average Nusselt number $\overline{Nu}$

Rayleigh number $Ra^*$

upward natural convection

3mm uncertainty
1mm uncertainty
theory

3mm 20160811 $T_F = 22.8^\circ C$
1mm 20170702 $T_F = 21.5^\circ C$
Ra

Temperature, C

28
27.5
27
26.5
26
25.5
25
24.5
24
23.5
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

Time, s

0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000

0
100000
200000

symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
\(\Delta T\) | 3.75K | 46.9%/K | 0.10K | 4.69% | LM35C differential
\(P\) | 101kPa | 0.0005%/Pa | 1.5kPa | 0.76% | MPXH6115A6U air pressure
\(C_{pt}\) | 4.69kJ/K | 0.032%/\(\text{J/K}\) | 47J/K | 1.50% | plate thermal capacity
\(C_S\) | 1.000 | −42.4% | 0.050 | 2.12% | side reuptake
\(C_B\) | 1.000 | −14.9% | 0.100 | 1.49% | back reuptake
\(L_c\) | 0.305m | 461%/m | 500um | 0.23% | characteristic-length
\(D_{Al}\) | 19.4mm | 1148%/m | 500um | 0.57% | metal slab thickness
\(D_{PIR}\) | 25.4mm | 1148%/m | 1.0mm | 1.15% | insulation thickness
\(D_g\) | 1.00mm | 1148%/m | 500um | 0.57% | air gap
\(\varepsilon_{XPS}\) | 0.470 | 34.7% | 0.010 | 0.35% | XPS emissivity
\(\varepsilon_{tp}\) | 0.890 | 41.7% | 0.015 | 0.63% | tape emissivity
\(\Omega_{tp}\) | 0.540 | 31.7% | 0.020 | 0.63% | tape coverage
\(\varepsilon_{rs}\) | 0.040 | 147% | 0.010 | 1.47% | rough surface emissivity
\(\varepsilon_{wt}\) | 0.900 | 65.9% | 0.025 | 1.65% | wind-tunnel emissivity

estimated measurement uncertainties of natural convection at \(\theta = -90.0\)
Temperature, C

symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$\Delta T$ | 7.10K | 23.8%/$K$ | 0.10K | 2.38% | LM35C differential
$P$ | 101kPa | 0.0005%/$Pa$ | 1.5kPa | 0.78% | MPXH6115A6U air pressure
$C_{pt}$ | 4.69kJ/$K$ | 0.030%/$(J/K)$ | 47J/$K$ | 1.41% | plate thermal capacity
$C_S$ | 1.000 | $-40.7\%$ | 0.050 | 2.04% | side reuptake
$C_B$ | 1.000 | $-12.7\%$ | 0.100 | 1.27% | back reuptake
$L_c$ | 0.305m | 437%/m | 500um | 0.22% | characteristic-length
$D_{Al}$ | 19.4mm | 964%/m | 500um | 0.48% | metal slab thickness
$D_{PIR}$ | 25.4mm | 964%/m | 1.0mm | 0.96% | insulation thickness
$D_g$ | 1.00mm | 964%/m | 500um | 0.48% | air gap
$\epsilon_{XPS}$ | 0.470 | 29.1% | 0.010 | 0.29% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 35.1% | 0.015 | 0.53% | tape emissivity
$\Omega_{tp}$ | 0.540 | 26.6% | 0.020 | 0.53% | tape coverage
$\epsilon_{rs}$ | 0.040 | 125% | 0.010 | 1.25% | rough surface emissivity
$\epsilon_{wt}$ | 0.900 | 55.5% | 0.025 | 1.39% | wind-tunnel emissivity

estimated measurement uncertainties of natural convection at $\theta = -90.0$
symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$\Delta T$ | 10.4K | 15.8%/K | 0.10K | 1.58% | LM35C differential
$P$ | 100kPa | 0.0005%/Pa | 1.5kPa | 0.79% | MPXH6115A6U air pressure
$C_{pt}$ | 4.69kJ/K | 0.029%//(J/K) | 47J/K | 1.37% | plate thermal capacity
$C_S$ | 1.000 | –39.7% | 0.050 | 1.99% | side reuptake
$C_B$ | 1.000 | –11.5% | 0.100 | 1.15% | back reuptake
$L_c$ | 0.305m | 423%/m | 500um | 0.21% | characteristic-length
$D_{Al}$ | 19.4mm | 853%/m | 500um | 0.43% | metal slab thickness
$D_{PIR}$ | 25.4mm | 853%/m | 1.0mm | 0.85% | insulation thickness
$D_g$ | 1.00mm | 853%/m | 500um | 0.43% | air gap
$\epsilon_{XPS}$ | 0.470 | 25.8% | 0.010 | 0.26% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 31.2% | 0.015 | 0.47% | tape emissivity
$\Omega_{tp}$ | 0.540 | 23.5% | 0.020 | 0.47% | tape coverage
$\epsilon_{rs}$ | 0.040 | 113% | 0.010 | 1.13% | rough surface emissivity
$\epsilon_{wt}$ | 0.900 | 49.3% | 0.025 | 1.23% | wind-tunnel emissivity

estimated measurement uncertainties of natural convection at $\theta = -90.0$
symbol | nominal | sensitivity | bias | uncertainty | component
---|---|---|---|---|---
$\Delta T$ | 13.8K | 11.9%/K | 0.10K | 1.19% | LM35C differential
$P$ | 101kPa | 0.0005%/Pa | 1.5kPa | 0.80% | MPXH6115A6U air pressure
$C_{pt}$ | 4.69kJ/K | 0.029%/J/K | 47J/K | 1.35% | plate thermal capacity
$C_B$ | 1.000 | −39.1% | 0.050 | 1.96% | side reuptake
$C_B$ | 1.000 | −10.8% | 0.100 | 1.08% | back reuptake
$L_c$ | 0.305m | 418%/m | 500um | 0.21% | characteristic-length
$D_{Al}$ | 19.4mm | 812%/m | 500um | 0.41% | metal slab thickness
$D_{PIR}$ | 25.4mm | 812%/m | 1.0mm | 0.81% | insulation thickness
$D_g$ | 1.00mm | 812%/m | 500um | 0.41% | air gap
$\epsilon_{XPS}$ | 0.470 | 24.6% | 0.010 | 0.25% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 29.7% | 0.015 | 0.45% | tape emissivity
$\Omega_{tp}$ | 0.540 | 22.4% | 0.020 | 0.45% | tape coverage
$\epsilon_{rs}$ | 0.040 | 108% | 0.010 | 1.08% | rough surface emissivity
$\epsilon_{wt}$ | 0.900 | 47.0% | 0.025 | 1.18% | wind-tunnel emissivity

