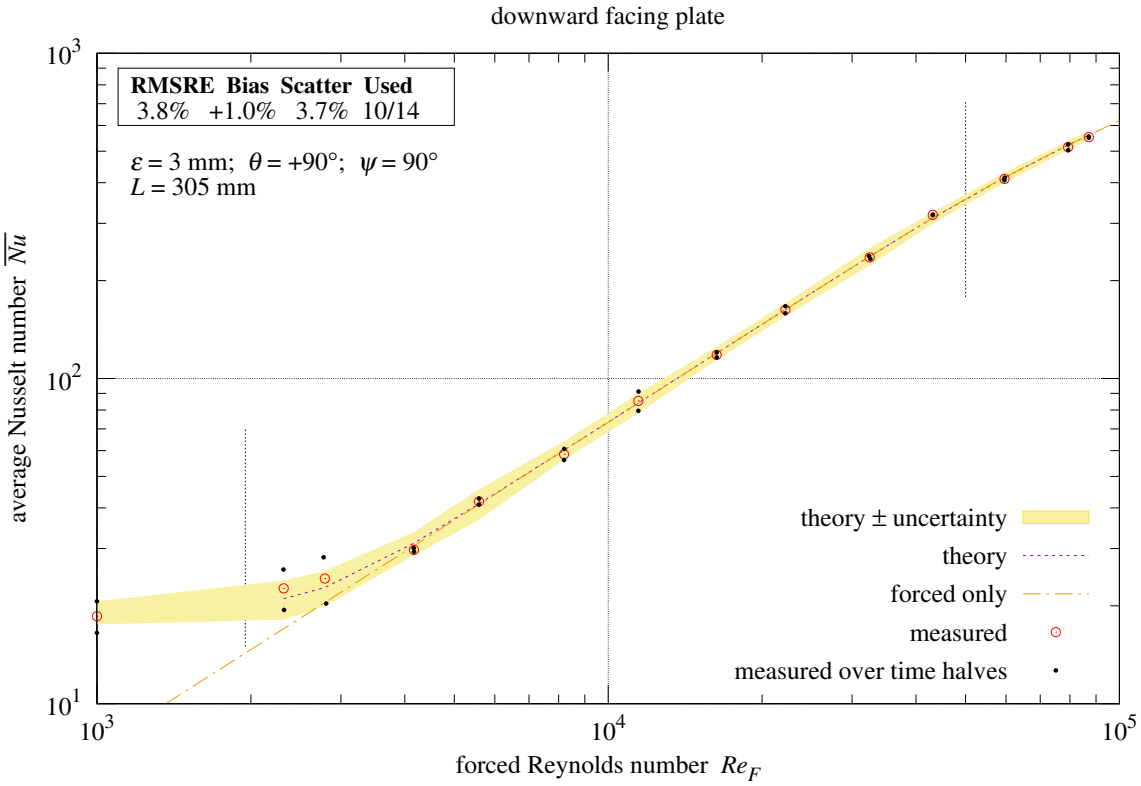
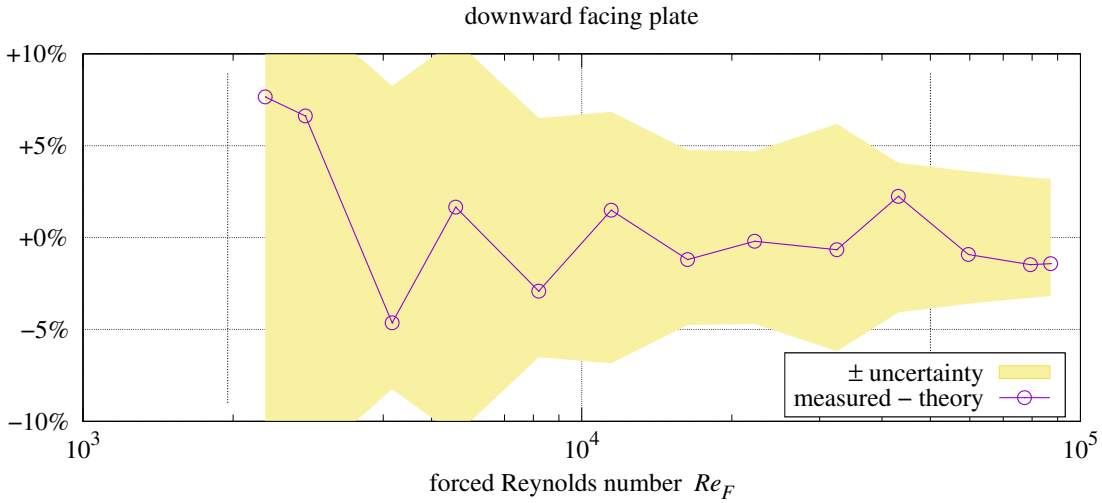
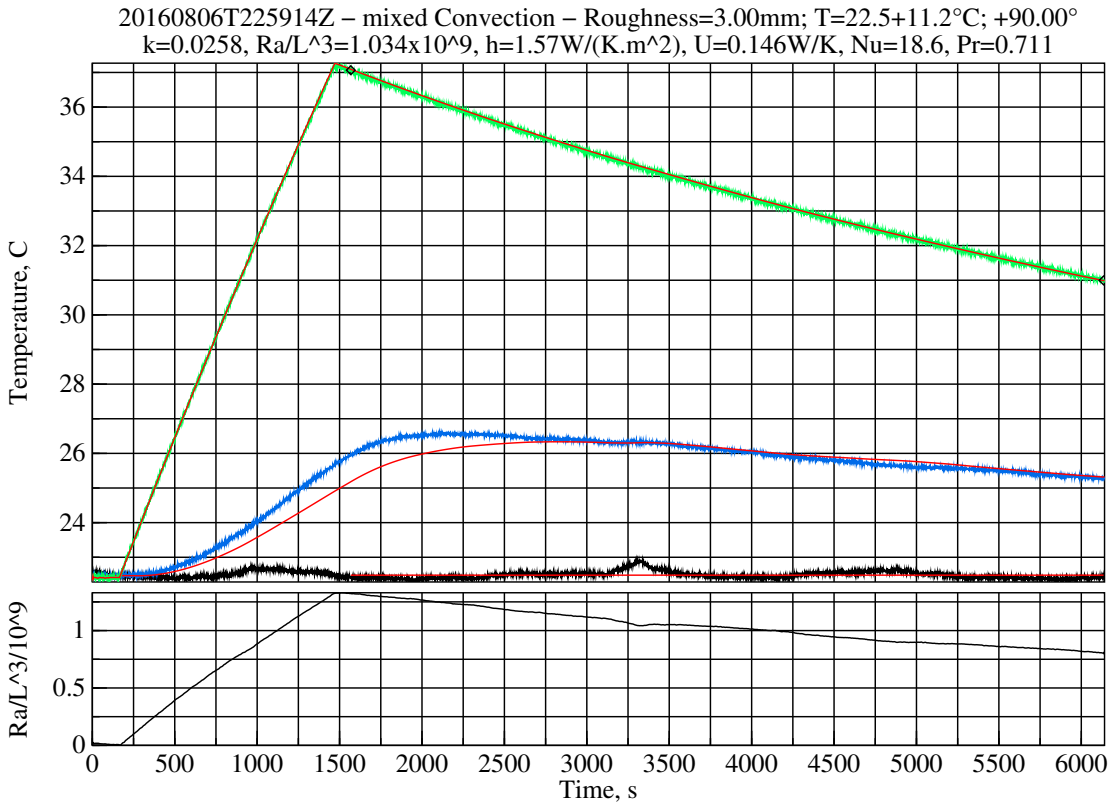
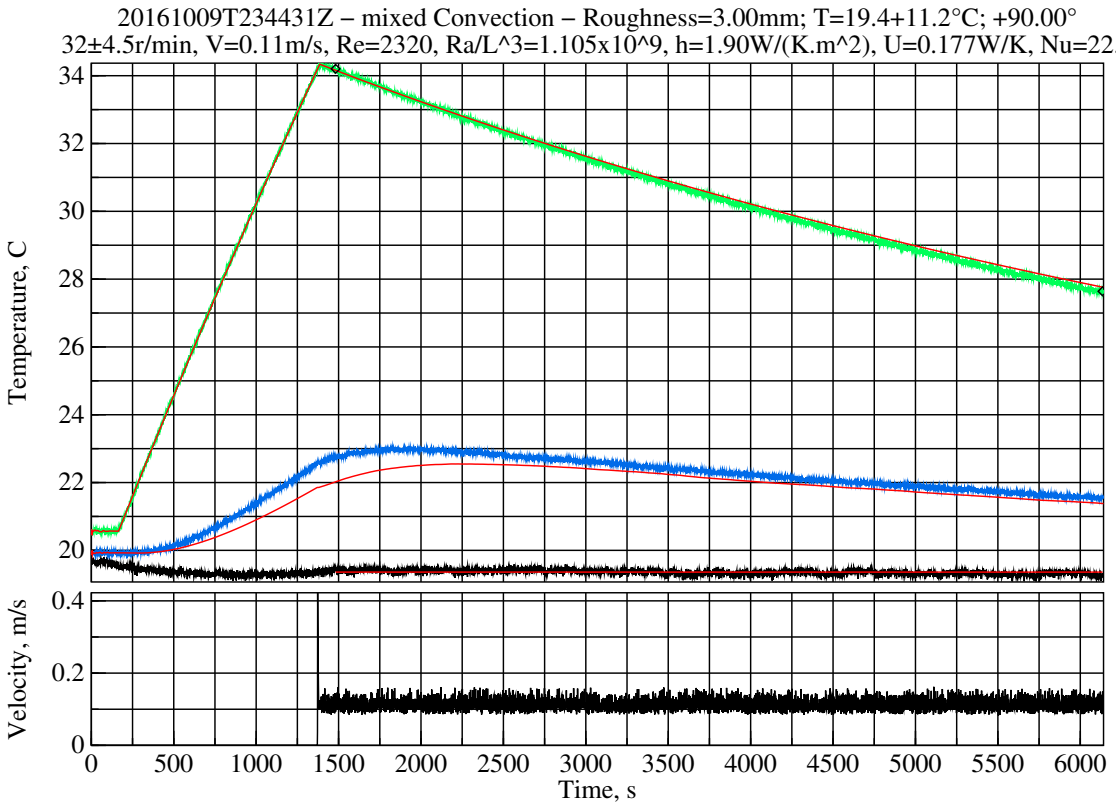

