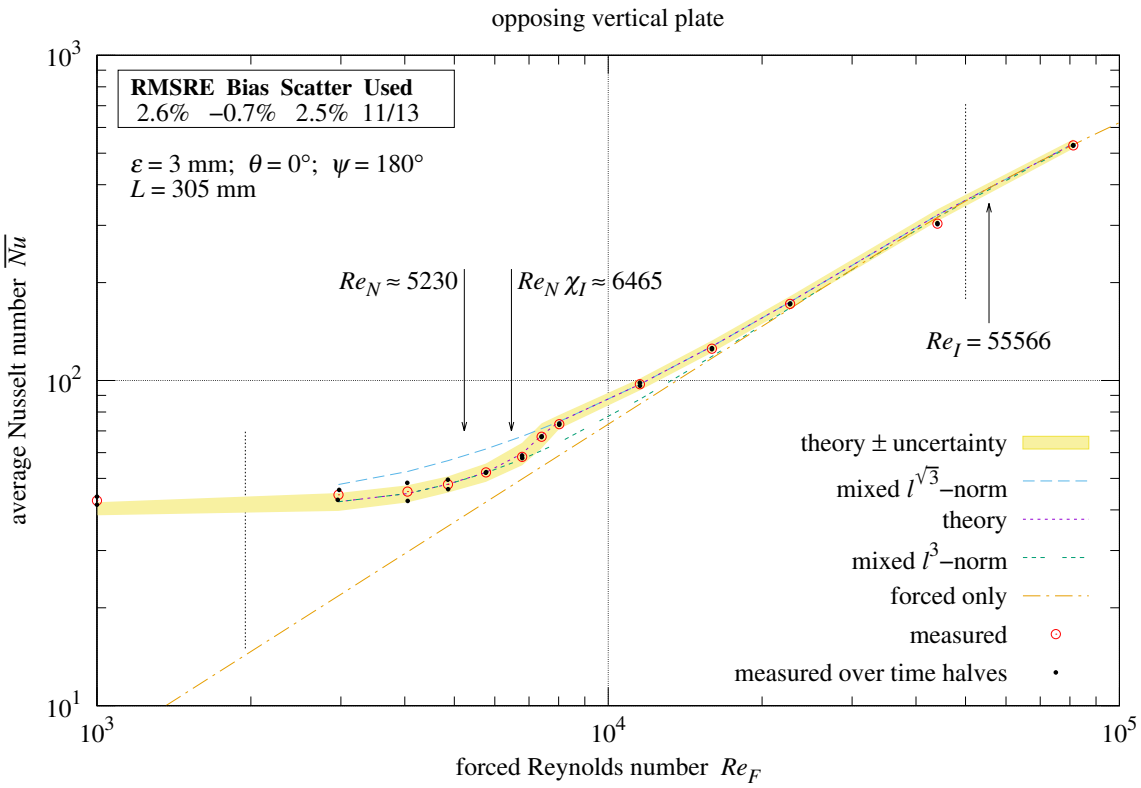
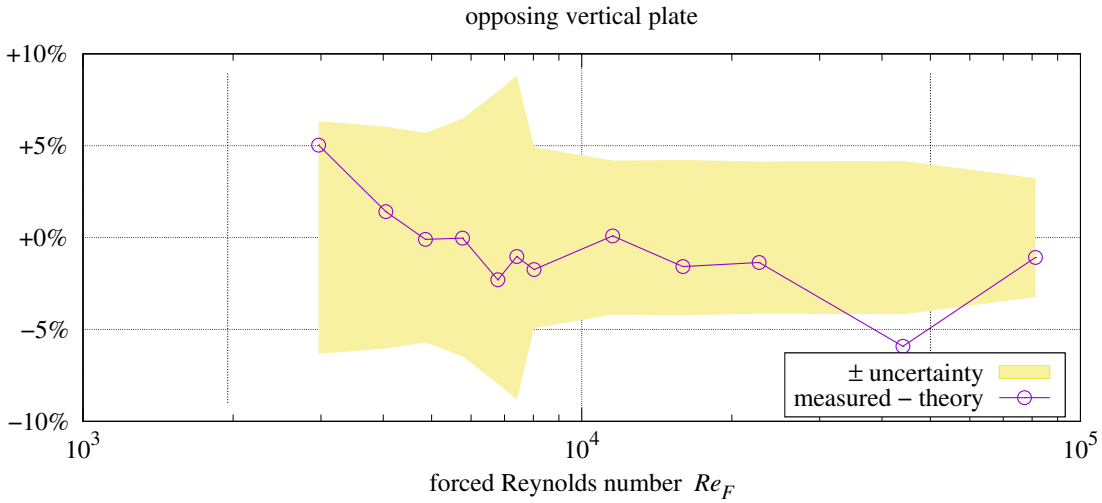
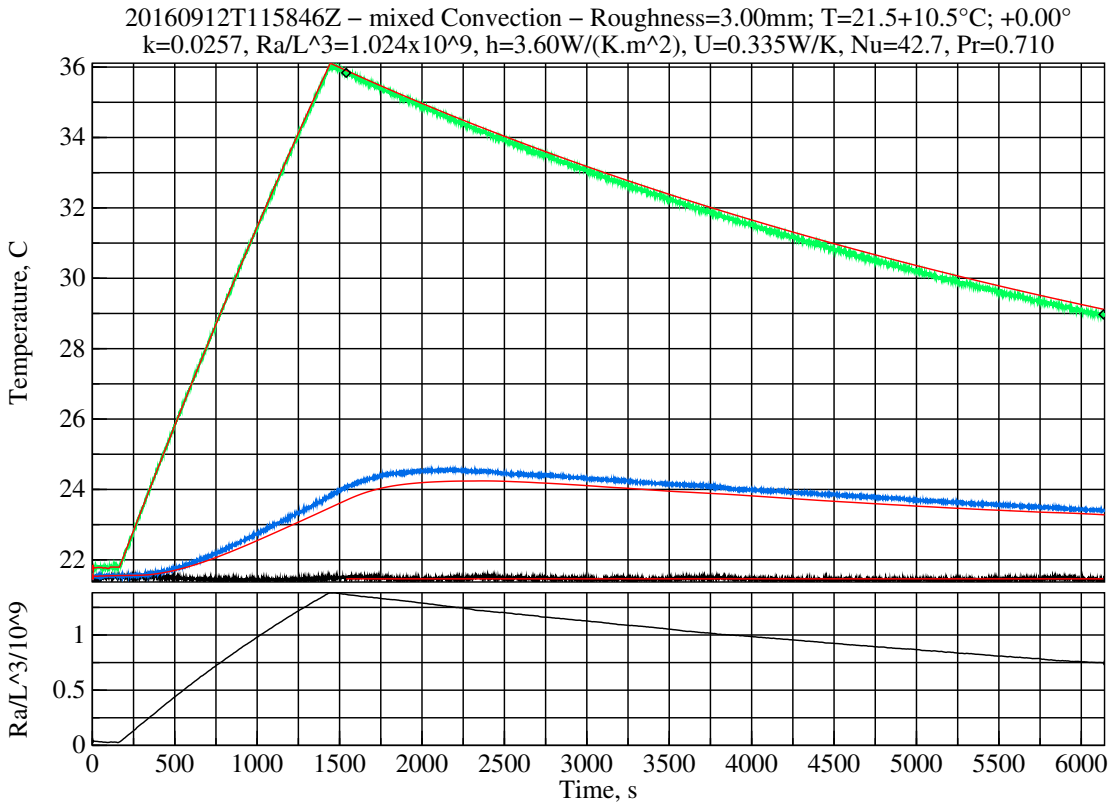
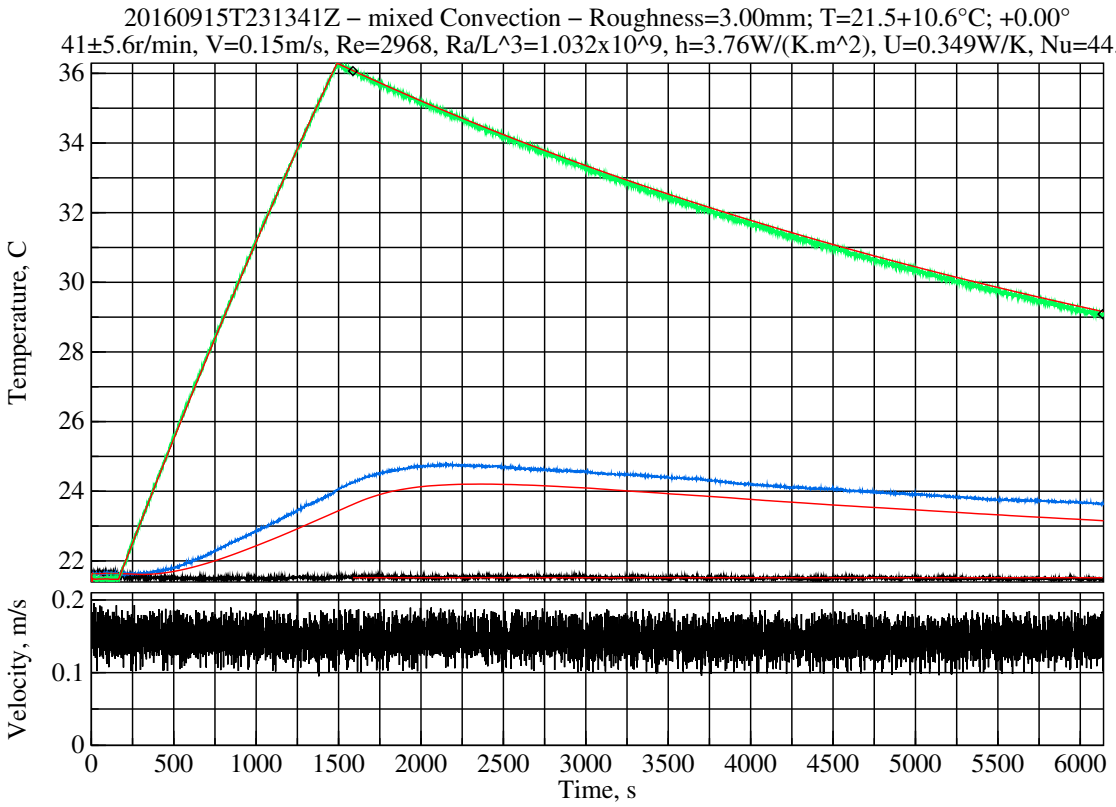

opposing vertical plate
RMSRE Bias Scatter Used
2.6% −0.7% 2.5% 11/13
ε = 3 mm; θ = 0°; ψ = 180°
L = 305 mm
Re_N ≈ 5230
Re_N χ_I ≈ 6465
Re_I = 55566
theory ± uncertainty
mixed l^√3–norm
theory
mixed l^3–norm
forced only
measured
measured over time halves
average Nusselt number Nu
forced Reynolds number Re_F


opposing vertical plate
± uncertainty
measured − theory
forced Reynolds number Re_F



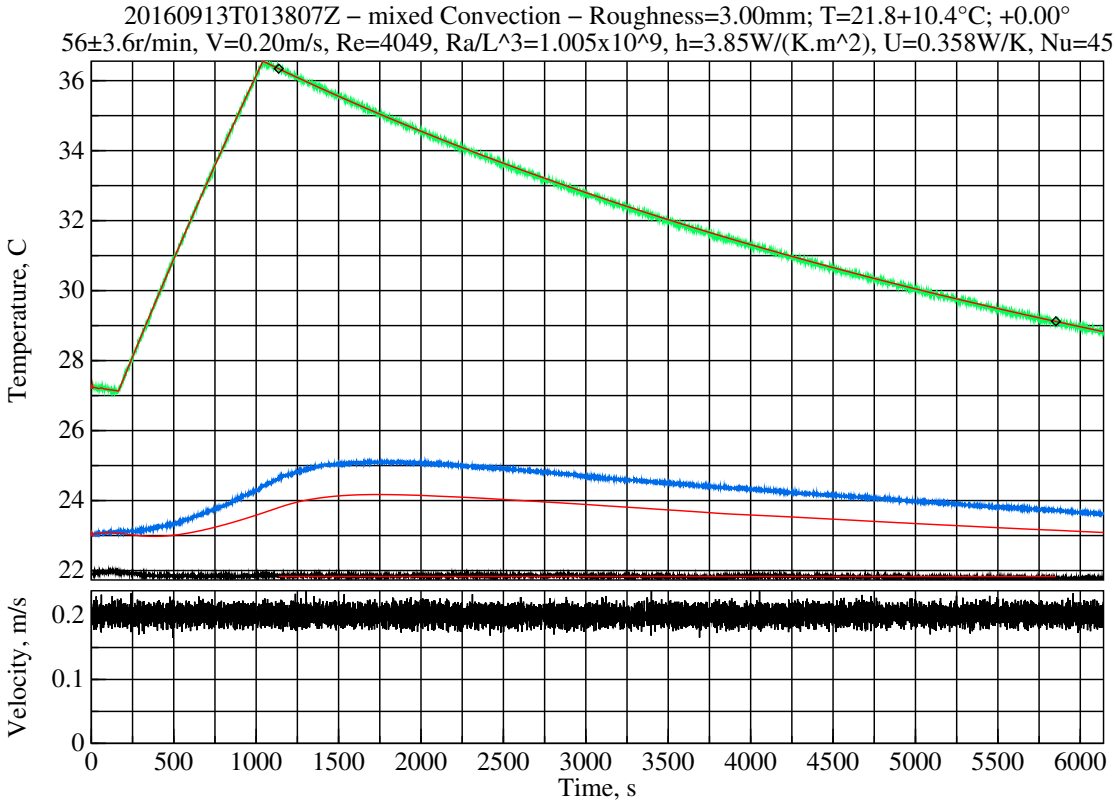
Estimated measurement uncertainties of natural convection at $\theta = 0.0$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.5K	+23.0%/K	0.10K	2.30%	LM35C differential
P	102kPa	+0.0007%/Pa	1.5kPa	1.03%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.044%/(J/K)	47J/K	2.06%	plate thermal capacity
C_V	1.000	−15.1%	0.100	1.51%	vertical reuptake
L_c	0.305m	+622%/m	500um	0.31%	characteristic length
D_{PIR}	25.4mm	−542%/m	1.0mm	0.54%	insulation thickness
D_g	1.00mm	−550%/m	500um	0.27%	air gap
L_m	3.57mm	+1198%/m	500um	0.60%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.524\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.58%	PIR thermal conductivity
ϵ_{XPS}	0.515	+38.9%	0.010	0.39%	XPS emissivity
ϵ_{tp}	0.890	+46.6%	0.015	0.70%	tape emissivity
Ω_{tp}	0.540	+31.7%	0.020	0.63%	tape coverage
ϵ_{rs}	0.040	+162%	0.010	1.62%	test-surface emissivity
ϵ_{wt}	0.900	+76.4%	0.025	1.91%	wind-tunnel emissivity
				4.63%	combined bias uncertainty



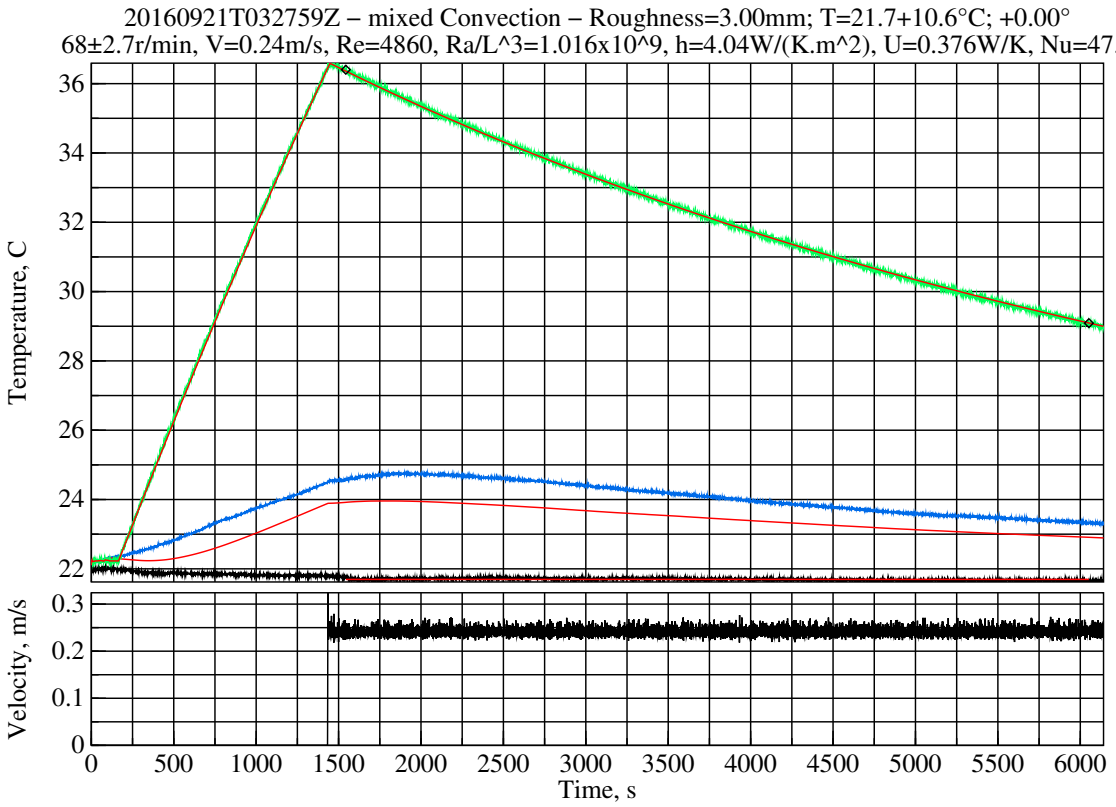
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 2968$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.6K	+21.9%/K	0.10K	2.19%	LM35C differential