3.60% combined bias uncertainty

estimated measurement uncertainties of natural convection at $\theta = -90.0$
20170702T154332Z – natural Convection – Roughness=1.04mm; T=21.5+03.7°C; −90.00°
k=0.0258, Ra_U=159845, h=3.66W/(K.m^2), U=0.340W/K, Nu=10.79, Pr=0.710

symbol | nominal | sensitivity | bias  | uncertainty | component
--- | --- | --- | --- | --- | ---
ΔT  | 3.66K  | 43.3%/K  | 0.10K | 4.33% | LM35C differential
P  | 101kPa  | 0.0005%/Pa  | 1.5kPa | 0.78% | MPXH6115A6U air pressure
C_{pt}  | 4.24kJ/K  | 0.031%(J/K)  | 42J/K | 1.32% | plate thermal capacity
C_{S}  | 1.000  | −39.6% | 0.050 | 1.98% | side reuptake
C_{B}  | 1.000  | −15.0% | 0.100 | 1.50% | back reuptake
L_{c}  | 0.305m  | 404%/m  | 500um | 0.20% | characteristic-length
D_{Al}  | 19.4mm  | 725%/m  | 500um | 0.36% | metal slab thickness
D_{PIR}  | 25.4mm  | 725%/m  | 1.0mm | 0.73% | insulation thickness
D_{g}  | 1.000mm  | 725%/m  | 500um | 0.36% | air gap
ε_{XPS}  | 0.470  | 65.2% | 0.010 | 0.65% | XPS emissivity
ε_{rs}  | 0.040  | 146% | 0.010 | 1.46% | rough surface emissivity
ε_{wt}  | 0.900  | 43.4% | 0.025 | 1.08% | wind-tunnel emissivity

5.64% combined bias uncertainty

estimated measurement uncertainties of natural convection at \theta = -90.0
estimated measurement uncertainties of natural convection at $\theta = -90.0$°
20170702T234939Z – natural Convection – Roughness=1.04mm; T=21.4+10.4°C; −90.00°
k=0.0261, Ra_U=425861, h=4.99W/(K.m²), U=0.465W/K, Nu=14.59, Pr=0.709

estimated measurement uncertainties of natural convection at $\theta = -90.0$
Ra

Time, s

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000

k=0.0262, Ra_U=543459, h=5.37W/(K.m²), U=0.499W/K, Nu=15.60, Pr=0.709

20170703T014525Z – natural Convection – Roughness=1.04mm; T=21.5+13.7°C; −90.00°

symbol      nominal    sensitivity    bias    uncertainty    component

\(\Delta T\) 13.7K  11.0%/K  0.10K  1.10%  LM35C differential

\(P\) 101kPa  0.0005%/Pa  1.5kPa  0.81%  MPXH6115A6U air pressure

\(C_{pt}\) 4.24kJ/K  0.029%//(J/K)  42J/K  1.22%  plate thermal capacity

\(C_S\) 1.000  −36.2%  0.050  1.81%  side reuptake

\(C_B\) 1.000  −10.7%  0.100  1.07%  back reuptake

\(D_{Al}\) 19.4mm  502%/m  500um  0.25%  metal slab thickness

\(D_{FIR}\) 25.4mm  502%/m  1.0mm  0.50%  insulation thickness

\(D_g\) 1.00mm  502%/m  500um  0.25%  air gap

\(\epsilon_{XPS}\) 0.470  45.1%  0.010  0.45%  XPS emissivity

\(\epsilon_{rs}\) 0.040  106%  0.010  1.06%  rough surface emissivity

\(\epsilon_{wt}\) 0.900  30.4%  0.025  0.76%  wind-tunnel emissivity

3.19% combined bias uncertainty

estimated measurement uncertainties of natural convection at \(\theta = -90.0\)
vertical plate natural convection

\[ \frac{1}{2} \left( \frac{\text{average Nusselt number} \; Nu}{\text{Rayleigh number} \; Ra'} \right)^{1/3} \]

ext 20160212 \( T_F = 18.7^\circ \text{C} \)

opp 20160913 \( T_F = 21.2^\circ \text{C} \)

opp 20170430 \( T_F = 18.0^\circ \text{C} \)

aid 20201222 \( T_F = 18.2^\circ \text{C} \)
estimated measurement uncertainties of natural convection at $\theta = -0.0$
| symbol | nominal | sensitivity | bias | uncertainty | component |
|--------|---------|-------------|------|-------------|-----------|
| $\Delta T$ | 10.7K | 21.7%/K | 0.10K | 2.17% | LM35C differential |
| $P$ | 99.4kPa | 0.007%/Pa | 1.5kPa | 1.06% | MPXH6115A6U air pressure |
| $C_{pt}$ | 4.69kJ/K | 0.042%(J/K) | 47J/K | 1.96% | plate thermal capacity |
| $C_V$ | 1.000 | -14.2% | 0.100 | 1.42% | vertical reuptake |
| $L_c$ | 0.305m | 591%/m | 500um | 0.30% | characteristic-length |
| $D_{Al}$ | 19.4mm | 1126%/m | 500um | 0.56% | metal slab thickness |
| $D_{PIR}$ | 25.4mm | 603%/m | 1.0mm | 0.60% | insulation thickness |
| $D_g$ | 1.00mm | 573%/m | 500um | 0.29% | air gap |
| $k_{PIR}$ | 23.0 mW/K·m | 0.48%/mW/K·m | 1.2 mW/K·m | 0.55% | PIR thermal conductivity |
| $\epsilon_{XPS}$ | 0.470 | 34.0% | 0.010 | 0.34% | XPS emissivity |
| $\epsilon_{tp}$ | 0.890 | 40.9% | 0.015 | 0.61% | tape emissivity |
| $\Omega_{tp}$ | 0.540 | 31.1% | 0.020 | 0.62% | tape coverage |
| $\epsilon_{rs}$ | 0.040 | 144% | 0.010 | 1.44% | rough surface emissivity |
| $\epsilon_{wt}$ | 0.900 | 65.5% | 0.025 | 1.64% | wind-tunnel emissivity |

