

THE EFFECTS OF TURBULENCE STRUCTURES ON THE
AIR-SIDE PERFORMANCE OF COMPACT TUBE-FIN HEAT
EXCHANGERS

By

Colin Bidden Allison

A Thesis submitted in fulfilment of the requirements for the
Degree of Doctor of Philosophy

SCHOOL OF MECHANICAL ENGINEERING
UNIVERSITY OF ADELAIDE



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Appendices

Appendix I Publications arising from this thesis

The following list of conference papers has been presented during the candidature.

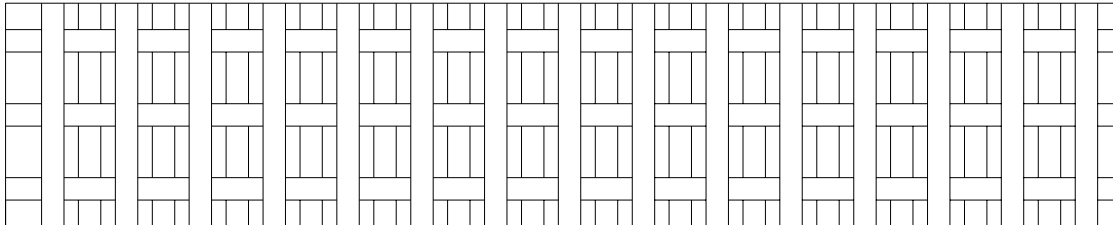
1. Allison, C.B. and B.B. Dally. *Performance of compact Tube-Fin heat exchangers having alternative shaped tubes*. in 3rd International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics. 2004. Cape Town, South Africa.
2. Allison, C.B. and B.B. Dally. *Assessment of Compact Heat Exchanger consisting entirely of tubes arranged in a turbulence generating mesh*. in 8th Australian Heat and Mass Transfer Conference. 2005. Curtin University, Perth.¹
3. Allison, C.B. and B.B. Dally. *Development of a Compact Heat Exchanger consisting of tubes and interconnecting struts forming parallel plate arrays: Part I Flow visualisation*. in 8th Australian Heat and Mass Transfer Conference. 2005. Curtin University, Perth.
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5. Allison, C.B. and B.B. Dally. *Effect of a Delta-Winglet vortex pair on the performance of a tube-fin heat exchanger*: (Pending publication in The International Journal of Heat and Mass transfer)

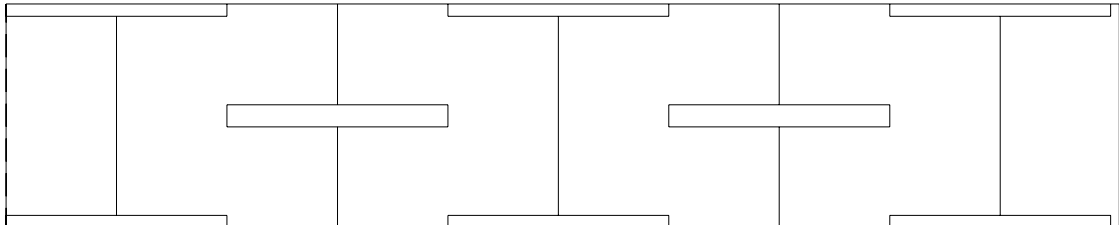
¹ This paper has been accepted for publication in the Australian Journal of Mechanical Engineering