downward facing plate
RMSRE Bias Scatter Used
3.8% +1.0% 3.7% 10/14
ε = 3 mm; θ = +90°; ψ = 90°
L = 305 mm
theory ± uncertainty
theory
forced only
measured
measured over time halves
average Nusselt number Nu
forced Reynolds number Re_F


downward facing plate
± uncertainty
measured − theory
forced Reynolds number Re_F



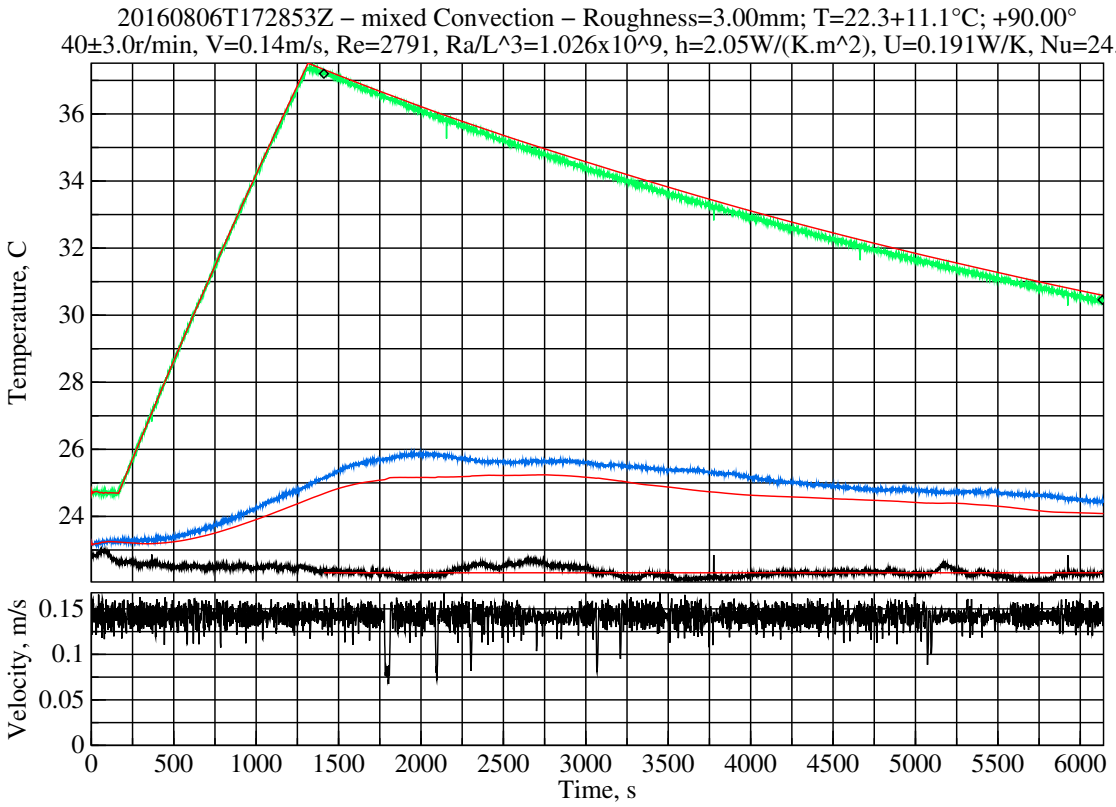
Estimated measurement uncertainties of natural convection at $\theta = 90.0$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
T	301K	+0.637%/K	0.50K	0.32%	LM35C temperature sensor
ΔT	11.2K	+37.0%/K	0.10K	3.70%	LM35C differential
T_{bb}	296K	+0.713%/K	0.50K	0.36%	radiative temperature
P	99.7kPa	+0.0009%/Pa	1.5kPa	1.28%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.079%/(J/K)	47J/K	3.72%	plate thermal capacity
L_c	0.305m	+1139%/m	500um	0.57%	characteristic length
L_w	0.305m	+402%/m	500um	0.20%	plate width
D_{PIR}	25.4mm	−898%/m	1.0mm	0.90%	insulation thickness
D_g	1.00mm	−910%/m	500um	0.46%	air gap
L_m	3.57mm	+2628%/m	500um	1.31%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.868\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.96%	PIR thermal conductivity
ϵ_{XPS}	0.515	+79.6%	0.010	0.80%	XPS emissivity
ϵ_{tp}	0.890	+96.2%	0.015	1.44%	tape emissivity
Ω_{tp}	0.540	+64.9%	0.020	1.30%	tape coverage
ϵ_{rs}	0.040	+347%	0.010	3.47%	test-surface emissivity
ϵ_b	0.190	+22.7%	0.020	0.45%	back emissivity
ϵ_{wt}	0.900	+161%	0.025	4.02%	wind-tunnel emissivity
θ	90.0°	−1.05%/°	0.50°	0.52%	plate angle
				8.16%	combined bias uncertainty