Estimated measurement uncertainties of natural convection at $\theta = -0.0$
symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$\Delta T$ | 3.64K | 72.1%/K | 0.10K | 7.21% | LM35C differential
$T_{bb}$ | 294K | 0.430%/K | 0.50K | 0.21% | radiative temperature
$P$ | 101kPa | 0.0007%/Pa | 1.5kPa | 1.01% | MPXH6115A6U air pressure
$C_{pt}$ | 4.69kJ/K | 0.048%//(J/K) | 47J/K | 2.27% | plate thermal capacity
$C_V$ | 1.000 | -17.6% | 0.100 | 1.76% | vertical reuptake
$L_c$ | 0.305m | 681%/m | 500um | 0.34% | characteristic-length
$D_{Al}$ | 19.4mm | 1628%/m | 500um | 0.81% | metal slab thickness
$D_{PIR}$ | 25.4mm | 962%/m | 1.0mm | 0.96% | insulation thickness
$D_g$ | 1.00mm | 923%/m | 500um | 0.46% | air gap
$k_{PIR}$ | 23.0mW/Km | 0.610%/mW/Km | 1.2mW/Km | 0.70% | PIR thermal conductivity
$\epsilon_{XPS}$ | 0.470 | 49.2% | 0.010 | 0.49% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 58.9% | 0.015 | 0.88% | tape emissivity
$\Omega_{tp}$ | 0.540 | 44.9% | 0.020 | 0.90% | tape coverage
$\epsilon_{rs}$ | 0.040 | 202% | 0.010 | 2.02% | rough surface emissivity
$\epsilon_{wt}$ | 0.900 | 94.7% | 0.025 | 2.37% | wind-tunnel emissivity

estimated measurement uncertainties of natural convection at $\theta = -0.0$
Temperature, °C

Ra

symbol | nominal | sensitivity | bias | uncertainty component
--- | --- | --- | --- | ---
ΔT | 7.20K | 34.2%/K | 0.10K | 3.42% | LM35C differential
P | 101kPa | 0.0007%/Pa | 1.5kPa | 1.02% | MPXH6115A6U air pressure
C\text{pt} | 4.69kJ/K | 0.045%(J/K) | 47J/K | 2.10% | plate thermal capacity
C\text{V} | 1.000 | −16.4% | 0.100 | 1.64% | vertical reuptake
L\text{c} | 0.305m | 634%/m | 500um | 0.32% | characteristic-length
D\text{Al} | 19.4mm | 1359%/m | 500um | 0.68% | metal slab thickness
D\text{FR} | 25.4mm | 776%/m | 1.0mm | 0.78% | insulation thickness
D\text{g} | 1.00mm | 743%/m | 500um | 0.37% | air gap
k\text{PIR} | 23.0 mW K\text{m}^{-1} | 0.534%/m W | 1.2 mW K\text{m}^{-1} | 0.61% | PIR thermal conductivity
\text{ε}_{\text{XPS}} | 0.470 | 41.1% | 0.010 | 0.41% | XPS emissivity
\text{ε}_{\text{tP}} | 0.890 | 49.3% | 0.015 | 0.74% | tape emissivity
Ω\text{tP} | 0.540 | 37.5% | 0.020 | 0.75% | tape coverage
\text{ε}_{\text{rs}} | 0.040 | 172% | 0.010 | 1.72% | rough surface emissivity
\text{ε}_{\text{wt}} | 0.900 | 79.0% | 0.025 | 1.98% | wind-tunnel emissivity

estimated measurement uncertainties of natural convection at θ = −0.0
20160912T115846Z – natural Convection – Roughness=3.00mm; T=21.5+10.5°C; +0.00°
k=0.0261, Ra_V=28016675, h=3.59W/(K.m²), U=0.334W/K, Nu=41.95, Pr=0.709

symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$\Delta T$ | 10.5K | 22.7%/K | 0.10K | 2.27% | LM35C differential
$P$ | 102kPa | 0.0007%/Pa | 1.5kPa | 1.03% | MPXH6115A6U air pressure
$C_{pt}$ | 4.69kJ/K | 0.043%/J/K | 47J/K | 2.01% | plate thermal capacity
$C_V$ | 1.000 | −15.7% | 0.100 | 1.57% | vertical reuptake
$L_c$ | 0.305m | 608%/m | 500um | 0.30% | characteristic-length
$D_{AI}$ | 19.4mm | 1211%/m | 500um | 0.61% | metal slab thickness
$D_{PIR}$ | 25.4mm | 674%/m | 1.0mm | 0.67% | insulation thickness
$D_g$ | 1.00mm | 643%/m | 500um | 0.32% | air gap
$k_{PIR}$ | 23.0 mW/Km | 0.493%/mW/Km | 1.2 mW/Km | 0.57% | PIR thermal conductivity
$\epsilon_{XPS}$ | 0.470 | 36.0% | 0.010 | 0.37% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 44.1% | 0.015 | 0.66% | tape emissivity
$\Omega_{tp}$ | 0.540 | 33.4% | 0.020 | 0.67% | tape coverage
$\epsilon_{rs}$ | 0.040 | 155% | 0.010 | 1.55% | rough surface emissivity
$\epsilon_{wt}$ | 0.900 | 70.5% | 0.025 | 1.76% | wind-tunnel emissivity

estimated measurement uncertainties of natural convection at $\theta = -0.0$
20160913T033648Z – natural Convection – Roughness=3.00mm; T=21.9+13.9°C; +0.00°
k=0.0263, Ra_V=35634045, h=3.85W/(K.m²), U=0.358W/K, Nu=44.64, Pr=0.708

symbol | nominal | sensitivity | bias | uncertainty | component
---|---|---|---|---|---
$\Delta T$ | 13.9K | 16.8%/K | 0.10K | 1.68% | LM35C differential
$P$ | 101kPa | 0.0007%/Pa | 1.5kPa | 1.04% | MPXH6115A6U air pressure
$C_{pt}$ | 4.69kJ/K | 0.042%/(J/K) | 47J/K | 1.96% | plate thermal capacity
$C_V$ | 1.000 | -15.3% | 0.100 | 1.53% | vertical reuptake
$L_c$ | 0.305m | 595%/m | 500um | 0.30% | characteristic-length
$D_{Al}$ | 19.4mm | 1135%/m | 500um | 0.57% | metal slab thickness
$D_{PIR}$ | 25.4mm | 628%/m | 1.0mm | 0.63% | insulation thickness
$D_g$ | 1.00mm | 599%/m | 500um | 0.30% | air gap
$k_{PIR}$ | 23.0mW/K·m | 0.465%/mW/K·m | 1.2mW/K·m | 0.53% | PIR thermal conductivity
$\epsilon_{XPS}$ | 0.470 | 34.3% | 0.010 | 0.34% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 41.3% | 0.015 | 0.62% | tape emissivity
$\Omega_{tp}$ | 0.540 | 31.3% | 0.020 | 0.63% | tape coverage
$\epsilon_{rs}$ | 0.040 | 146% | 0.010 | 1.46% | rough surface emissivity
$\epsilon_{wt}$ | 0.900 | 66.0% | 0.025 | 1.65% | wind-tunnel emissivity