P	102kPa	+0.0007%/Pa	1.5kPa	1.12%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.043%/(J/K)	47J/K	2.01%	plate thermal capacity
η	0.401	+40.5%	0.014	0.57%	anemometer calibration
C_V	1.000	−14.4%	0.100	1.44%	vertical reuptake
L_c	0.305m	+586%/m	500um	0.29%	characteristic length
D_{PIR}	25.4mm	−511%/m	1.0mm	0.51%	insulation thickness
D_g	1.00mm	−518%/m	500um	0.26%	air gap
L_m	3.57mm	+1205%/m	500um	0.60%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.500\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.55%	PIR thermal conductivity
ϵ_{XPS}	0.515	+36.9%	0.010	0.37%	XPS emissivity
ϵ_{tp}	0.890	+44.3%	0.015	0.66%	tape emissivity
Ω_{tp}	0.540	+30.1%	0.020	0.60%	tape coverage
ϵ_{rs}	0.040	+154%	0.010	1.54%	test-surface emissivity
ϵ_{wt}	0.900	+72.6%	0.025	1.81%	wind-tunnel emissivity
				4.50%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	41.2r/min	+0.394%/(r/min)	5.6r/min	2.22%	fan rotation rate
				6.33%	RSS combined uncertainty



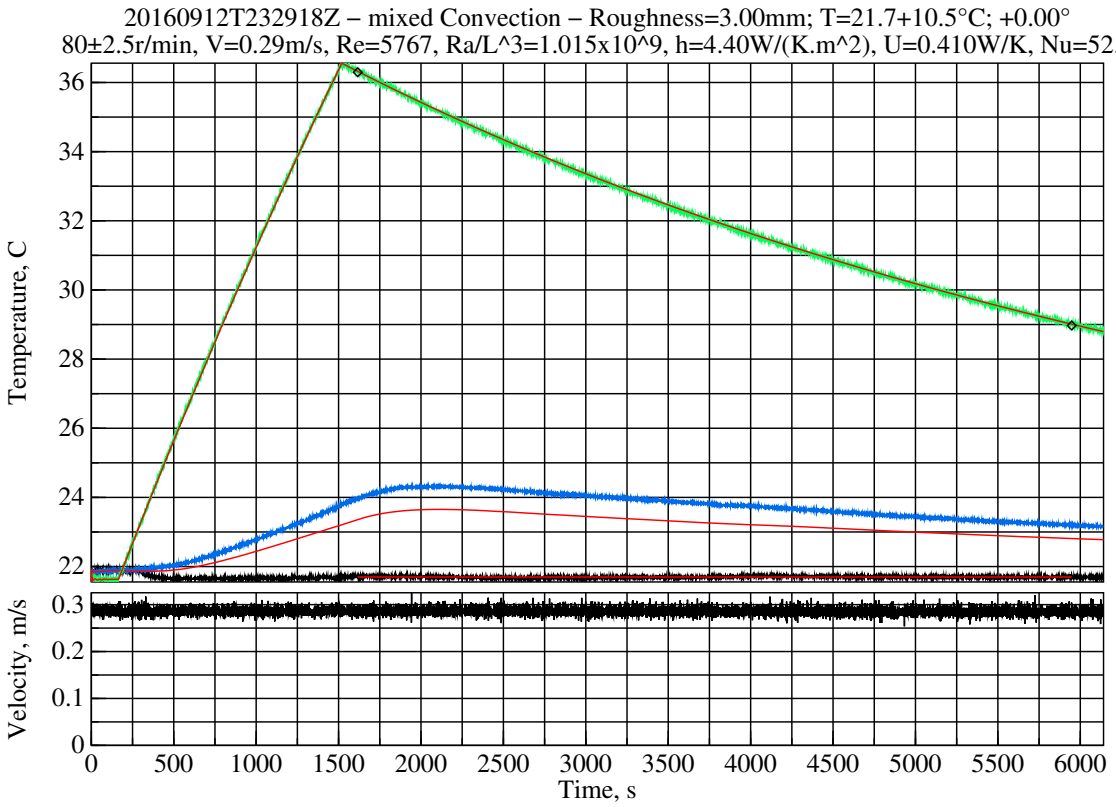
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 4049$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+21.3%/K	0.10K	2.13%	LM35C differential
P	101kPa	+0.0008%/Pa	1.5kPa	1.20%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.042%/(J/K)	47J/K	1.96%	plate thermal capacity
η	0.401	+78.5%	0.014	1.10%	anemometer calibration
C_V	1.000	−13.5%	0.100	1.35%	vertical reuptake
L_c	0.305m	+547%/m	500um	0.27%	characteristic length
ς	6.00mm	+2075%/m	100um	0.21%	post height
D_{PIR}	25.4mm	−519%/m	1.0mm	0.52%	insulation thickness
D_g	1.00mm	−527%/m	500um	0.26%	air gap
L_m	3.57mm	+1180%/m	500um	0.59%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.511\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.57%	PIR thermal conductivity
