
				3.91%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	95.3r/min	+0.653%/(r/min)	1.7r/min	1.11%	fan rotation rate
				4.50%	RSS combined uncertainty



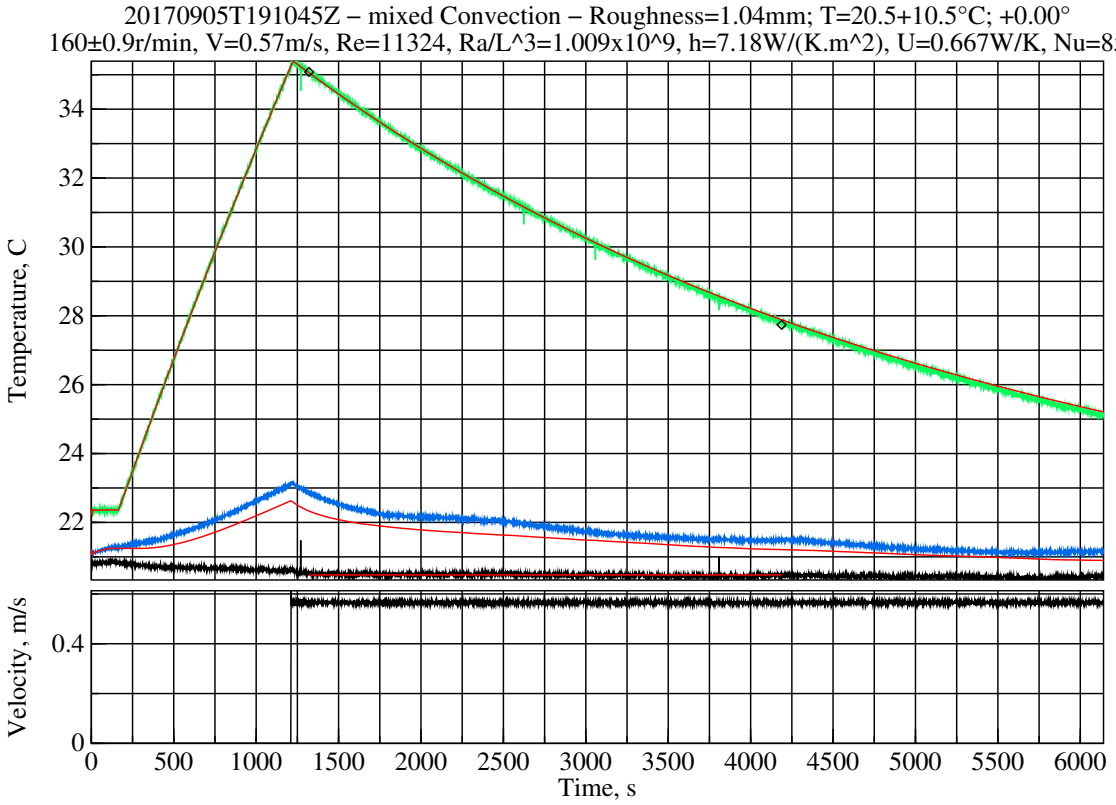
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 8096$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.6K	+17.4%/K	0.10K	1.74%	LM35C differential
P	100kPa	+0.0010%/Pa	1.5kPa	1.53%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.040%/(J/K)	42J/K	1.67%	plate thermal capacity
η	0.400	+180%	0.004	0.72%	anemometer calibration
C_V	1.000	−8.74%	0.100	0.87%	vertical reuptake
L_c	0.305m	+529%/m	500um	0.26%	characteristic length
L_T	8.34mm	+4401%/m	100um	0.44%	post length
ς	2.00mm	−11189%/m	100um	1.12%	post height
D_{PIR}	25.4mm	−411%/m	1.0mm	0.41%	insulation thickness
D_g	1.00mm	−417%/m	500um	0.21%	air gap
L_m	3.57mm	+1047%/m	500um	0.52%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.417\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.46%	PIR thermal conductivity
ϵ_{XPS}	0.515	+23.7%	0.010	0.24%	XPS emissivity
ϵ_{tp}	0.890	+28.4%	0.015	0.43%	tape emissivity
Ω_{tp}	0.540	+19.3%	0.020	0.39%	tape coverage
ϵ_{rs}	0.040	+99.3%	0.010	0.99%	test-surface emissivity
ϵ_{wt}	0.900	+46.2%	0.025	1.15%	wind-tunnel emissivity