4.14% combined bias uncertainty

estimated measurement uncertainties of natural convection at $\theta = -0.0$
estimated measurement uncertainties of natural convection at $\theta = -0.0$
20170501T003012Z - natural Convection - Roughness=1.04mm; T=18.2+07.0°C; +0.00°  
k=0.0258, Ra_V=20358262, h=3.07W/(K.m²), U=0.285W/K, Nu=36.32, Pr=0.709  

| symbol | nominal | sensitivity | bias     | uncertainty | component                        |
|--------|---------|-------------|----------|-------------|----------------------------------|
| $\Delta T$ | 7.03K   | 32.1%/K   | 0.10K    | 3.21%       | LM35C differential               |
| $P$     | 102kPa  | 0.0007%/Pa | 1.5kPa   | 1.02%       | MPXH6115A6U air pressure          |
| $C_{pt}$| 4.24kJ/K| 0.045%/kJ  | 42J/K    | 1.90%       | plate thermal capacity           |
| $C_V$   | 1.000   | -15.3%     | 0.100    | 1.53%       | vertical reuptake                |
| $L_c$   | 0.305m  | 567%/m     | 500μm    | 0.28%       | characteristic-length            |
| $D_{Al}$| 19.4mm  | 919%/m     | 500μm    | 0.46%       | metal slab thickness             |
| $D_{PIR}$| 25.4mm | 339%/m     | 1.0mm    | 0.34%       | insulation thickness             |
| $k_{PIR}$| 23.0mW/m² | 0.531%/m² | 1.2mW/m² | 0.61%       | PIR thermal conductivity         |
| $\epsilon_{XPS}$ | 0.470 | 37.7%   | 0.010 | 0.38%       | XPS emissivity                   |
| $\epsilon_{tp}$ | 0.550 | 45.6%  | 0.015 | 0.68%       | tape emissivity                  |
| $\epsilon_{rs}$ | 0.040 | 165% | 0.010 | 1.65%       | rough surface emissivity         |
| $\epsilon_{wt}$ | 0.900 | 56.0% | 0.025 | 1.40%       | wind-tunnel emissivity           |

estimated measurement uncertainties of natural convection at $\theta = -0.0$
| Symbol | Nominal | Sensitivity | Bias | Uncertainty | Component |
|--------|---------|-------------|------|-------------|-----------|
| $\Delta T$ | 10.5K | 20.8%/K | 0.10K | 2.08% | LM35C differential |
| $P$ | 101kPa | 0.0007%/Pa | 1.5kPa | 1.03% | MPXH6115A6U air pressure |
| $C_{pt}$ | 4.24kJ/K | 0.043%(J/K) | 42J/K | 1.83% | plate thermal capacity |
| $C_V$ | 1.000 | -14.7% | 0.100 | 1.47% | vertical reuptake |
| $L_c$ | 0.305m | 548%/m | 500um | 0.27% | characteristic-length |
| $D_{Al}$ | 19.4mm | 819%/m | 500um | 0.41% | metal slab thickness |
| $D_{PIR}$ | 25.4mm | 286%/m | 1.0mm | 0.29% | insulation thickness |
| $k_{PIR}$ | 23.0$\text{mW/Km}$ | 0.489%/m$\text{W}$ | 1.2$\text{mW/Km}$ | 0.56% | PIR thermal conductivity |
| $\epsilon_{XPS}$ | 0.470 | 33.6% | 0.010 | 0.34% | XPS emissivity |
| $\epsilon_{tp}$ | 0.550 | 40.8% | 0.015 | 0.61% | tape emissivity |
| $\epsilon_{rs}$ | 0.040 | 149% | 0.010 | 1.49% | rough surface emissivity |
| $\epsilon_{wt}$ | 0.900 | 49.9% | 0.025 | 1.25% | wind-tunnel emissivity |

Estimated measurement uncertainties of natural convection at $\theta = -0.0$
symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$\Delta T$ | 14.4K | 15.0%/K | 0.10K | 1.50% | LM35C differential
$P$ | 101kPa | 0.0007%/Pa | 1.5kPa | 1.04% | MPXH6115A6U air pressure
$C_{pt}$ | 4.24kJ/K | 0.042%/J/K | 42J/K | 1.78% | plate thermal capacity
$C_V$ | 1.000 | −14.2% | 0.100 | 1.42% | characteristic-length
$L_c$ | 0.305m | 536%/m | 500um | 0.27% | metal slab thickness
$D_{Al}$ | 19.4mm | 761%/m | 500um | 0.38% | insulation thickness
$D_{PIR}$ | 25.4mm | 259%/m | 1.0mm | 0.26% | PIR thermal conductivity
$k_{PIR}$ | 23.0 mW/K·m | 0.460%/mW/K·m | 1.2 mW/K·m | 0.53% | PIR thermal conductivity
$\epsilon_{XPS}$ | 0.470 | 31.2% | 0.010 | 0.31% | XPS emissivity
$\epsilon_{tp}$ | 0.550 | 37.9% | 0.015 | 0.57% | tape emissivity
$\epsilon_{rs}$ | 0.040 | 140% | 0.010 | 1.40% | rough surface emissivity
$\epsilon_{wt}$ | 0.900 | 46.4% | 0.025 | 1.16% | wind-tunnel emissivity

estimated measurement uncertainties of natural convection at $\theta = -0.0$
symbol      nominal    sensitivity   bias      uncertainty  component
\( \Delta T \)     3.84K    66.6%/K    0.10K   6.66%    LM35C differential
\( T_{bb} \)       292K    0.417%/K   0.50K   0.21%    radiative temperature
\( P \)           101kPa  0.0007%/Pa  1.5kPa  1.00%    MPXH6115A6U air pressure
\( C_{pt} \)      4.24kJ/K  0.052%(J/K) 42kJ/K  2.21%    plate thermal capacity
\( C_v \)         1.000    -16.4%     0.100  1.64%    vertical reuptake
\( L_c \)         0.305m   664%/m    500um   0.33%    characteristic-length
\( D_{AI} \)      19.4mm   1565%/m   500um   0.78%    metal slab thickness
\( D_{PIR} \)     25.4mm   909%/m    1.0mm   0.91%    insulation thickness
\( D_g \)         1.00mm   871%/m    500um   0.44%    air gap
\( k_{PIR} \)     23.0mW/Km 0.602%/mW  1.2mW/Km 0.69%    PIR thermal conductivity
\( \epsilon_{XPS} \) 0.470  47.3%     0.010  0.47%    XPS emissivity
\( \epsilon_{tp} \) 0.890  56.6%     0.015  0.85%    tape emissivity
\( \Omega_{tp} \)   0.540  43.2%     0.020  0.86%    tape coverage
\( \epsilon_{rs} \) 0.040  194%      0.010  1.94%    rough surface emissivity
\( \epsilon_{wt} \) 0.900  90.9%     0.025  2.27%    wind-tunnel emissivity

estimated measurement uncertainties of natural convection at \( \theta = -0.0 \)
20201222T211021Z – natural Convection – Roughness=1.04mm; T=17.9±0.1°C; ±0.00°
k=0.0258, Ra_V=19829276, h=2.98W/(K.m²), U=0.277W/K, Nu=35.31, Pr=0.708