ϵ_{XPS}	0.515	+34.9%	0.010	0.35%	XPS emissivity
ϵ_{tp}	0.890	+41.9%	0.015	0.63%	tape emissivity
Ω_{tp}	0.540	+28.4%	0.020	0.57%	tape coverage
ϵ_{rs}	0.040	+146%	0.010	1.46%	test-surface emissivity
ϵ_{wt}	0.900	+68.4%	0.025	1.71%	wind-tunnel emissivity
				4.47%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	56.5r/min	+0.558%/(r/min)	3.6r/min	2.03%	fan rotation rate
				6.03%	RSS combined uncertainty



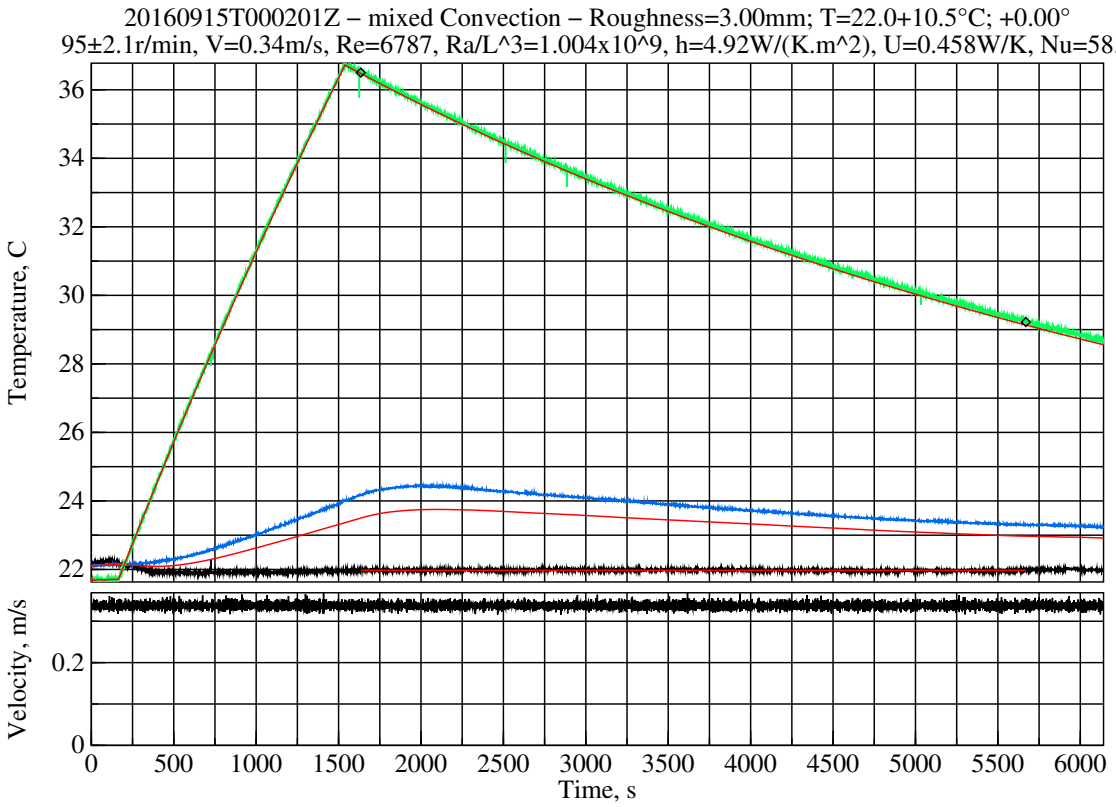
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 4860$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.6K	+20.1%/K	0.10K	2.01%	LM35C differential
P	101kPa	+0.0009%/Pa	1.5kPa	1.28%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.041%/(J/K)	47J/K	1.91%	plate thermal capacity
η	0.401	+111%	0.014	1.56%	anemometer calibration
C_V	1.000	−12.7%	0.100	1.27%	vertical reuptake
L_c	0.305m	+513%/m	500um	0.26%	characteristic length
ς	6.00mm	+2940%/m	100um	0.29%	post height
D_{PIR}	25.4mm	−506%/m	1.0mm	0.51%	insulation thickness
D_g	1.00mm	−513%/m	500um	0.26%	air gap
L_m	3.57mm	+1140%/m	500um	0.57%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.500\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.55%	PIR thermal conductivity
ϵ_{XPS}	0.515	+32.6%	0.010	0.33%	XPS emissivity
ϵ_{tp}	0.890	+39.2%	0.015	0.59%	tape emissivity
Ω_{tp}	0.540	+26.6%	0.020	0.53%	tape coverage
ϵ_{rs}	0.040	+136%	0.010	1.36%	test-surface emissivity
ϵ_{wt}	0.900	+63.9%	0.025	1.60%	wind-tunnel emissivity
				4.44%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	67.9r/min	+0.655%/(r/min)	2.7r/min	1.79%	fan rotation rate
				5.70%	RSS combined uncertainty



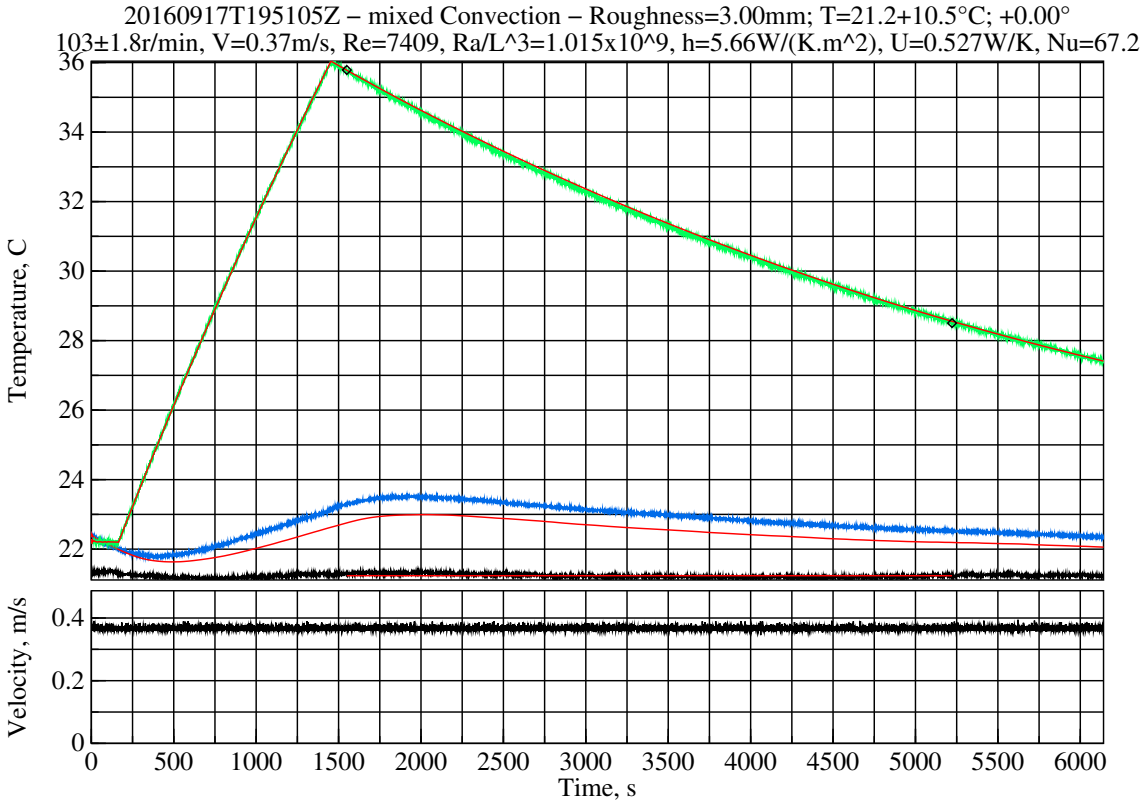
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 5767$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.5K	+19.0%/K	0.10K	1.90%	LM35C differential