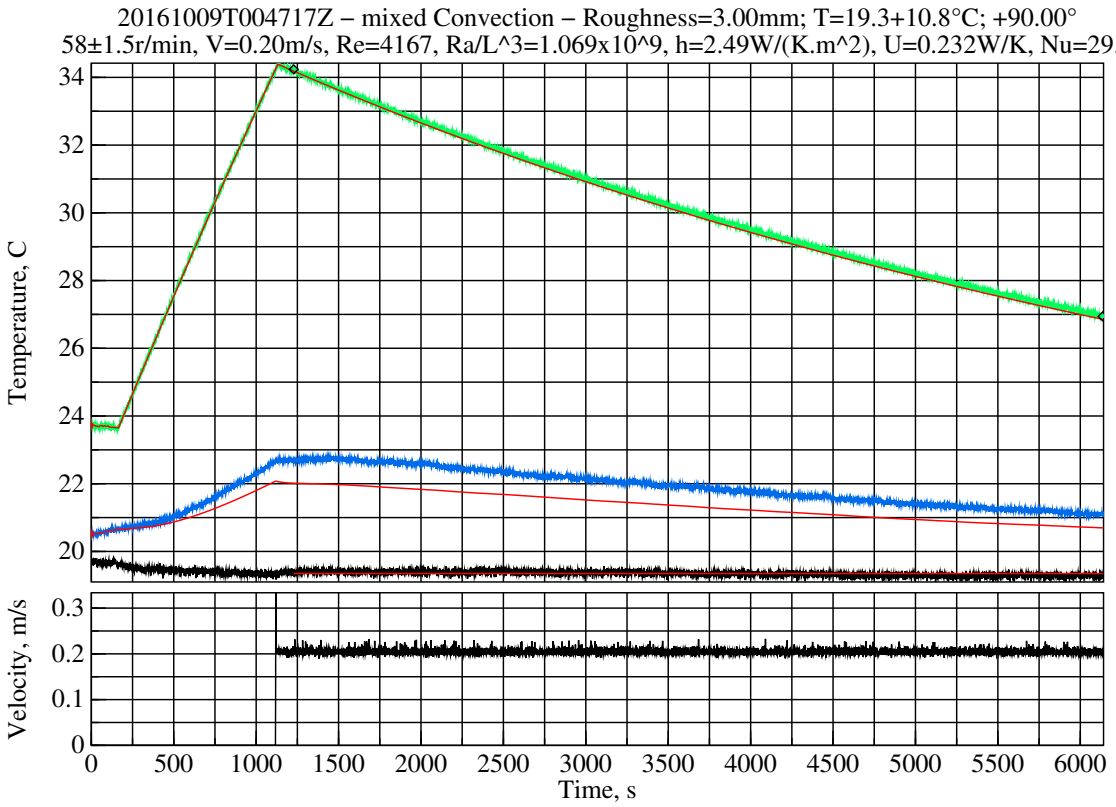
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 2319$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
T	298K	+0.441%/K	0.50K	0.22%	LM35C temperature sensor
ΔT	11.2K	+34.3%/K	0.10K	3.43%	LM35C differential
T_{bb}	292K	+0.623%/K	0.50K	0.31%	radiative temperature
P	101kPa	+0.0011%/Pa	1.5kPa	1.58%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.074%/(J/K)	47J/K	3.49%	plate thermal capacity
η	0.401	+101%	0.014	1.42%	anemometer calibration
L_c	0.305m	+1002%/m	500um	0.50%	characteristic length
ς	6.00mm	+2492%/m	100um	0.25%	post height
D_{PIR}	25.4mm	−965%/m	1.0mm	0.96%	insulation thickness
D_g	1.00mm	−978%/m	500um	0.49%	air gap
L_m	3.57mm	+2462%/m	500um	1.23%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.945\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	1.05%	PIR thermal conductivity
k_{XPS}	$28.5\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.160\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.4\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.23%	XPS thermal conductivity
ϵ_{XPS}	0.515	+69.8%	0.010	0.70%	XPS emissivity
ϵ_{tp}	0.890	+84.4%	0.015	1.27%	tape emissivity
Ω_{tp}	0.540	+56.9%	0.020	1.14%	tape coverage
ϵ_{rs}	0.040	+307%	0.010	3.07%	test-surface emissivity
ϵ_b	0.190	+10.7%	0.020	0.21%	back emissivity
ϵ_{wt}	0.900	+139%	0.025	3.48%	wind-tunnel emissivity
θ	90.0°	−0.966%/°	0.50°	0.48%	plate angle
				7.62%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	32.0r/min	+1.27%/(r/min)	4.5r/min	5.74%	fan rotation rate
				13.78%	RSS combined uncertainty



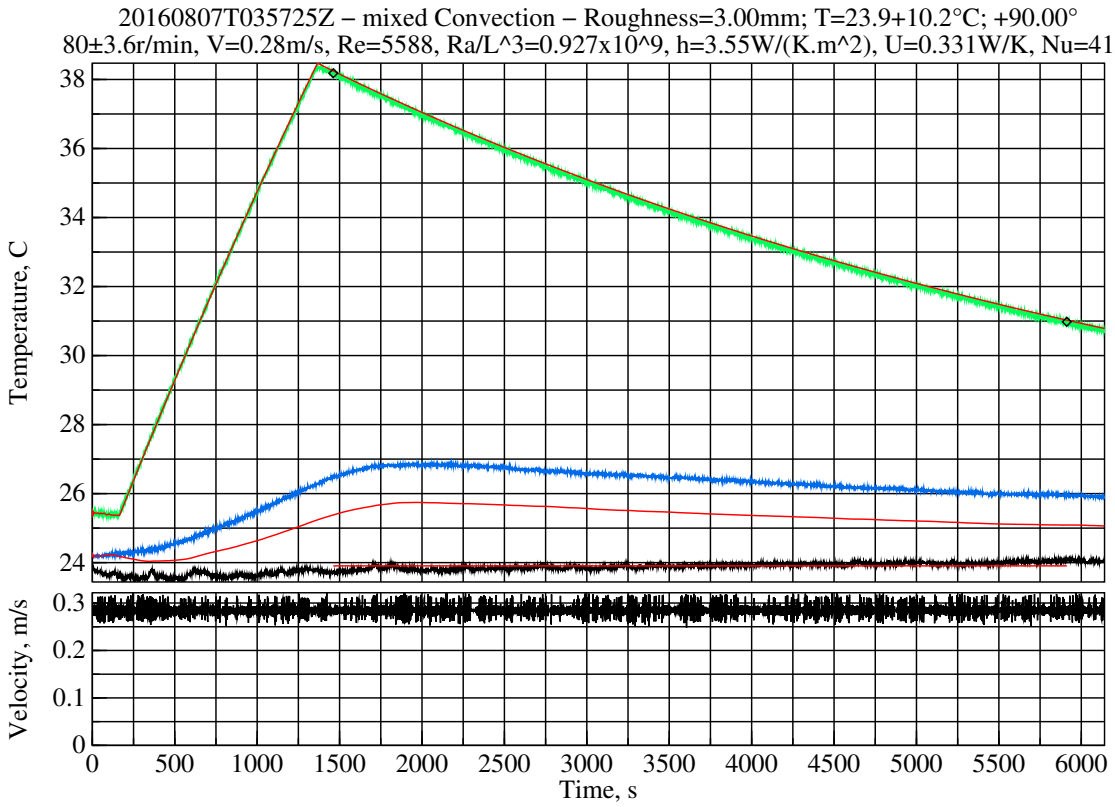
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 2791$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	11.1K	+32.5%/K	0.10K	3.25%	LM35C differential
T_{bb}	296K	+0.585%/K	0.50K	0.29%	radiative temperature
P	99.7kPa	+0.0012%/Pa	1.5kPa	1.75%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.071%/(J/K)	47J/K	3.32%	plate thermal capacity
η	0.401	+161%	0.014	2.25%	anemometer calibration
L_c	0.305m	+914%/m	500um	0.46%	characteristic length
ς	6.00mm	+4239%/m	100um	0.42%	post height
D_{PIR}	25.4mm	−936%/m	1.0mm	0.94%	insulation thickness
D_g	1.00mm	−949%/m	500um	0.47%	air gap
L_m	3.57mm	+2349%/m	500um	1.17%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.920\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	1.02%	PIR thermal conductivity
k_{XPS}	$28.5\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.160\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.4\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.23%	XPS thermal conductivity
ϵ_{XPS}	0.515	+66.4%	0.010	0.66%	XPS emissivity
ϵ_{tp}	0.890	+80.3%	0.015	1.20%	tape emissivity
Ω_{tp}	0.540	+54.2%	0.020	1.08%	tape coverage
ϵ_{rs}	0.040	+290%	0.010	2.90%	test-surface emissivity
ϵ_{wt}	0.900	+132%	0.025	3.30%	wind-tunnel emissivity
θ	90.0°	−0.878%/°	0.50°	0.44%	plate angle
				7.51%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	39.7r/min	+1.62%/(r/min)	3.0r/min	4.93%	fan rotation rate
				12.40%	RSS combined uncertainty