				3.80%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	113r/min	+0.635%/(r/min)	1.9r/min	1.21%	fan rotation rate
				4.51%	RSS combined uncertainty



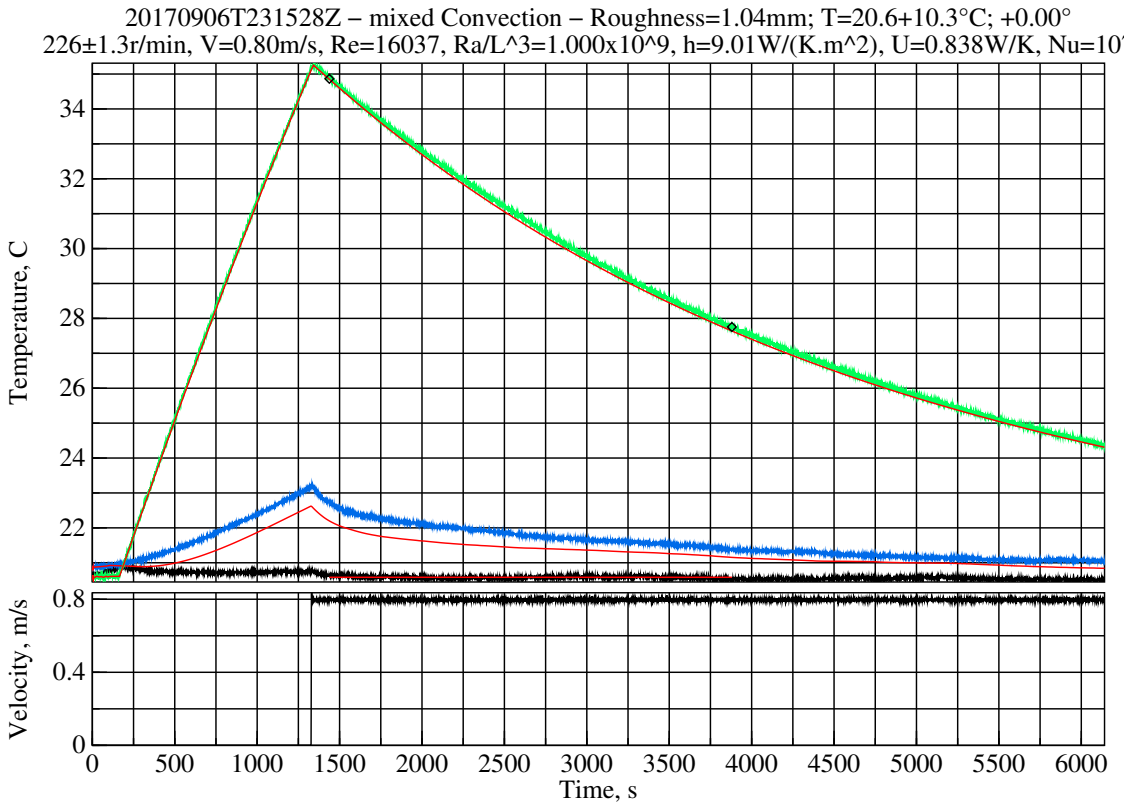
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 9640$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+16.8%/K	0.10K	1.68%	LM35C differential
P	101kPa	+0.0010%/Pa	1.5kPa	1.55%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.038%/(J/K)	42J/K	1.60%	plate thermal capacity
η	0.400	+200%	0.004	0.80%	anemometer calibration
C_V	1.000	−7.66%	0.100	0.77%	vertical reuptake
L_c	0.305m	+484%/m	500um	0.24%	characteristic length
L_T	8.34mm	+5569%/m	100um	0.56%	post length
ς	2.00mm	−12599%/m	100um	1.26%	post height
D_{PIR}	25.4mm	−371%/m	1.0mm	0.37%	insulation thickness
L_m	3.57mm	+976%/m	500um	0.49%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.378\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.42%	PIR thermal conductivity
ϵ_{XPS}	0.515	+20.9%	0.010	0.21%	XPS emissivity
ϵ_{tp}	0.890	+25.1%	0.015	0.38%	tape emissivity
Ω_{tp}	0.540	+17.1%	0.020	0.34%	tape coverage
ϵ_{rs}	0.040	+87.9%	0.010	0.88%	test-surface emissivity
ϵ_{wt}	0.900	+40.8%	0.025	1.02%	wind-tunnel emissivity