P	101kPa	+0.0009%/Pa	1.5kPa	1.42%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.039%/(J/K)	47J/K	1.84%	plate thermal capacity
η	0.401	+173%	0.014	2.43%	anemometer calibration
C_V	1.000	−11.7%	0.100	1.17%	vertical reuptake
L_c	0.305m	+496%/m	500um	0.25%	characteristic length
ς	6.00mm	+3727%/m	100um	0.37%	post height
D_{PIR}	25.4mm	−481%/m	1.0mm	0.48%	insulation thickness
D_g	1.00mm	−488%/m	500um	0.24%	air gap
L_m	3.57mm	+1137%/m	500um	0.57%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.481\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.53%	PIR thermal conductivity
ϵ_{XPS}	0.515	+29.8%	0.010	0.30%	XPS emissivity
ϵ_{tp}	0.890	+35.8%	0.015	0.54%	tape emissivity
Ω_{tp}	0.540	+24.3%	0.020	0.49%	tape coverage
ϵ_{rs}	0.040	+125%	0.010	1.25%	test-surface emissivity
ϵ_{wt}	0.900	+58.3%	0.025	1.46%	wind-tunnel emissivity
θ	0.00°	+1.79%/°	0.50°	0.90%	plate angle
				4.75%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	80.4r/min	+0.865%/(r/min)	2.5r/min	2.19%	fan rotation rate
				6.47%	RSS combined uncertainty



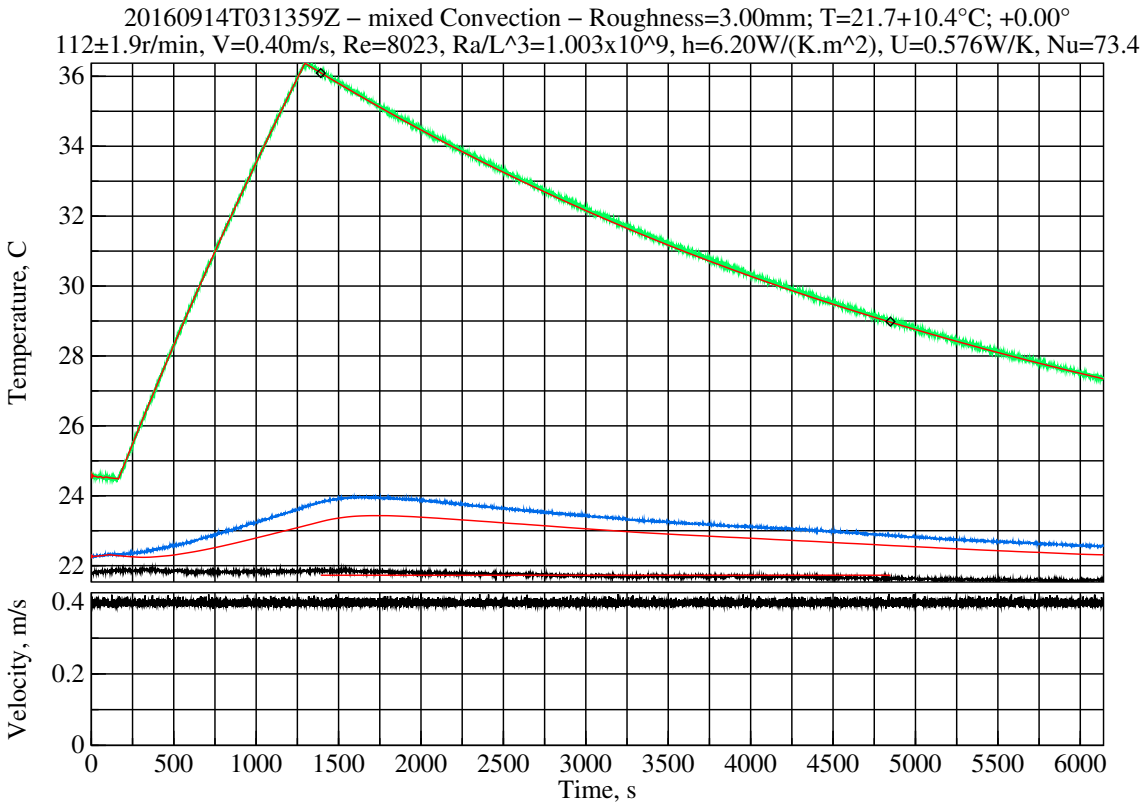
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 6788$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.5K	+16.7%/K	0.10K	1.67%	LM35C differential
P	101kPa	+0.0012%/Pa	1.5kPa	1.75%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.037%/(J/K)	47J/K	1.75%	plate thermal capacity
η	0.401	+311%	0.014	4.37%	anemometer calibration
C_V	1.000	−10.2%	0.100	1.02%	vertical reuptake
L_c	0.305m	+653%/m	500um	0.33%	characteristic length
ς	6.00mm	+3073%/m	100um	0.31%	post height
D_{PIR}	25.4mm	−433%/m	1.0mm	0.43%	insulation thickness
D_g	1.00mm	−439%/m	500um	0.22%	air gap