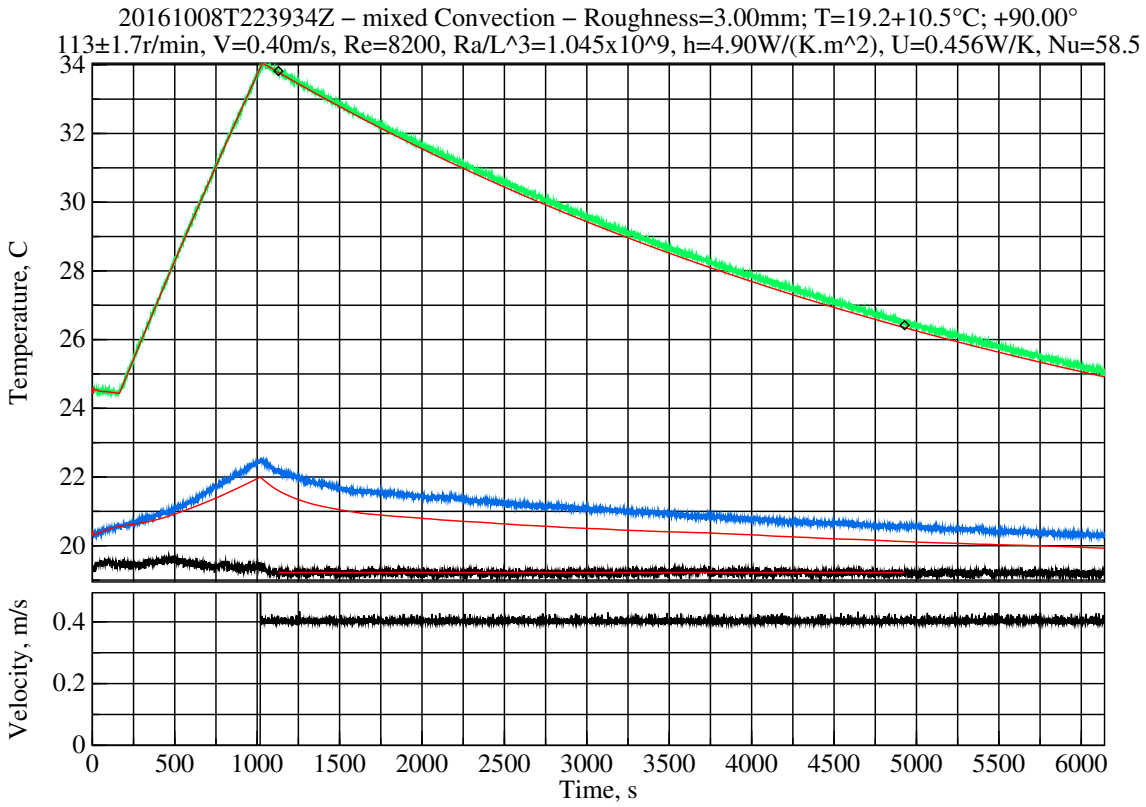
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 4168$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.8K	+26.6%/K	0.10K	2.66%	LM35C differential
T_{bb}	293K	+0.416%/K	0.50K	0.21%	radiative temperature
P	101kPa	+0.0012%/Pa	1.5kPa	1.86%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.058%/(J/K)	47J/K	2.70%	plate thermal capacity
η	0.401	+237%	0.014	3.32%	anemometer calibration
L_c	0.305m	+680%/m	500um	0.34%	characteristic length
ς	6.00mm	+6534%/m	100um	0.65%	post height
D_{PIR}	25.4mm	−756%/m	1.0mm	0.76%	insulation thickness
D_g	1.00mm	−767%/m	500um	0.38%	air gap
L_m	3.57mm	+1754%/m	500um	0.88%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.746\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.83%	PIR thermal conductivity
ϵ_{XPS}	0.515	+47.0%	0.010	0.47%	XPS emissivity
ϵ_{tp}	0.890	+56.9%	0.015	0.85%	tape emissivity
Ω_{tp}	0.540	+38.3%	0.020	0.77%	tape coverage
ϵ_{rs}	0.040	+207%	0.010	2.07%	test-surface emissivity
ϵ_{wt}	0.900	+93.0%	0.025	2.33%	wind-tunnel emissivity
θ	90.0°	−0.647%/°	0.50°	0.32%	plate angle
				6.56%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	57.6r/min	+1.65%/(r/min)	1.5r/min	2.50%	fan rotation rate
				8.25%	RSS combined uncertainty



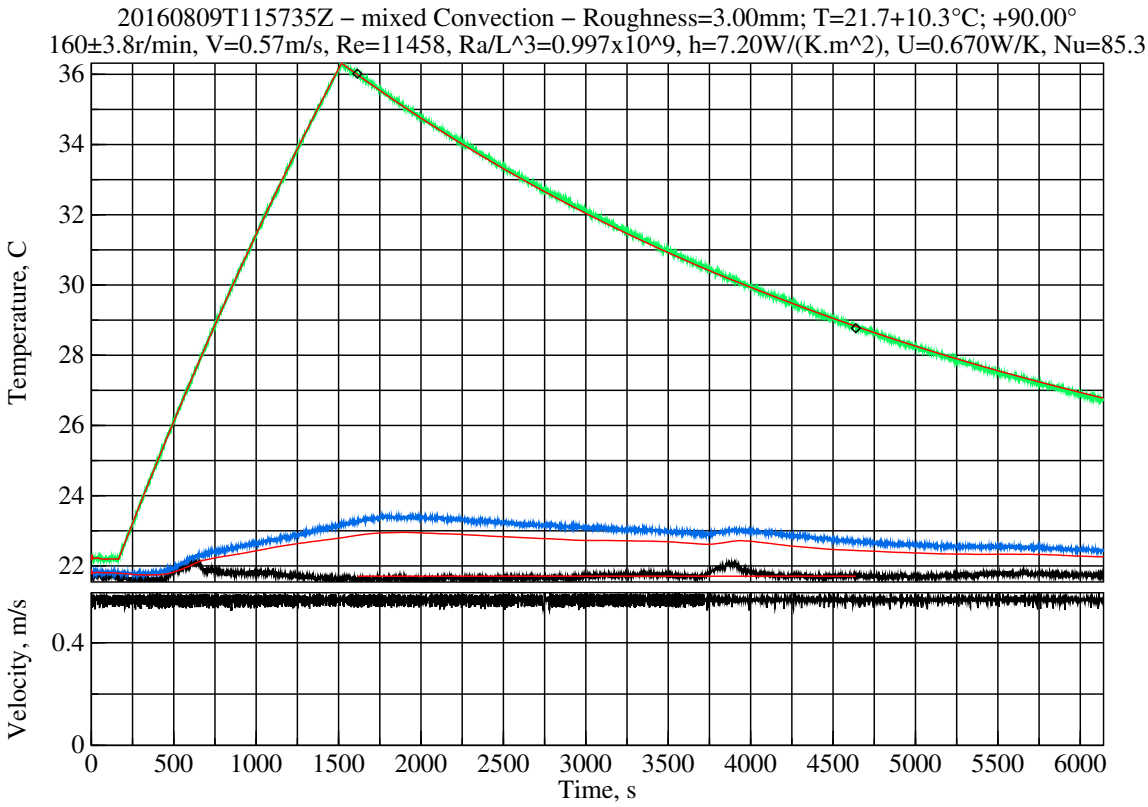
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 5588$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.2K	+23.8%/K	0.10K	2.38%	LM35C differential
P	99.9kPa	+0.0012%/Pa	1.5kPa	1.81%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.049%/(J/K)	47J/K	2.30%	plate thermal capacity
η	0.401	+251%	0.014	3.53%	anemometer calibration
L_c	0.305m	+552%/m	500um	0.28%	characteristic length
ς	6.00mm	+7030%/m	100um	0.70%	post height
D_{PIR}	25.4mm	−604%/m	1.0mm	0.60%	insulation thickness
D_g	1.00mm	−613%/m	500um	0.31%	air gap
L_m	3.57mm	+1414%/m	500um	0.71%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.599\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.66%	PIR thermal conductivity
ϵ_{XPS}	0.515	+37.0%	0.010	0.37%	XPS emissivity
ϵ_{tp}	0.890	+44.7%	0.015	0.67%	tape emissivity
Ω_{tp}	0.540	+30.1%	0.020	0.60%	tape coverage
ϵ_{rs}	0.040	+161%	0.010	1.61%	test-surface emissivity
ϵ_{wt}	0.900	+72.9%	0.025	1.82%	wind-tunnel emissivity
θ	90.0°	−0.474%/°	0.50°	0.24%	plate angle
				5.97%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	80.1r/min	+1.26%/(r/min)	3.6r/min	4.47%	fan rotation rate
				10.75%	RSS combined uncertainty