| symbol | nominal | sensitivity | bias   | uncertainty | component              |
|--------|---------|-------------|--------|-------------|------------------------|
| ΔT     | 7.06K   | 34.2%/K     | 0.10K  | 3.42%       | LM35C differential      |
| P      | 100.0kPa| 0.0007%/Pa   | 1.5kPa | 1.02%       | MPXH6115A6U air pressure|
| Cₚₜ   | 4.24kJ/K| 0.049%//(J/K)| 42J/K | 2.06%       | plate thermal capacity  |
| Cₐ    | 1.000   | -15.4%      | 0.100  | 1.54%       | vertical reuptake       |
| Lₙ    | 0.305m  | 620%/m      | 500µm  | 0.31%       | characteristic-length   |
| Dₐₐ   | 19.4mm  | 1316%/m     | 500µm  | 0.66%       | metal slab thickness    |
| Dₚₚ   | 25.4mm  | 733%/m      | 1.0mm  | 0.73%       | insulation thickness    |
| Dₙ    | 1.00nm  | 700%/m      | 500µm  | 0.35%       | air gap                 |
| kₚₚ   | 23.0µW/K·m| 0.534%/µW/K·m| 1.2µW/K·m| 0.61%| PIR thermal conductivity|
| εₓₓₛ   | 0.470   | 39.8%      | 0.010  | 0.40%       | XPS emissivity          |
| εₜₚ   | 0.890   | 47.7%      | 0.015  | 0.72%       | tape emissivity         |
| Ωₜₚ   | 0.540   | 36.3%      | 0.020  | 0.73%       | tape coverage           |
| εᵣₛ   | 0.040   | 165%       | 0.010  | 1.65%       | rough surface emissivity|
| εₜₑ    | 0.900   | 76.4%      | 0.025  | 1.91%       | wind-tunnel emissivity  |

estimated measurement uncertainties of natural convection at $\theta = -0.0$
20201222T230047Z – natural Convection – Roughness=1.04mm; T=18.0+10.5°C; +0.00°
k=0.0259, Ra_V=28520204, h=3.33W/(K.m²), U=0.310W/K, Nu=39.27, Pr=0.708

| symbol | nominal | sensitivity | bias | uncertainty | component |
|--------|---------|-------------|------|-------------|-----------|
| ∆T    | 10.5K   | 22.4%/K     | 0.10K| 2.24%       | LM35C differential |
| P     | 100kPa  | 0.0007%/Pa  | 1.5kPa| 1.03%       | MPXH6115A6U air pressure |
| Cpt   | 4.24kJ/K | 0.047%/(J/K) | 42J/K | 1.98%       | plate thermal capacity |
| CV    | 1.00    | -14.7%      | 0.100| 1.47%       | vertical reuptake |
| Lc    | 0.305m  | 597%/m      | 500μm| 0.30%       | characteristic-length |
| DAl   | 19.4mm  | 1184%/m     | 500μm| 0.59%       | metal slab thickness |
| DPIR  | 25.4mm  | 647%/m      | 1.0mm| 0.65%       | insulation thickness |
| Dg    | 1.00mm  | 616%/m      | 500μm| 0.31%       | air gap |
| kPIR  | 23.0mW/m | 0.493%/mW/m | 1.2mW/m | 0.57%   | PIR thermal conductivity |
| cXPS  | 0.470   | 35.8%       | 0.010| 0.36%       | XPS emissivity |
| ctP   | 0.890   | 43.0%       | 0.015| 0.64%       | tape emissivity |
| ΩtP   | 0.540   | 32.7%       | 0.020| 0.65%       | tape coverage |
| crs   | 0.040   | 150%        | 0.010| 1.50%       | rough surface emissivity |
| cwt   | 0.900   | 68.7%       | 0.025| 1.72%       | wind-tunnel emissivity |

estimated measurement uncertainties of natural convection at θ = -0.0
Ra = 20000000
40000000

Time, s

0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000

Temperature, C

20
24
28
32
36

symbol
ΔT
P
C_{pt}
C_V
L_c
D_{Al}
D_{P\text{IR}}
D_g
k_{P\text{IR}}
ε_{\text{XPS}}
ε_{\text{tp}}
Ω_{\text{tp}}
ε_{rs}
ε_{\text{wt}}
nominal
14.0 K
100 kPa
4.24 kJ/K
1.00
0.305 m
19.4 mm
25.4 mm
1.00 mm
23.0 mW/K·m
0.470
0.890
0.540
0.040
0.900
sensitivity
16.4% K⁻¹
0.0007 %/Pa
0.045 %/(J/K)
−14.3%
582 %/m
1101 %/m
596 %/m
567 %/m
0.463 %/m
33.3%
40.0%
30.4%
141%
64.0%
bias
0.10 K
1.5 kPa
0.100
500 µm
500 µm
500 µm
1.0 mm
500 µm
1.2 µW/K·m
0.010
0.015
0.020
0.010
0.025
uncertainty
0.10 K
1.5 kPa
42 J/K
0.100
500 µm
500 µm
500 µm
0.100
500 µm
0.10 K
0.010
0.015
0.020
0.010
0.025
component
LM35C differential
MPXH6115A6U air pressure
plate thermal capacity
vertical reuptake
characteristic-length
metal slab thickness
insulation thickness
air gap
PIR thermal conductivity
XPS emissivity
tape emissivity
tape coverage
rough surface emissivity
wind-tunnel emissivity
combined bias uncertainty

estimated measurement uncertainties of natural convection at θ = −0.0
average Nusselt number $\overline{Nu}$