L_m	3.57mm	+1092%/m	500um	0.55%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.438\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.49%	PIR thermal conductivity
ϵ_{XPS}	0.515	+26.0%	0.010	0.26%	XPS emissivity
ϵ_{tp}	0.890	+31.2%	0.015	0.47%	tape emissivity
Ω_{tp}	0.540	+21.2%	0.020	0.42%	tape coverage
ϵ_{rs}	0.040	+110%	0.010	1.10%	test-surface emissivity
ϵ_{wt}	0.900	+50.8%	0.025	1.27%	wind-tunnel emissivity
				5.77%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	95.0r/min	+1.31%/(r/min)	2.1r/min	2.74%	fan rotation rate
				7.95%	RSS combined uncertainty



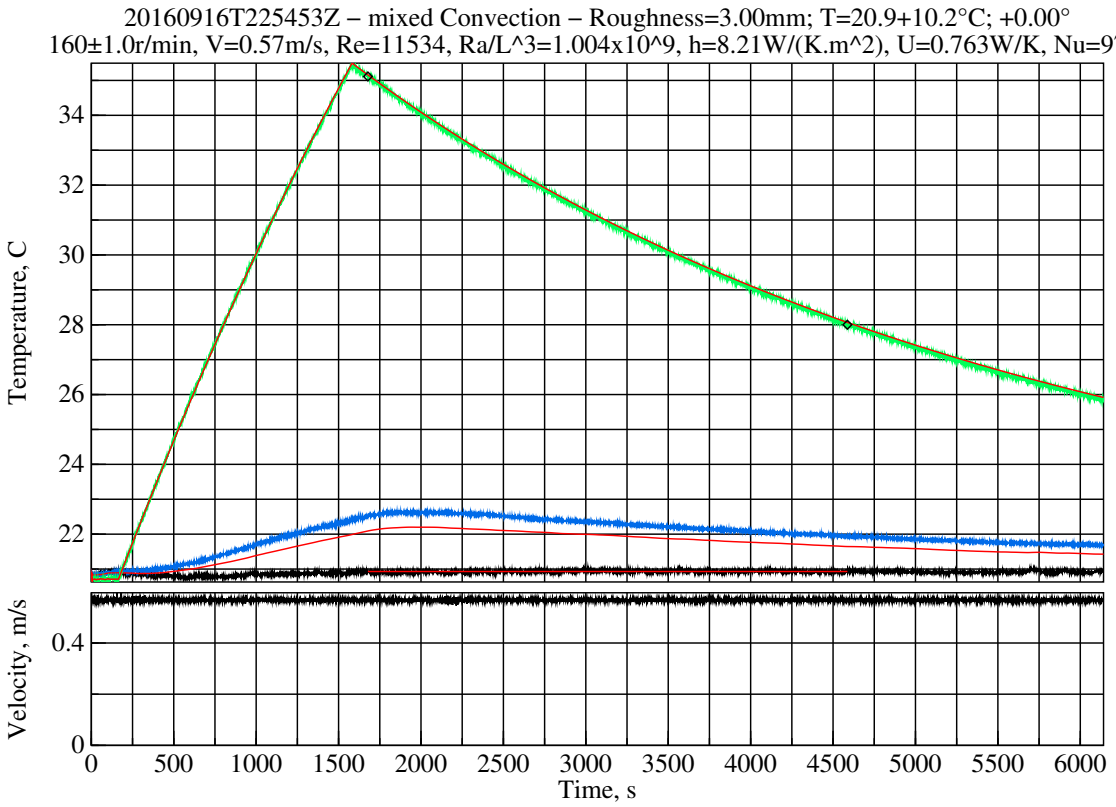
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 7410$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.5K	+14.7%/K	0.10K	1.47%	LM35C differential
P	101kPa	+0.0013%/Pa	1.5kPa	1.98%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.035%/(J/K)	47J/K	1.66%	plate thermal capacity
η	0.401	+411%	0.014	5.78%	anemometer calibration
C_V	1.000	−8.96%	0.100	0.90%	vertical reuptake
L_c	0.305m	+777%/m	500um	0.39%	characteristic length
ς	6.00mm	+2157%/m	100um	0.22%	post height
D_{PIR}	25.4mm	−387%/m	1.0mm	0.39%	insulation thickness
L_m	3.57mm	+978%/m	500um	0.49%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.391\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.43%	PIR thermal conductivity
ϵ_{XPS}	0.515	+22.6%	0.010	0.23%	XPS emissivity
ϵ_{tp}	0.890	+27.2%	0.015	0.41%	tape emissivity
Ω_{tp}	0.540	+18.5%	0.020	0.37%	tape coverage
ϵ_{rs}	0.040	+95.9%	0.010	0.96%	test-surface emissivity
ϵ_{wt}	0.900	+44.3%	0.025	1.11%	wind-tunnel emissivity
				6.81%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	103r/min	+1.60%/(r/min)	1.8r/min	2.80%	fan rotation rate
				8.82%	RSS combined uncertainty