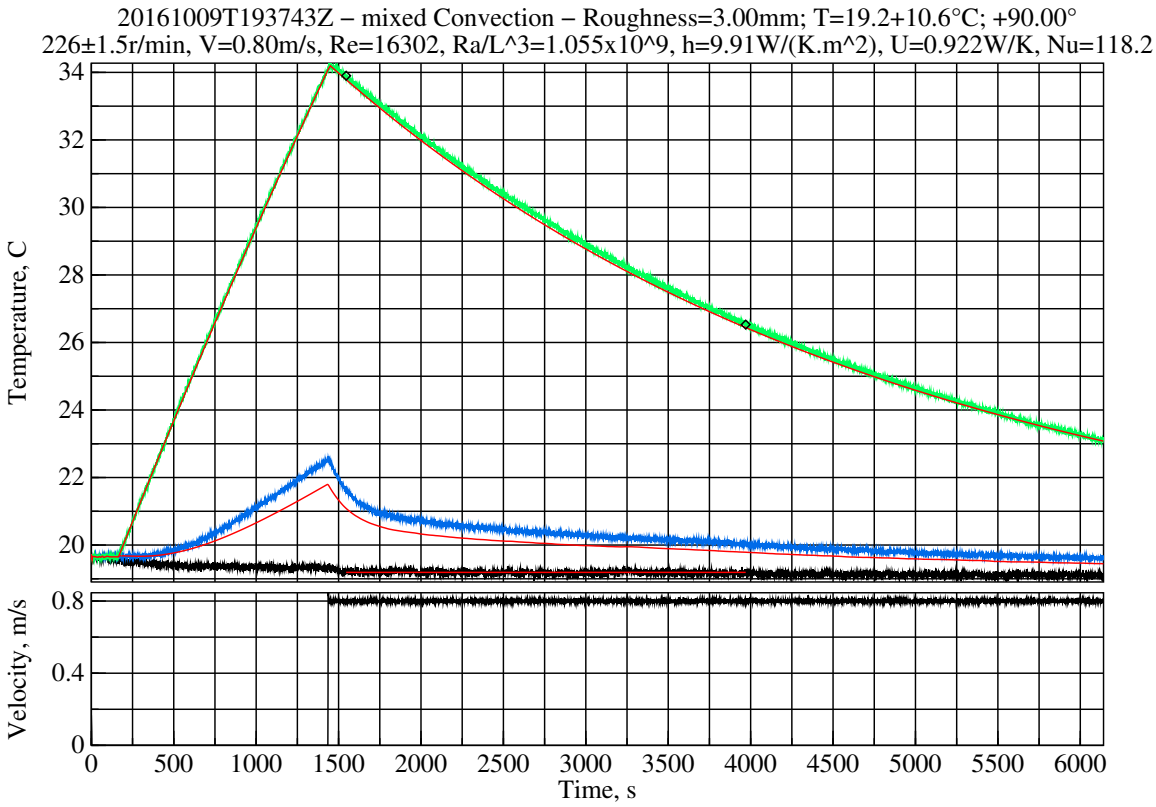
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 8200$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.5K	+18.8%/K	0.10K	1.88%	LM35C differential
P	101kPa	+0.0011%/Pa	1.5kPa	1.71%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.040%/(J/K)	47J/K	1.88%	plate thermal capacity
η	0.401	+250%	0.014	3.51%	anemometer calibration
L_c	0.305m	+432%/m	500um	0.22%	characteristic length
ς	6.00mm	+7075%/m	100um	0.71%	post height
D_{PIR}	25.4mm	−443%/m	1.0mm	0.44%	insulation thickness
D_g	1.00mm	−449%/m	500um	0.22%	air gap
L_m	3.57mm	+1012%/m	500um	0.51%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.441\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.49%	PIR thermal conductivity
ϵ_{XPS}	0.515	+24.1%	0.010	0.24%	XPS emissivity
ϵ_{tp}	0.890	+29.2%	0.015	0.44%	tape emissivity
Ω_{tp}	0.540	+19.6%	0.020	0.39%	tape coverage
ϵ_{rs}	0.040	+106%	0.010	1.06%	test-surface emissivity
ϵ_{wt}	0.900	+47.5%	0.025	1.19%	wind-tunnel emissivity
θ	90.0°	−5.24%/°	0.50°	2.62%	plate angle
				5.79%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	113r/min	+0.886%/(r/min)	1.7r/min	1.49%	fan rotation rate
				6.51%	RSS combined uncertainty