				3.71%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	135r/min	+0.590%/(r/min)	2.3r/min	1.34%	fan rotation rate
				4.57%	RSS combined uncertainty



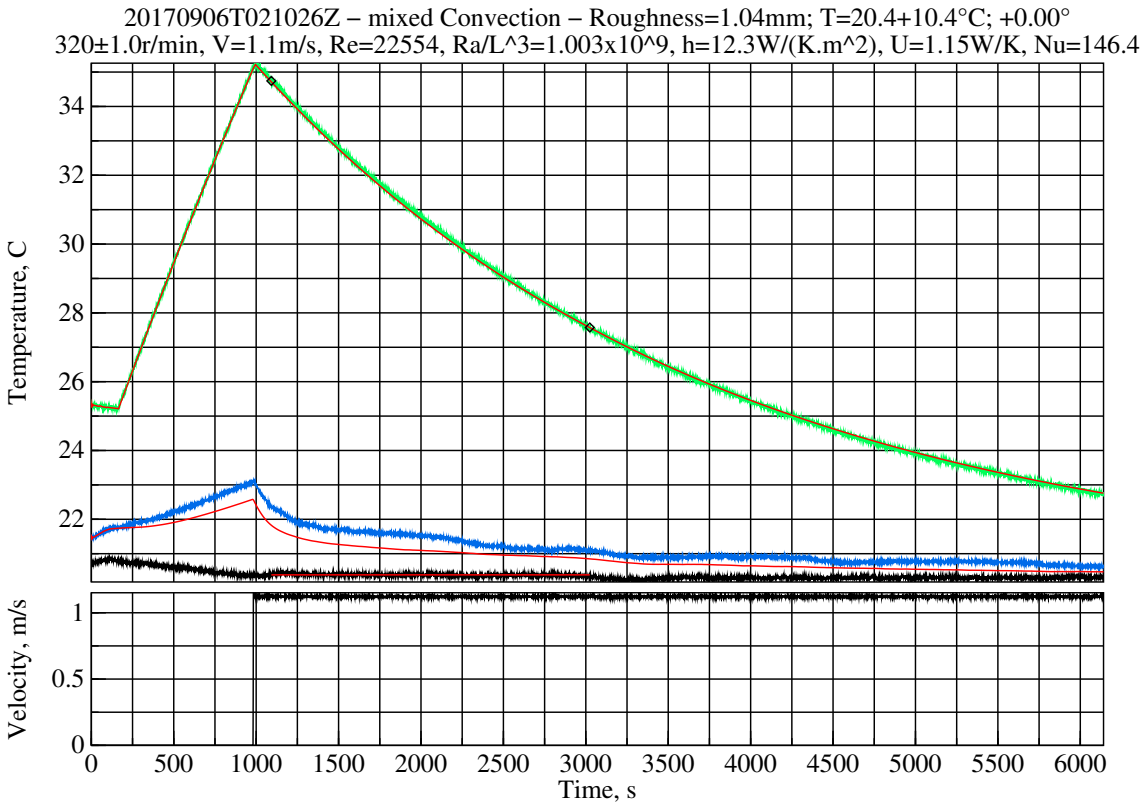
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 11324$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.5K	+15.6%/K	0.10K	1.56%	LM35C differential
P	99.9kPa	+0.0010%/Pa	1.5kPa	1.56%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.036%/(J/K)	42J/K	1.53%	plate thermal capacity
η	0.400	+210%	0.004	0.84%	anemometer calibration
C_V	1.000	−6.73%	0.100	0.67%	vertical reuptake
L_c	0.305m	+431%/m	500um	0.22%	characteristic length
L_T	8.34mm	+6451%/m	100um	0.65%	post length
ς	2.00mm	−12554%/m	100um	1.26%	post height
D_{PIR}	25.4mm	−333%/m	1.0mm	0.33%	insulation thickness
L_m	3.57mm	+904%/m	500um	0.45%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.340\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.38%	PIR thermal conductivity
ϵ_{tp}	0.890	+22.0%	0.015	0.33%	tape emissivity
Ω_{tp}	0.540	+15.0%	0.020	0.30%	tape coverage
ϵ_{rs}	0.040	+77.3%	0.010	0.77%	test-surface emissivity
ϵ_{wt}	0.900	+35.8%	0.025	0.89%	wind-tunnel emissivity