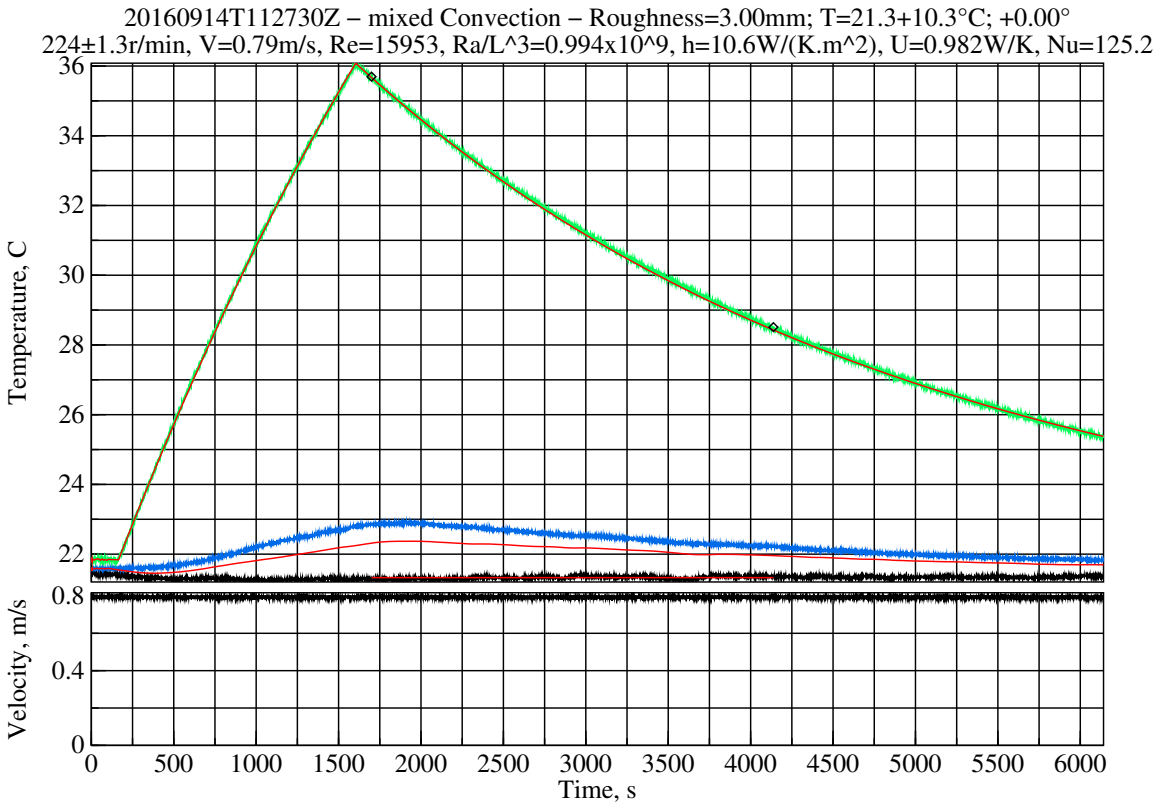
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 8022$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+16.5%/K	0.10K	1.65%	LM35C differential
P	101kPa	+0.0009%/Pa	1.5kPa	1.42%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.034%/(J/K)	47J/K	1.60%	plate thermal capacity
η	0.401	+188%	0.014	2.64%	anemometer calibration
C_V	1.000	−8.13%	0.100	0.81%	vertical reuptake
L_c	0.305m	+415%/m	500um	0.21%	characteristic length
ς	6.00mm	+4553%/m	100um	0.46%	post height
D_{PIR}	25.4mm	−356%/m	1.0mm	0.36%	insulation thickness
L_m	3.57mm	+911%/m	500um	0.46%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.361\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.40%	PIR thermal conductivity
ϵ_{XPS}	0.515	+20.7%	0.010	0.21%	XPS emissivity
ϵ_{tp}	0.890	+24.9%	0.015	0.37%	tape emissivity
Ω_{tp}	0.540	+16.9%	0.020	0.34%	tape coverage
ϵ_{rs}	0.040	+87.6%	0.010	0.88%	test-surface emissivity
ϵ_{wt}	0.900	+40.4%	0.025	1.01%	wind-tunnel emissivity
				4.22%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	112r/min	+0.671%/(r/min)	1.9r/min	1.27%	fan rotation rate
				4.93%	RSS combined uncertainty



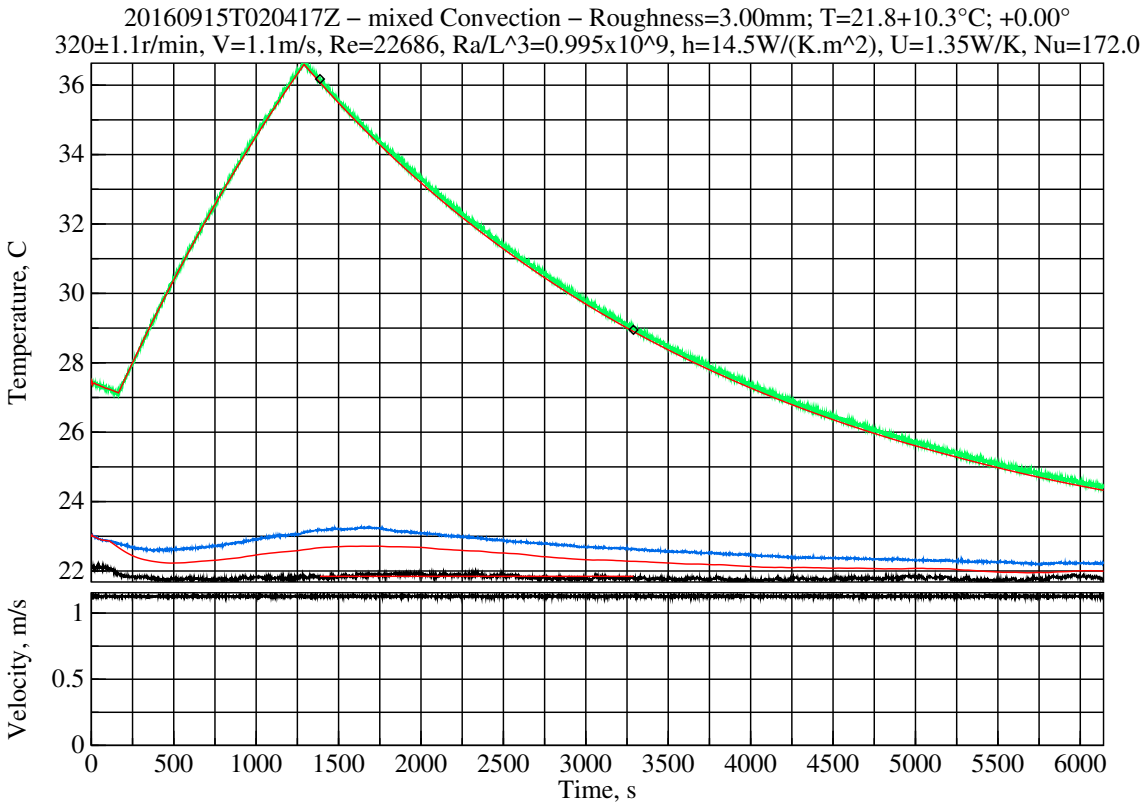
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 11534$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.2K	+15.3%/K	0.10K	1.53%	LM35C differential
P	102kPa	+0.0009%/Pa	1.5kPa	1.42%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.031%/(J/K)	47J/K	1.46%	plate thermal capacity
η	0.401	+199%	0.014	2.79%	anemometer calibration
C_V	1.000	−6.24%	0.100	0.62%	vertical reuptake
ς	6.00mm	+5620%/m	100um	0.56%	post height
D_{PIR}	25.4mm	−288%/m	1.0mm	0.29%	insulation thickness
L_m	3.57mm	+780%/m	500um	0.39%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.294\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.33%	PIR thermal conductivity