Downward natural convection

$R_{a}$

$\Xi$

3 mm uncertainty $0.341 + 0.550 \left( \frac{Ra}{\Xi} \right)^{1/5}$

1 mm uncertainty $0.682 + 0.844 \left( \frac{Ra}{\Xi} \right)^{1/6}$

$T_F = 22.2^\circ C$

$T_F = 21.4^\circ C$
symbol | nominal | sensitivity | bias | uncertainty | component
---|---|---|---|---|---
\( \Delta T \) | 3.59K | 120% /K | 0.10K | 12.03% | LM35C differential
\( T \) | 297K | 0.873% /K | 0.50K | 0.44% | LM35C temperature sensor
\( C_{pt} \) | 4.69kJ /K | 0.084% /（J /K） | 47J /K | 3.95% | plate thermal capacity
\( P \) | 101kPa | 0.0007% /Pa | 1.5kPa | 1.05% | MPXH6115A6U air pressure
\( \rho \) | 1.00mm | 319% /m | 500um | 1.07% | air gap
\( L_c \) | 0.305m | 1207% /m | 500um | 0.60% | characteristic-length
\( L_w \) | 0.21% | 422% /m | 500um | plate width
\( D_{Al} \) | 19.4mm | 3199% /m | 500um | 1.60% | metal slab thickness
\( D_{PIR} \) | 25.4mm | 2191% /m | 1.0mm | 2.19% | insulation thickness
\( D_g \) | 1.00mm | 2133% /m | 500um | 1.07% | air gap
\( L_m \) | 3.57mm | 676% /m | 500um | 0.34% | side metal strip width
\( k_{PIR} \) | 23.0 mW /K·m | 0.924% /mW /K·m | 1.2 mW /K·m | 1.06% | PIR thermal conductivity
\( k_{XPS} \) | 33.0 mW /K·m | 0.132% /mW /K·m | 1.7 mW /K·m | 0.22% | XPS thermal conductivity
\( \epsilon_XPS \) | 0.470 | 96.7% | 0.010 | 0.97% | XPS emissivity
\( \epsilon_{tp} \) | 0.890 | 116% | 0.015 | 1.74% | tape emissivity
\( \Omega_{tp} \) | 0.540 | 88.3% | 0.020 | 1.77% | tape coverage
\( \epsilon_{rs} \) | 0.040 | 408% | 0.010 | 4.08% | rough surface emissivity
\( \epsilon_b \) | 0.190 | 39.5% | 0.020 | 0.79% | back emissivity
\( \epsilon_{wt} \) | 0.900 | 192% | 0.025 | 4.80% | wind-tunnel emissivity
\( \theta \) | 90.0° | 1.26% /° | 0.50° | 0.63% | plate angle

estimated measurement uncertainties of natural convection at \( \theta = 90.0 \)
symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$T$ | 299K | 0.756%/K | 0.50K | 0.38% | LM35C temperature sensor
$\Delta T$ | 7.35K | 57.5%/K | 0.10K | 5.75% | LM35C differential
$T_{bb}$ | 295K | 0.765%/K | 0.50K | 0.38% | radiative temperature
$P$ | 101kPa | 0.0008%/Pa | 1.5kPa | 1.13% | MPXH6115A6U air pressure
$C_{pt}$ | 4.69kJ/K | 0.081%/J/K | 47J/K | 3.82% | plate thermal capacity
$L_c$ | 0.305m | 1166%/m | 500um | 0.58% | characteristic-length
$L_w$ | 0.305m | 411%/m | 500um | 0.21% | plate width
$D_{Al}$ | 19.4mm | 2850%/m | 500um | 1.42% | metal slab thickness
$D_{PIR}$ | 25.4mm | 1891%/m | 1.0mm | 1.89% | insulation thickness
$D_g$ | 1.00mm | 1836%/m | 500um | 0.92% | air gap
$L_m$ | 3.57mm | 703%/m | 500um | 0.35% | side metal strip width
$k_{PIR}$ | 23.0 mW/Km | 0.879%/mW/Km | 1.2 mW/Km | 1.01% | PIR thermal conductivity
$k_{XPS}$ | 33.0 mW/Km | 0.125%/mW/Km | 1.7 mW/Km | 0.21% | XPS thermal conductivity
$\epsilon_{XPS}$ | 0.470 | 86.2% | 0.010 | 0.86% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 104% | 0.015 | 1.56% | tape emissivity
$\Omega_{tp}$ | 0.540 | 78.7% | 0.020 | 1.57% | tape coverage
$\epsilon_{rs}$ | 0.040 | 372% | 0.010 | 3.72% | rough surface emissivity
$\epsilon_b$ | 0.190 | 30.4% | 0.020 | 0.61% | back emissivity
$\epsilon_{wt}$ | 0.900 | 171% | 0.025 | 4.27% | wind-tunnel emissivity
$\theta$ | 90.0° | 1.31%/° | 0.50° | 0.66% | plate angle

estimated measurement uncertainties of natural convection at $\theta = 90.0$°
20160910T190723Z – natural Convection – Roughness=3.00mm; T=22.3+11.5°C; +90.00°
k=0.0262, Ra_D=3700641, h=1.70W/(K.m²), U=0.158W/K, Nu=9.87, Pr=0.709

| symbol      | nominal     | sensitivity | bias     | uncertainty | component                                      |
|-------------|-------------|-------------|----------|-------------|------------------------------------------------|
| T           | 301K        | 0.692%/K    | 0.50K    | 0.35%       | LM35C temperature sensor                       |
| ΔT          | 11.5K       | 36.4%/K     | 0.10K    | 3.64%       | LM35C differential                              |
| T_{bb}      | 296K        | 0.708%/K    | 0.50K    | 0.35%       | radiative temperature                           |
| P           | 101kPa      | 0.0008%/Pa   | 1.5kPa   | 1.17%       | MPXH6115A6U air pressure                        |
| C_{pt}      | 4.69kJ/K    | 0.080%/(/J/K)| 47J/K   | 3.75%       | plate thermal capacity                          |
| L_c         | 0.305m      | 1148%/m     | 500nm    | 0.57%       | characteristic-length                           |
| L_w         | 0.305m      | 406%/m      | 500nm    | 0.20%       | plate width                                     |
| D_{Al}      | 19.4mm      | 267%/m      | 500nm    | 1.34%       | metal slab thickness                            |
| D_{PIR}     | 25.4mm      | 174%/m      | 1.0mm    | 1.74%       | insulation thickness                            |
| D_{g}       | 1.00mm      | 1691%/m     | 500um    | 0.85%       | air gap                                        |
| L_m         | 3.57mm      | 719%/m      | 500nm    | 0.36%       | side metal strip width                          |
| k_{PIR}     | 23.0 mW/Km  | 0.852%/(/mW)| 1.2 mW/Km | 0.98%       | PIR thermal conductivity                        |
| k_{XPS}     | 33.0 mW/Km  | 0.122%/(/mW)| 1.7 mW/Km | 0.20%       | XPS thermal conductivity                        |
| η_{XPS}     | 0.470       | 80.8%       | 0.010    | 0.81%       | XPS emissivity                                  |
| η_{tp}      | 0.890       | 97.8%       | 0.015    | 1.47%       | tape emissivity                                 |
| Ω_{tp}      | 0.540       | 73.8%       | 0.020    | 1.48%       | tape coverage                                   |
| η_{rs}      | 0.040       | 35.4%       | 0.010    | 3.54%       | rough surface emissivity                        |
| η_{b}       | 0.190       | 25.3%       | 0.020    | 0.51%       | back emissivity                                 |
| η_{wt}      | 0.900       | 160%        | 0.025    | 4.00%       | wind-tunnel emissivity                          |
| θ           | 90.0°       | 1.35%/°     | 0.50°    | 0.67%       | plate angle                                     |