				3.55%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	160r/min	+0.525%/(r/min)	0.90r/min	0.47%	fan rotation rate
				3.67%	RSS combined uncertainty



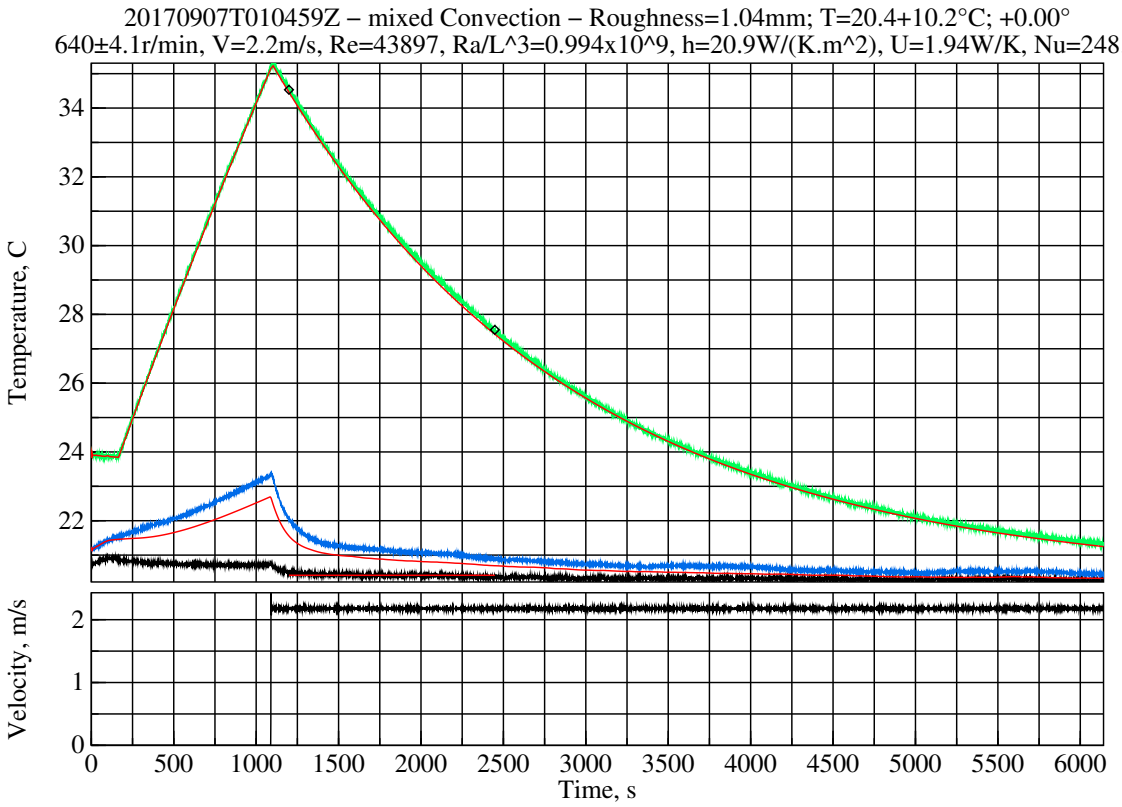
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 16038$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+14.3%/K	0.10K	1.43%	LM35C differential
P	101kPa	+0.0010%/Pa	1.5kPa	1.47%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.033%/(J/K)	42J/K	1.40%	plate thermal capacity
η	0.400	+217%	0.004	0.87%	anemometer calibration
C_V	1.000	−5.00%	0.100	0.50%	vertical reuptake
L_T	8.34mm	+7811%/m	100um	0.78%	post length
ς	2.00mm	−10268%/m	100um	1.03%	post height
D_{PIR}	25.4mm	−259%/m	1.0mm	0.26%	insulation thickness
L_m	3.57mm	+768%/m	500um	0.38%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.266\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.29%	PIR thermal conductivity
ϵ_{tp}	0.890	+16.3%	0.015	0.25%	tape emissivity
Ω_{tp}	0.540	+11.1%	0.020	0.22%	tape coverage
ϵ_{rs}	0.040	+57.5%	0.010	0.57%	test-surface emissivity
ϵ_{wt}	0.900	+26.5%	0.025	0.66%	wind-tunnel emissivity
				3.18%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	226r/min	+0.384%/(r/min)	1.3r/min	0.49%	fan rotation rate
				3.33%	RSS combined uncertainty