ϵ_{tp}	0.890	+18.8%	0.015	0.28%	tape emissivity
Ω_{tp}	0.540	+12.8%	0.020	0.26%	tape coverage
ϵ_{rs}	0.040	+66.7%	0.010	0.67%	test-surface emissivity
ϵ_{wt}	0.900	+30.6%	0.025	0.77%	wind-tunnel emissivity
				4.08%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	160r/min	+0.498%/(r/min)	0.95r/min	0.47%	fan rotation rate
				4.19%	RSS combined uncertainty



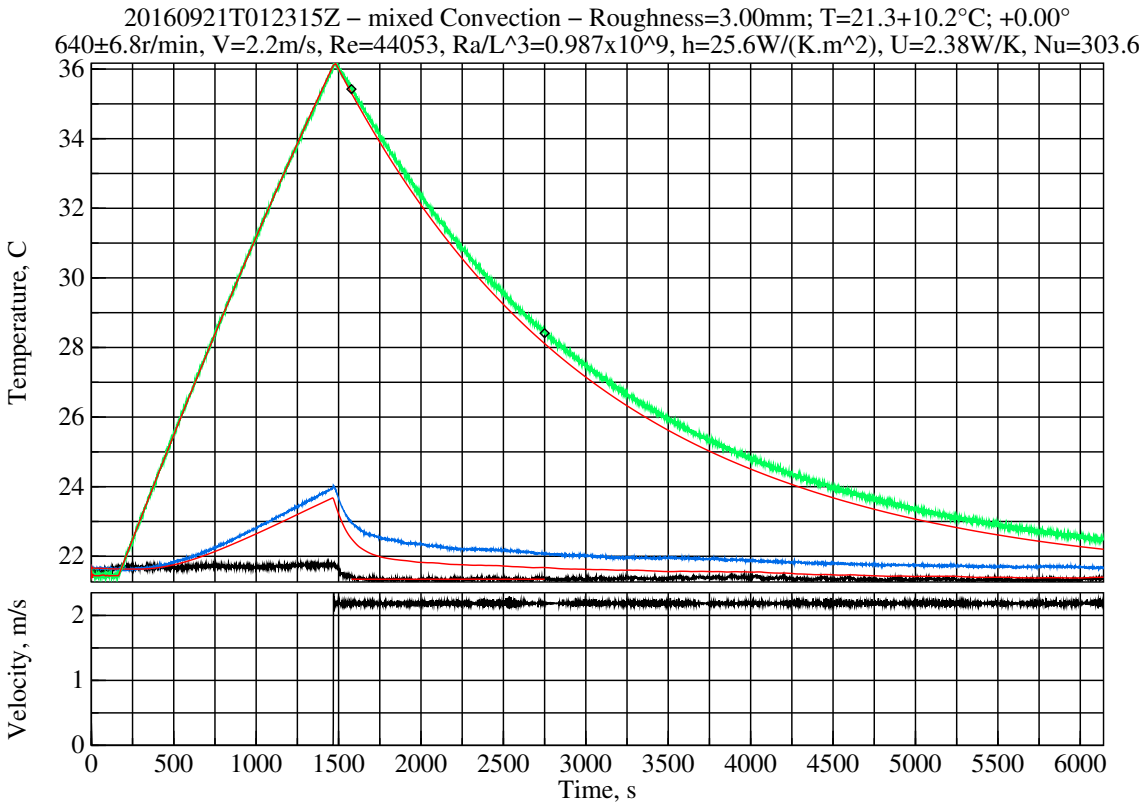
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 15953$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+13.9%/K	0.10K	1.39%	LM35C differential
P	101kPa	+0.0010%/Pa	1.5kPa	1.47%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.029%/(J/K)	47J/K	1.36%	plate thermal capacity
η	0.401	+217%	0.014	3.04%	anemometer calibration
C_V	1.000	−4.76%	0.100	0.48%	vertical reuptake
ς	6.00mm	+6194%/m	100um	0.62%	post height
D_{PIR}	25.4mm	−229%/m	1.0mm	0.23%	insulation thickness
L_m	3.57mm	+675%/m	500um	0.34%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.234\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.26%	PIR thermal conductivity
ϵ_{tp}	0.890	+14.4%	0.015	0.22%	tape emissivity
ϵ_{rs}	0.040	+51.2%	0.010	0.51%	test-surface emissivity
ϵ_{wt}	0.900	+23.4%	0.025	0.59%	wind-tunnel emissivity
				4.10%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	224r/min	+0.388%/(r/min)	1.3r/min	0.51%	fan rotation rate
				4.23%	RSS combined uncertainty



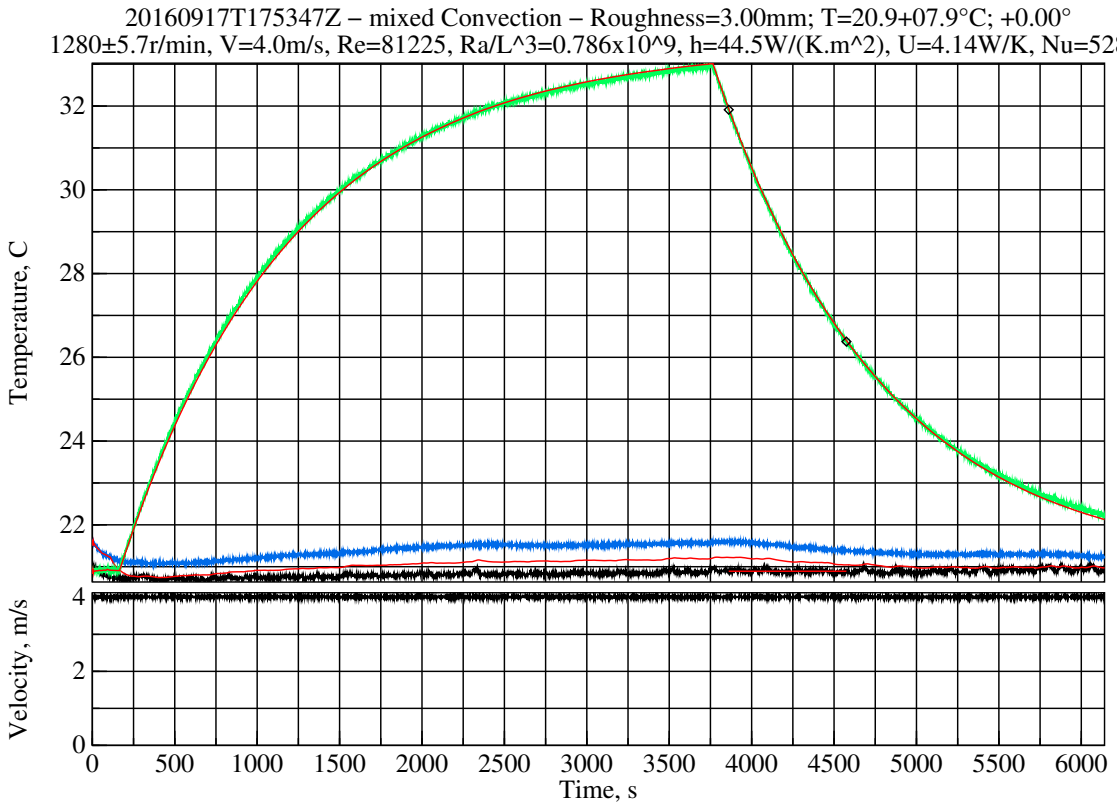
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 22686$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+12.8%/K	0.10K	1.28%	LM35C differential
P	101kPa	+0.0010%/Pa	1.5kPa	1.48%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.027%/(J/K)	47J/K	1.27%	plate thermal capacity