estimated measurement uncertainties of natural convection at θ = 90.0
symbol | nominal | sensitivity | bias  | uncertainty | component                      
--- | --- | --- | --- | --- | ---                    
\( T \) | 303K | 0.660%/K | 0.50K | 0.33% | LM35C temperature sensor 
\( \Delta T \) | 15.1K | 27.7%/K | 0.10K | 2.77% | LM35C differential 
\( T_{bb} \) | 295K | 0.676%/K | 0.50K | 0.34% | radiative temperature 
\( P \) | 100kPa | 0.008%/Pa | 1.5kPa | 1.20% | 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 | 403%/m | 500um | 0.20% | plate width 
\( D_{Al} \) | 19.4mm | 2576%/m | 500um | 1.29% | metal slab thickness 
\( D_{PIR} \) | 25.4mm | 1664%/m | 1.0mm | 1.66% | insulation thickness 
\( D_g \) | 1.00mm | 1612%/m | 500um | 0.81% | air gap 
\( L_m \) | 3.57mm | 729%/m | 500um | 0.36% | side metal strip width 
\( k_{PIR} \) | 2.30 mW/K·m | 0.836%/m·K | 1.2 mW | 0.96% | PIR thermal conductivity 
\( \epsilon_{XPS} \) | 0.470 | 77.9% | 0.010 | 0.78% | XPS emissivity 
\( \epsilon_{tp} \) | 0.890 | 94.3% | 0.015 | 1.42% | tape emissivity 
\( \Omega_{tp} \) | 0.540 | 71.1% | 0.020 | 1.42% | tape coverage 
\( \epsilon_{rs} \) | 0.040 | 344% | 0.010 | 3.44% | rough surface emissivity 
\( \epsilon_b \) | 0.190 | 22.8% | 0.020 | 0.46% | back emissivity 
\( \epsilon_{wt} \) | 0.900 | 154% | 0.025 | 3.85% | wind-tunnel emissivity 
\( \theta \) | 90.0° | 1.37%/° | 0.50° | 0.69% | plate angle 

estimated measurement uncertainties of natural convection at \( \theta = 90.0 \)°
### Natural Convection Measurement Details

- **Temperature:**
  - \( T = 296 \text{K} \)
  - \( \Delta T = 3.65 \text{K} \)
  - \( T_{bb} = 295 \text{K} \)
  - \( P = 100 \text{kPa} \)
  - \( C_{pt} = 4.24 \text{kJ/K} \)
  - \( L_c = 0.305 \text{m} \)
  - \( L_w = 0.305 \text{m} \)
  - \( D_{Al} = 19.4 \text{mm} \)
  - \( D_{PIR} = 25.4 \text{mm} \)
  - \( D_g = 1.00 \text{mm} \)
  - \( L_m = 3.57 \text{mm} \)
  - \( k_{PIR} = 32.0 \text{mW/Km} \)
  - \( k_{XPS} = 33.0 \text{mW/Km} \)

- **Emissivity:**
  - \( \epsilon_{tp} = 0.890 \)
  - \( \Omega_{tp} = 0.540 \)
  - \( \epsilon_{rs} = 0.040 \)
  - \( \epsilon_b = 0.190 \)
  - \( \epsilon_{wt} = 0.900 \)
  - \( \theta = 90.0^\circ \)

- **Estimated Measurement Uncertainties:**
  - \( 14.43\% \) combined bias uncertainty

---

**Symbol Table:**

| Symbol | Nominal Value | Sensitivity | Bias | Uncertainty | Component |
|--------|---------------|-------------|------|-------------|------------|
| \( T \) | 296K | 0.877%/K | 0.50K | 0.44% | LM35C temperature sensor |
| \( \Delta T \) | 3.65K | 116%/K | 0.10K | 11.58% | LM35C differential |
| \( T_{bb} \) | 295K | 0.870%/K | 0.50K | 0.44% | radiative temperature |
| \( P \) | 100kPa | 0.0007%/Pa | 1.5kPa | 1.00% | MPXH6115A6U air pressure |
| \( C_{pt} \) | 4.24kJ/K | 0.092%/(J/K) | 42J/K | 3.88% | plate thermal capacity |
| \( L_c \) | 0.305m | 1183%/m | 500um | 0.59% | characteristic-length |
| \( L_w \) | 0.305m | 422%/m | 500um | 0.21% | plate width |
| \( D_{Al} \) | 19.4mm | 3204%/m | 500um | 1.60% | metal slab thickness |
| \( D_{PIR} \) | 25.4mm | 2198%/m | 1.0mm | 2.20% | insulation thickness |
| \( D_g \) | 1.00mm | 2140%/m | 500um | 1.07% | air gap |
| \( L_m \) | 3.57mm | 630%/m | 500um | 0.31% | side metal strip width |
| \( k_{PIR} \) | 32.0mW/Km | 0.922%/mW/Km | 1.2mW/Km | 1.06% | PIR thermal conductivity |
| \( k_{XPS} \) | 33.0mW/Km | 0.132%/mW/Km | 1.7mW/Km | 0.22% | XPS thermal conductivity |
| \( \epsilon_{XPS} \) | 0.900 | 96.9% | 0.010 | 0.97% | XPS emissivity |
| \( \epsilon_{tp} \) | 0.890 | 116% | 0.015 | 1.74% | tape emissivity |
| \( \Omega_{tp} \) | 0.540 | 88.4% | 0.020 | 1.77% | tape coverage |
| \( \epsilon_{rs} \) | 0.040 | 405% | 0.010 | 4.05% | rough surface emissivity |
| \( \epsilon_b \) | 0.190 | 39.1% | 0.020 | 0.78% | back emissivity |
| \( \epsilon_{wt} \) | 0.900 | 192% | 0.025 | 4.79% | wind-tunnel emissivity |
| \( \theta \) | 90.0^\circ | 1.18%/\^\circ | 0.50^\circ | 0.59% | plate angle |

---

**Combined Bias Uncertainty:**

\[ 14.43\% \]