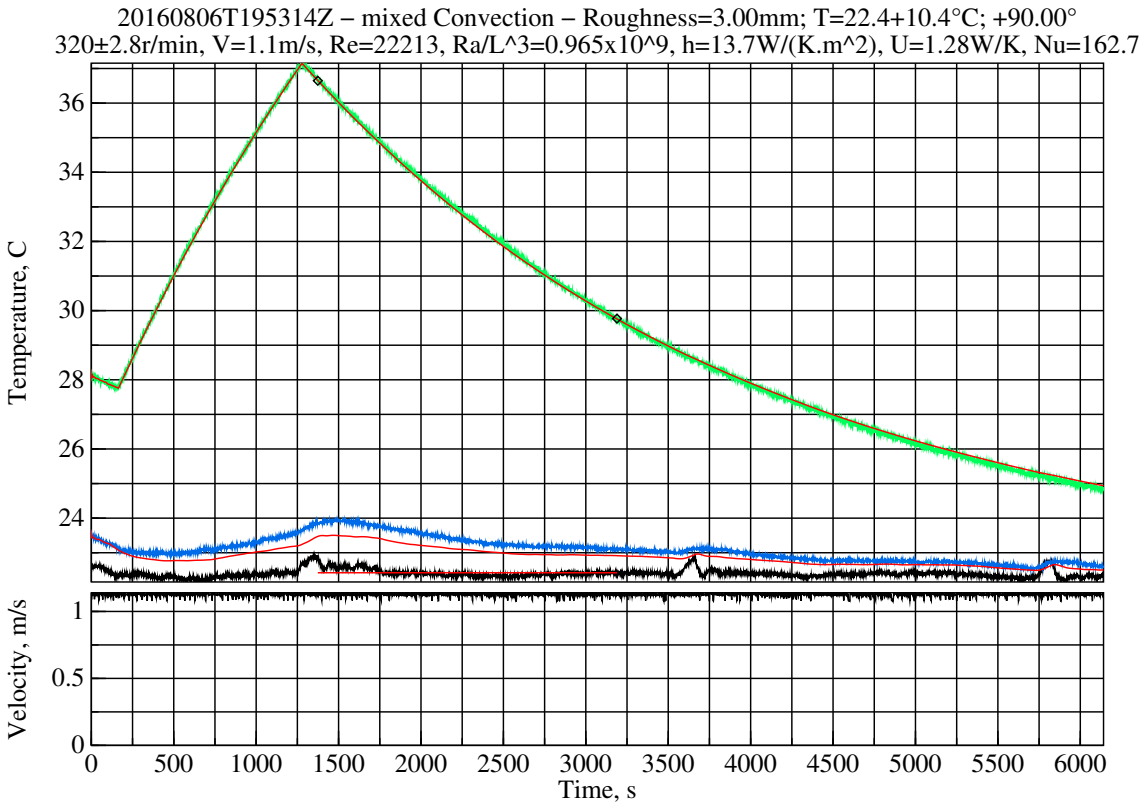
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 11457$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.3K	+16.6%/K	0.10K	1.66%	LM35C differential
P	101kPa	+0.0011%/Pa	1.5kPa	1.64%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.035%/(J/K)	47J/K	1.64%	plate thermal capacity
η	0.401	+250%	0.014	3.51%	anemometer calibration
ς	6.00mm	+7113%/m	100um	0.71%	post height
D_{PIR}	25.4mm	−332%/m	1.0mm	0.33%	insulation thickness
L_m	3.57mm	+798%/m	500um	0.40%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.332\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.37%	PIR thermal conductivity
ϵ_{tp}	0.890	+21.3%	0.015	0.32%	tape emissivity
Ω_{tp}	0.540	+14.4%	0.020	0.29%	tape coverage
ϵ_{rs}	0.040	+77.5%	0.010	0.77%	test-surface emissivity
ϵ_{wt}	0.900	+34.7%	0.025	0.87%	wind-tunnel emissivity
θ	90.0°	−2.55%/°	0.50°	1.28%	plate angle
				4.97%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	160r/min	+0.627%/(r/min)	3.8r/min	2.35%	fan rotation rate
				6.84%	RSS combined uncertainty



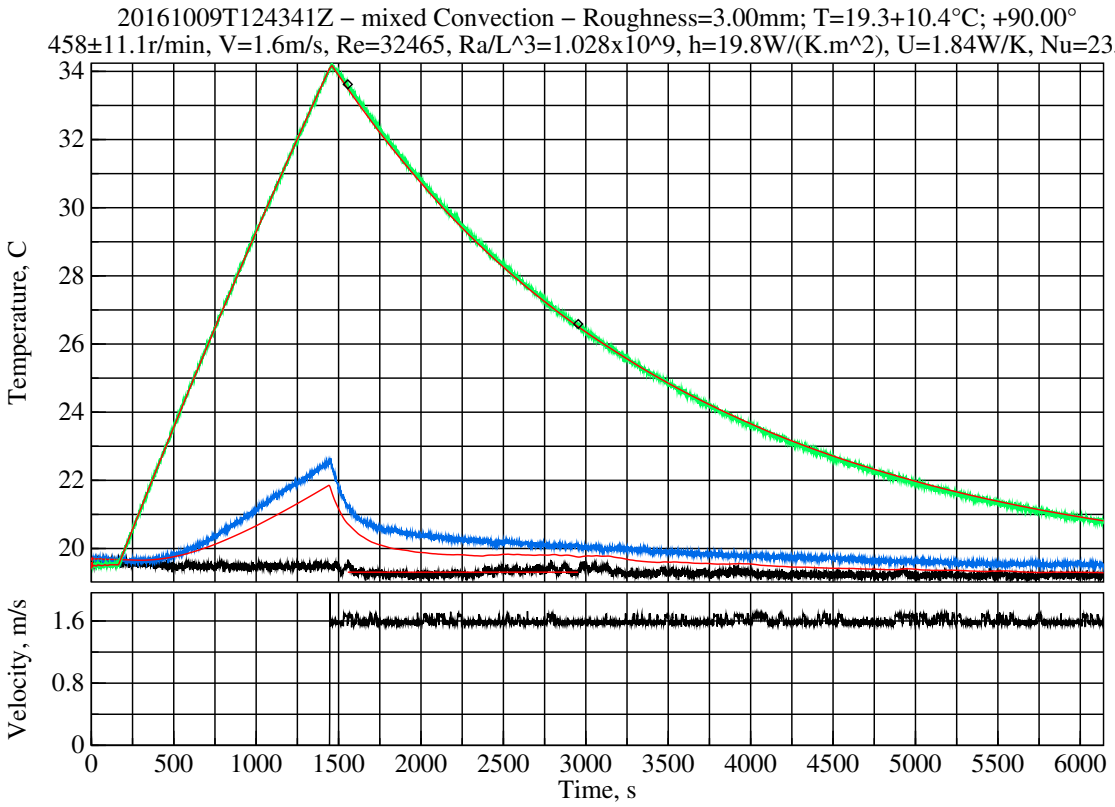
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 16304$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.6K	+14.2%/K	0.10K	1.42%	LM35C differential
P	101kPa	+0.0011%/Pa	1.5kPa	1.60%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.031%/(J/K)	47J/K	1.45%	plate thermal capacity
η	0.401	+248%	0.014	3.49%	anemometer calibration
ς	6.00mm	+7134%/m	100um	0.71%	post height
D_{PIR}	25.4mm	−245%/m	1.0mm	0.24%	insulation thickness
L_m	3.57mm	+623%/m	500um	0.31%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.246\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.27%	PIR thermal conductivity
ϵ_{tp}	0.890	+14.7%	0.015	0.22%	tape emissivity
ϵ_{rs}	0.040	+53.7%	0.010	0.54%	test-surface emissivity
ϵ_{wt}	0.900	+23.8%	0.025	0.60%	wind-tunnel emissivity
θ	90.0°	−1.24%/°	0.50°	0.62%	plate angle
				4.56%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	226r/min	+0.441%/(r/min)	1.5r/min	0.67%	fan rotation rate
				4.76%	RSS combined uncertainty