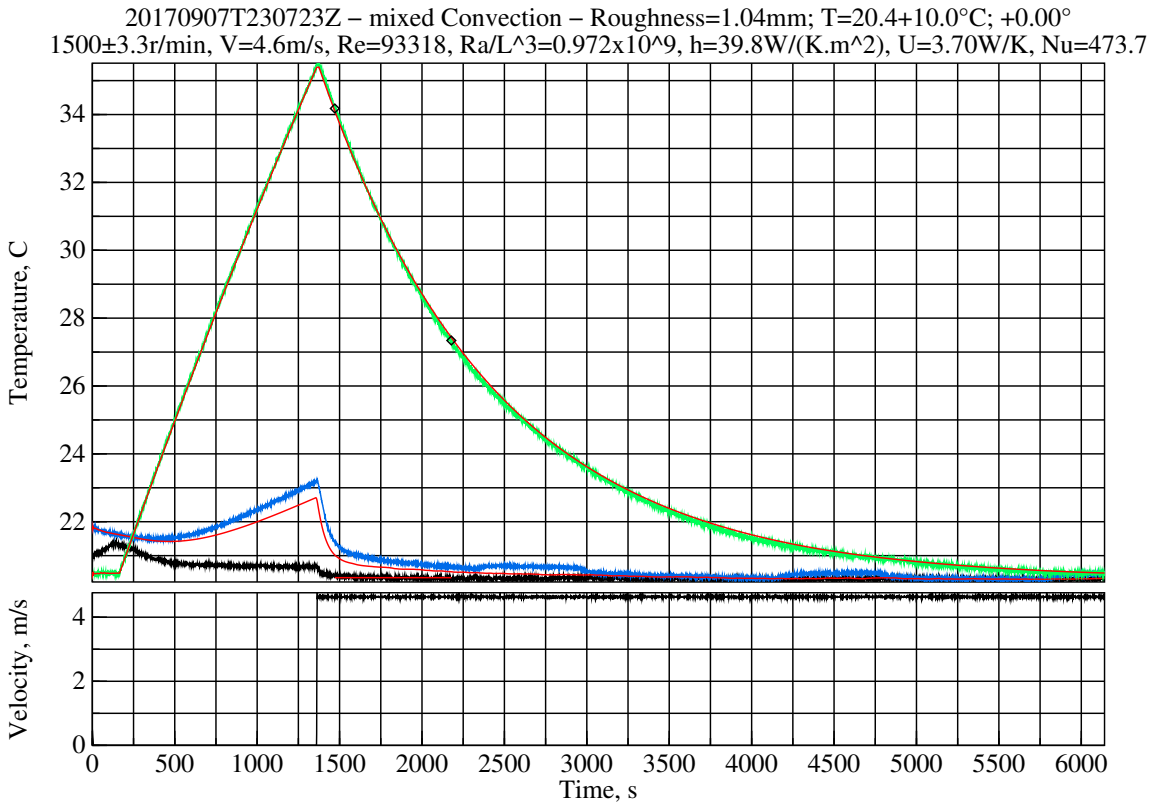
Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 22552$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+13.0%/K	0.10K	1.30%	LM35C differential
P	100kPa	+0.0009%/Pa	1.5kPa	1.39%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.031%/(J/K)	42J/K	1.30%	plate thermal capacity
η	0.400	+212%	0.004	0.85%	anemometer calibration
C_V	1.000	−3.74%	0.100	0.37%	vertical reuptake
L_T	8.34mm	+8536%/m	100um	0.85%	post length
ς	2.00mm	−7329%/m	100um	0.73%	post height
L_m	3.57mm	+665%/m	500um	0.33%	side metal strip width
k_{PIR}	22.2$\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	+0.206%/$\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	1.1$\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.23%	PIR thermal conductivity
ϵ_{rs}	0.040	+42.8%	0.010	0.43%	test-surface emissivity
ϵ_{wt}	0.900	+19.7%	0.025	0.49%	wind-tunnel emissivity
				2.87%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	320r/min	+0.265%/(r/min)	1.0r/min	0.28%	fan rotation rate
				2.92%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 43897$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.2K	+11.8%/K	0.10K	1.18%	LM35C differential