---

**Notes:**

- Estimated measurement uncertainties of natural convection at \( \theta = 90.0^\circ \)
symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$T$ | 298K | 0.770%/K | 0.50K | 0.38% | LM35C temperature sensor
$\Delta T$ | 7.15K | 57.8%/K | 0.10K | 5.78% | LM35C differential
$T_{bb}$ | 295K | 0.773%/K | 0.50K | 0.39% | radiative temperature
$P$ | 100kPa | 0.0007%/Pa | 1.5kPa | 1.06% | MPXH6115A6U air pressure
$C_{pt}$ | 4.24kJ/K | 0.088%//(J/K) | 42J/K | 3.74% | plate thermal capacity
$L_c$ | 0.305m | 1142%/m | 500um | 0.57% | characteristic-length
$L_w$ | 0.305m | 412%/m | 500um | 0.21% | plate width
$D_{Al}$ | 19.4mm | 2879%/m | 500um | 1.44% | metal slab thickness
$D_{PIR}$ | 25.4mm | 1920%/m | 1.0mm | 1.92% | insulation thickness
$D_g$ | 1.00mm | 1865%/m | 500um | 0.93% | air gap
$L_m$ | 3.57mm | 653%/m | 500um | 0.33% | side metal strip width
$k_{PIR}$ | 23.0mW/K\(m\) | 0.880%/mW/K\(m\) | 1.2mW/K\(m\) | 1.01% | PIR thermal conductivity
$k_{XPS}$ | 33.0mW/K\(m\) | 0.126%/mW/K\(m\) | 1.7mW/K\(m\) | 0.21% | XPS thermal conductivity
$\epsilon_{XPS}$ | 0.470 | 87.1% | 0.010 | 0.87% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 105% | 0.015 | 1.57% | tape emissivity
$\Omega_{tp}$ | 0.540 | 79.5% | 0.020 | 1.59% | tape coverage
$\epsilon_{rs}$ | 0.040 | 371% | 0.010 | 3.71% | rough surface emissivity
$\epsilon_b$ | 0.190 | 30.6% | 0.020 | 0.61% | back emissivity
$\epsilon_{wt}$ | 0.900 | 172% | 0.025 | 4.30% | wind-tunnel emissivity
$\theta$ | 90.0° | 1.22%/° | 0.50° | 0.61% | plate angle

estimated measurement uncertainties of natural convection at $\theta = 90.0$
20220702T010304Z – natural Convection – Roughness=1.04mm; T=21.4+10.6°C; +90.00°
k=0.0261, Ra_D=3442698, h=1.61W/(K.m²), U=0.149W/K, Nu=9.39, Pr=0.710

| symbol   | nominal | sensitivity | bias  | uncertainty | component                                      |
|----------|---------|-------------|-------|-------------|------------------------------------------------|
| $T$      | 300K    | 0.715%/K    | 0.50K | 0.36%       | LM35C temperature sensor                       |
| $\Delta T$ | 10.6K  | 38.7%/K     | 0.10K | 3.87%       | LM35C differential                             |
| $T_{bb}$ | 294K    | 0.723%/K    | 0.50K | 0.36%       | radiative temperature                          |
| $P$      | 100kPa  | 0.0007%/Pa   | 1.5kPa| 1.10%       | MPXH6115A6U air pressure                       |
| $C_{pt}$ | 4.24kJ/K| 0.087%/KJK  | 42J/K | 3.68%       | plate thermal capacity                         |
| $L_c$    | 0.305m  | 1124%/m     | 500um | 0.56%       | characteristic-length                          |
| $L_w$    | 0.305m  | 407%/m      | 500um | 0.20%       | plate width                                    |
| $D_{Al}$ | 19.4mm  | 2720%/m     | 500um | 1.36%       | metal slab thickness                           |
| $D_{PIR}$| 25.4mm  | 1786%/m     | 1.0mm | 1.79%       | insulation thickness                           |
| $D_g$    | 1.00mm  | 1732%/m     | 500um | 0.87%       | air gap                                        |
| $L_m$    | 3.57mm  | 666%/m      | 500um | 0.33%       | side metal strip width                         |
| $k_{PIR}$| 23.0$mW/ K\cdot m$ | 0.856%/$mW/ K\cdot m$ | 1.2$mW/K\cdot m$ | 0.98%       | PIR thermal conductivity                       |
| $k_{XPS}$| 33.0$mW/ K\cdot m$ | 0.122%/$mW/ K\cdot m$ | 1.7$mW/K\cdot m$ | 0.20%       | XPS thermal conductivity                       |
| $e_{XPS}$| 0.470   | 82.2%       | 0.010 | 0.82%       | XPS emissivity                                 |
| $\epsilon_{tp}$ | 0.890 | 99.2%       | 0.015 | 1.49%       | tape emissivity                                |
| $\Omega_{tp}$ | 0.540 | 75.1%       | 0.020 | 1.50%       | tape coverage                                  |
| $\epsilon_{rs}$ | 0.040 | 355%        | 0.010 | 3.55%       | rough surface emissivity                       |
| $\epsilon_b$ | 0.190 | 26.3%       | 0.020 | 0.53%       | back emissivity                                |
| $\epsilon_{wt}$ | 0.900 | 162%        | 0.025 | 4.06%       | wind-tunnel emissivity                         |
| $\theta$ | 90.0°   | 1.25%/°     | 0.50° | 0.62%       | plate angle                                    |

estimated measurement uncertainties of natural convection at $\theta = 90.0$
symbol | nominal | sensitivity | bias | uncertainty | component
--- | --- | --- | --- | --- | ---
$T$ | 302K | 0.676%/K | 0.50K | 0.34% | LM35C temperature sensor
$\Delta T$ | 14.5K | 28.1%/K | 0.10K | 2.81% | LM35C differential
$T_{bb}$ | 295K | 0.687%/K | 0.50K | 0.34% | radiative temperature
$P$ | 100kPa | 0.0008%/Pa | 1.5kPa | 1.13% | MPXH6115A6U air pressure
$C_{pt}$ | 4.24kJ/K | 0.086%//(J/K) | 42J/K | 3.64% | plate thermal capacity
$L_c$ | 0.305m | 1114%/m | 500um | 0.56% | characteristic-length
$L_w$ | 0.305m | 403%/m | 500um | 0.20% | plate width
$D_{Al}$ | 19.4mm | 2615%/m | 500um | 1.31% | metal slab thickness
$D_{PIR}$ | 25.4mm | 1701%/m | 1.0mm | 1.70% | insulation thickness
$L_m$ | 3.57mm | 677%/m | 500um | 0.34% | side metal strip width
$k_{PIR}$ | 23.0 mW/K·m | 0.838%/mW/K·m | 1.2 mW/K·m | 0.96% | PIR thermal conductivity
$\epsilon_{XPS}$ | 0.470 | 79.1% | 0.010 | 0.79% | XPS emissivity
$\epsilon_{tp}$ | 0.890 | 95.5% | 0.015 | 1.43% | tape emissivity
$\Omega_{tp}$ | 0.540 | 72.2% | 0.020 | 1.44% | tape coverage
$\epsilon_{rs}$ | 0.040 | 344% | 0.010 | 3.44% | rough surface emissivity
$\epsilon_b$ | 0.190 | 23.1% | 0.020 | 0.46% | back emissivity
$\epsilon_wt$ | 0.900 | 156% | 0.025 | 3.90% | wind-tunnel emissivity
$\theta$ | 90.0° | 1.27%/° | 0.50° | 0.64% | plate angle

estimated measurement uncertainties of natural convection at $\theta = 90.0$