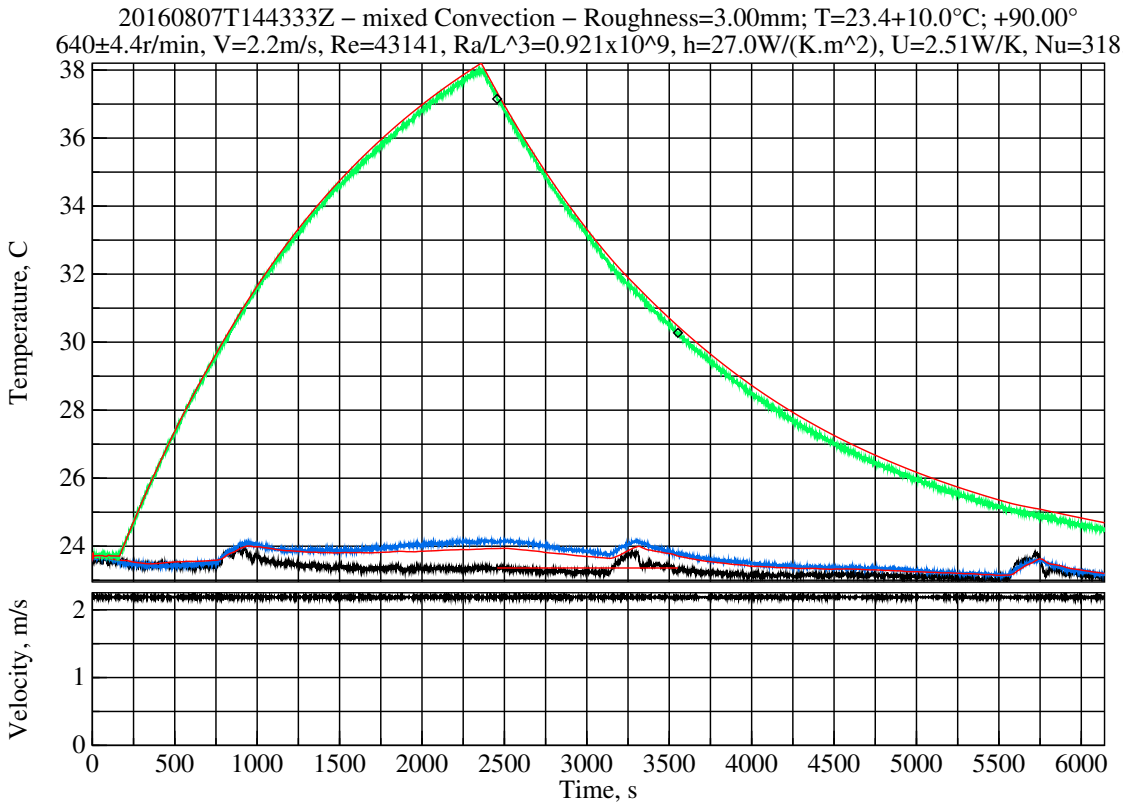
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 22213$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+13.2%/K	0.10K	1.32%	LM35C differential
P	99.5kPa	+0.0011%/Pa	1.5kPa	1.59%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.029%/(J/K)	47J/K	1.34%	plate thermal capacity
η	0.401	+245%	0.014	3.44%	anemometer calibration
ς	6.00mm	+7198%/m	100um	0.72%	post height
L_m	3.57mm	+524%/m	500um	0.26%	side metal strip width
k_{PIR}	$22.2\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$+0.186\%/\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	$1.1\frac{\mathrm{mW}}{\mathrm{K\cdot m}}$	0.21%	PIR thermal conductivity
ϵ_{rs}	0.040	+40.3%	0.010	0.40%	test-surface emissivity
ϵ_{wt}	0.900	+18.0%	0.025	0.45%	wind-tunnel emissivity
θ	90.0°	−0.597%/°	0.50°	0.30%	plate angle
				4.38%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	320r/min	+0.307%/(r/min)	2.8r/min	0.85%	fan rotation rate
				4.70%	RSS combined uncertainty



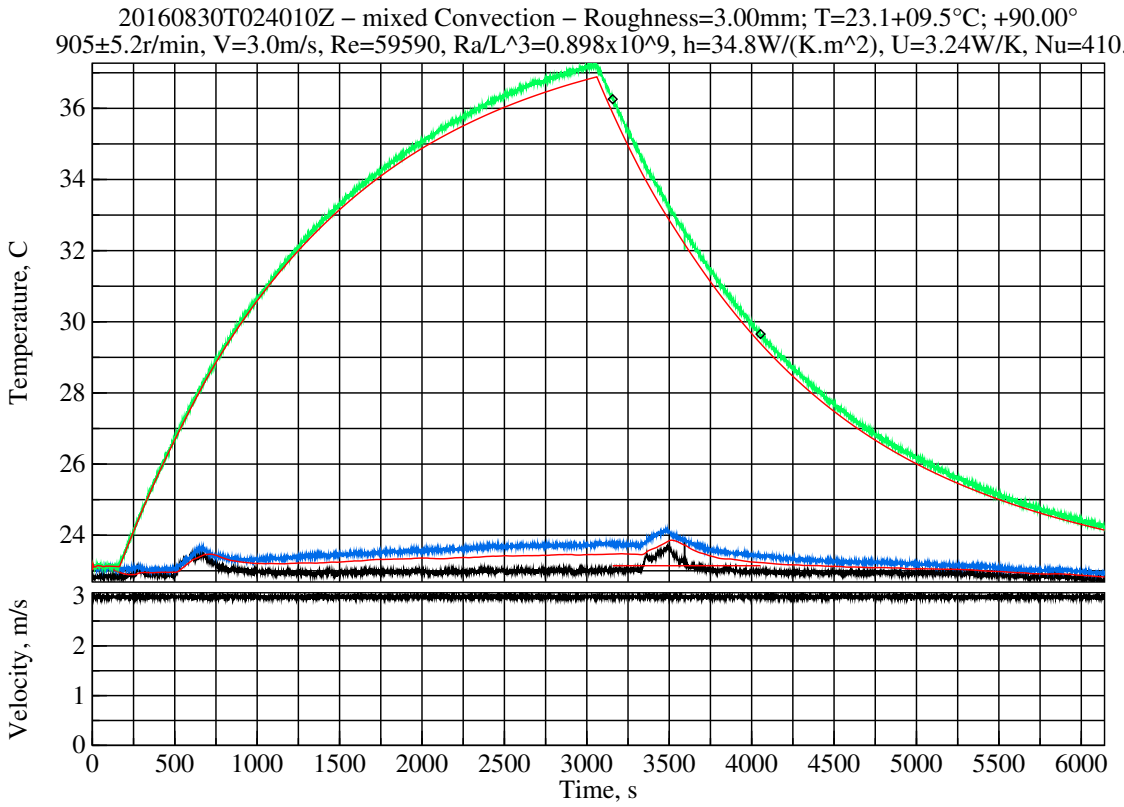
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 32467$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	10.4K	+12.3%/K	0.10K	1.23%	LM35C differential
P	101kPa	+0.0010%/Pa	1.5kPa	1.52%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.026%/(J/K)	47J/K	1.23%	plate thermal capacity
η	0.401	+235%	0.014	3.30%	anemometer calibration
ς	6.00mm	+7685%/m	100um	0.77%	post height
L_m	3.57mm	+427%/m	500um	0.21%	side metal strip width
ϵ_{rs}	0.040	+27.1%	0.010	0.27%	test-surface emissivity
ϵ_{wt}	0.900	+12.0%	0.025	0.30%	wind-tunnel emissivity
				4.14%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	458r/min	+0.206%/(r/min)	11r/min	2.29%	fan rotation rate
				6.18%	RSS combined uncertainty