P	101kPa	+0.0008%/Pa	1.5kPa	1.26%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.028%/(J/K)	42J/K	1.18%	plate thermal capacity
η	0.400	+189%	0.004	0.76%	anemometer calibration
C_V	1.000	−2.14%	0.100	0.21%	vertical reuptake
L_T	8.34mm	+9120%/m	100um	0.91%	post length
ς	2.00mm	−2950%/m	100um	0.30%	post height
L_m	3.57mm	+543%/m	500um	0.27%	side metal strip width
ϵ_{rs}	0.040	+24.6%	0.010	0.25%	test-surface emissivity
ϵ_{wt}	0.900	+11.2%	0.025	0.28%	wind-tunnel emissivity
				2.50%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	640r/min	+0.118%/(r/min)	4.1r/min	0.48%	fan rotation rate
				2.68%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 1mm roughness at $Re = 93318$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.0K	+11.2%/K	0.10K	1.12%	LM35C differential
P	100kPa	+0.0008%/Pa	1.5kPa	1.19%	MPXH6115A6U air pressure
C_{pt}	4.24kJ/K	+0.026%/(J/K)	42J/K	1.10%	plate thermal capacity
η	0.400	+127%	0.004	0.51%	anemometer calibration
u_u	7.755	+3.63%	0.100	0.36%	diffuser airflow upper bound
L_T	8.34mm	+9330%/m	100um	0.93%	post length
L_m	3.57mm	+483%/m	500um	0.24%	side metal strip width
				2.31%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	1.50kr/min	+0.056%/(r/min)	3.3r/min	0.18%	fan rotation rate
				2.34%	RSS combined uncertainty