η	0.401	+227%	0.014	3.19%	anemometer calibration
C_V	1.000	−3.48%	0.100	0.35%	vertical reuptake
ς	6.00mm	+6657%/m	100um	0.67%	post height
L_m	3.57mm	+574%/m	500um	0.29%	side metal strip width
ϵ_{rs}	0.040	+37.5%	0.010	0.37%	test-surface emissivity
ϵ_{wt}	0.900	+17.1%	0.025	0.43%	wind-tunnel emissivity
				4.09%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	320r/min	+0.285%/(r/min)	1.1r/min	0.31%	fan rotation rate
				4.14%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 44051$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.2K	+11.5%/K	0.10K	1.15%	LM35C differential
P	101kPa	+0.0009%/Pa	1.5kPa	1.39%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.024%/(J/K)	47J/K	1.15%	plate thermal capacity
η	0.401	+209%	0.014	2.93%	anemometer calibration
ς	6.00mm	+8842%/m	100um	0.88%	post height
L_m	3.57mm	+439%/m	500um	0.22%	side metal strip width
ϵ_{rs}	0.040	+20.2%	0.010	0.20%	test-surface emissivity
ϵ_{wt}	0.900	+9.10%	0.025	0.23%	wind-tunnel emissivity
				3.78%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	640r/min	+0.131%/(r/min)	6.8r/min	0.89%	fan rotation rate
				4.17%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 81229$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	7.93K	+14.0%/K	0.10K	1.40%	LM35C differential
P	101kPa	+0.0008%/Pa	1.5kPa	1.15%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.023%/(J/K)	47J/K	1.09%	plate thermal capacity
η	0.401	+140%	0.014	1.97%	anemometer calibration
u_u	7.787	+2.62%	0.100	0.26%	diffuser airflow upper bound
ς	6.00mm	+12379%/m	100um	1.24%	post height
				3.18%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	1.28kr/min	+0.052%/(r/min)	5.7r/min	0.30%	fan rotation rate
				3.23%	RSS combined uncertainty