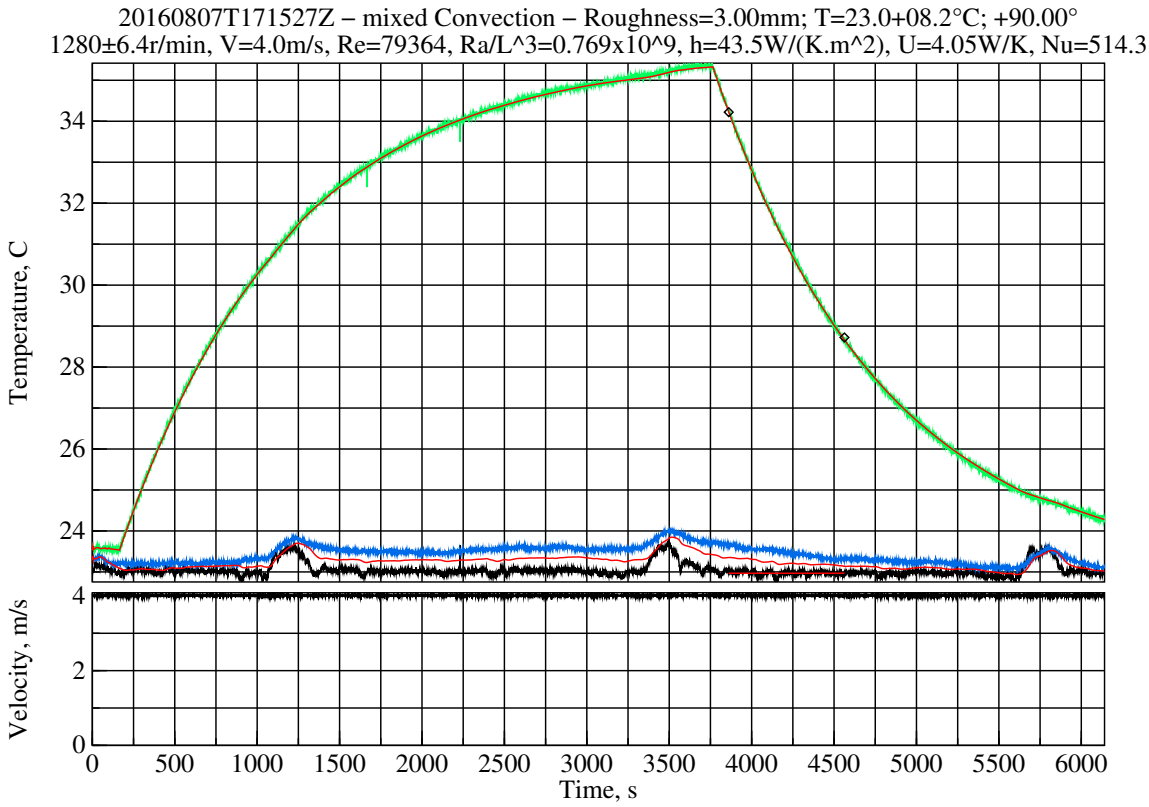
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 43136$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	9.97K	+12.1%/K	0.10K	1.21%	LM35C differential
P	100kPa	+0.0010%/Pa	1.5kPa	1.44%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.025%/(J/K)	47J/K	1.18%	plate thermal capacity
η	0.401	+215%	0.014	3.02%	anemometer calibration
ς	6.00mm	+8945%/m	100um	0.89%	post height
ϵ_{rs}	0.040	+21.2%	0.010	0.21%	test-surface emissivity
ϵ_{wt}	0.900	+9.41%	0.025	0.24%	wind-tunnel emissivity
				3.89%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	640r/min	+0.135%/(r/min)	4.4r/min	0.60%	fan rotation rate
				4.07%	RSS combined uncertainty



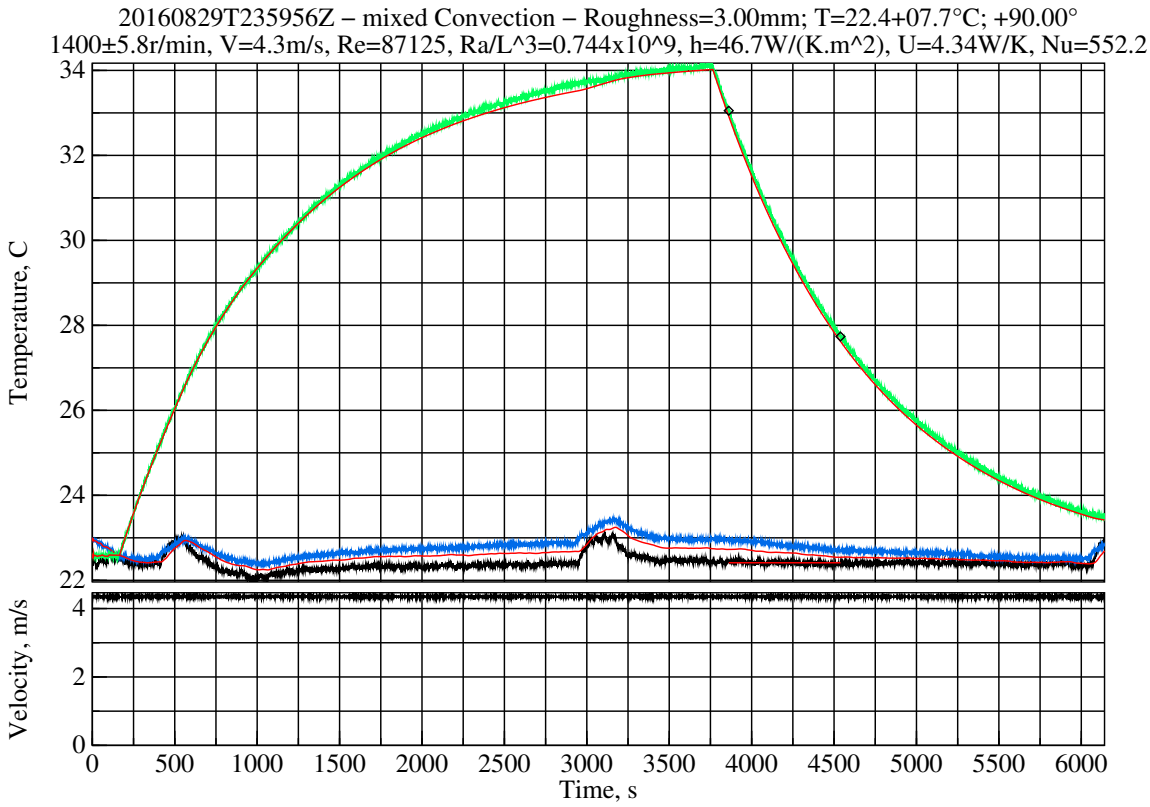
Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 59593$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	9.47K	+12.2%/K	0.10K	1.22%	LM35C differential
P	101kPa	+0.0009%/Pa	1.5kPa	1.28%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.024%/(J/K)	47J/K	1.14%	plate thermal capacity
η	0.401	+180%	0.014	2.52%	anemometer calibration
ς	6.00mm	+11299%/m	100um	1.13%	post height
				3.50%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	905r/min	+0.081%/(r/min)	5.2r/min	0.43%	fan rotation rate
				3.60%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 79374$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	8.18K	+13.7%/K	0.10K	1.37%	LM35C differential
P	100kPa	+0.0008%/Pa	1.5kPa	1.18%	MPXH6115A6U air pressure
C_{pt}	4.69kJ/K	+0.024%/(J/K)	47J/K	1.11%	plate thermal capacity
η	0.401	+142%	0.014	2.00%	anemometer calibration
u_u	7.787	+2.65%	0.100	0.26%	diffuser airflow upper bound
ς	6.00mm	+12473%/m	100um	1.25%	post height
				3.20%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	1.28kr/min	+0.053%/(r/min)	6.4r/min	0.34%	fan rotation rate
				3.27%	RSS combined uncertainty



Estimated measurement uncertainties, bi-level 3mm roughness at $Re = 87122$.

Symbol	Nominal	Sensitivity	Bias	Uncertainty	Component
ΔT	7.68K	+14.5%/K	0.10K	1.45%	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	1.10%	plate thermal capacity
η	0.401	+131%	0.014	1.84%	anemometer calibration
u_u	7.787	+3.06%	0.100	0.31%	diffuser airflow upper bound
ς	6.00mm	+12511%/m	100um	1.25%	post height
				3.13%	combined bias uncertainty
Symbol	**Nominal**	**Sensitivity**	**Variability**	**Uncertainty**	**Component**
ω	1.40kr/min	+0.051%/(r/min)	5.8r/min	0.30%	fan rotation rate
				3.19%	RSS combined uncertainty