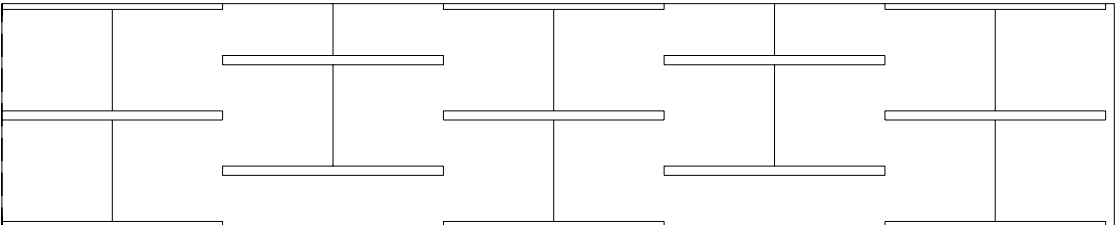
Appendix II Coil Specification Data

Coil	4 row 11 fpi	
Tubes	Profile	flat
	D_h	3.68mm
	Rows	4
	Tubes/row	19/18/19/18
	Pitch(transverse)	12mm
	Total Tubes	74
	Tube Material	Brass (Tin Flux)
Fins	Type	Louvre, $\Theta=30, L_p=1.5mm$
	Density	11 fpi
	Pitch	2.31mm
	Material	Copper
	Thickness	0.076mm
Coil Dimensions	Width	760mm
	Height	260mm
	Face Area	0.1976 sq m
	Depth	58mm
	A_o	10.17sq m
<p>Louvre:30deg,Pitch:1.5mm</p>		

Coil	4 row 9 fpi	
Tubes	Profile	flat
	D_h	3.68mm
	Rows	4
	Tubes/row	19/18/19/18
	Pitch(transverse)	12mm
	Total Tubes	74
	Tube Material	Brass (Tin Flux)
Fins	Type	Louvre, $\theta=30, L_p=1.5mm$
	Density	9 fpi
	Pitch	2.82mm
	Material	Copper
	Thickness	0.076mm
Coil Dimensions	Width	760mm
	Height	260mm
	Face Area	0.1976 sq m
	Depth	58mm
	A_o	8.60sq m
<p>Louvre:30deg, Pitch:1.5mm</p>		

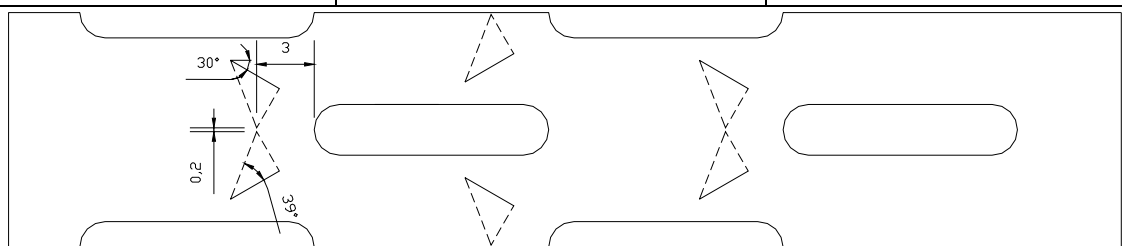
Coil	Tube Mesh	
Tubes	Profile	flat
	D_h	3.68mm
	Rows	4
	Tubes/row	19/19/19/19
	Pitch(transverse)	12mm
	Total Tubes	76
	Tube Material	Brass (Tin Flux)
Vertical Tubes	Type	
	Density	2.1 fpi
	Pitch	12mm
	Total tubes	224
Coil Dimensions	Width	760mm
	Height	260mm
	Face Area	0.1976 sq m
	Depth	72mm
	A_o	3.17sq m
		
<h2>Tube Mesh</h2>		

Coil	Tube Strut Sp=Tp	
Tubes	Profile	flat
	D_h	3.68mm
	Rows	4
	Tubes/row	19/18/19/18
	Pitch(transverse)	12mm
	Total Tubes	74
	Tube Material	Brass (Tin Flux)
Struts	Type	PPA
	Density	2.1 fpi
	Pitch	12mm
	Material	Brass
	Thickness	1.2mm
Coil Dimensions	Width	760mm
	Height	260mm
	Face Area	0.1976 sq m
	Depth	58mm
	A_o	3.20sq m
		
<p>Tube Strut Sp=Tp</p>		

Coil	Tube Strut $S_p=T_p/2$	
Tubes	Profile	flat
	D_h	3.68mm
	Rows	4
	Tubes/row	19/18/19/18
	Pitch(transverse)	12mm
	Total Tubes	74
	Tube Material	Brass (Tin Flux)
Struts	Type	PPA
	Density	4.2 fpi
	Pitch	6mm
	Material	Copper
	Thickness	0.5mm
Coil Dimensions	Width	760mm
	Height	260mm
	Face Area	0.1976 sq m
	Depth	72mm
	A_o	4.86sq m
		
Tube Strut $S_p=T_p/2$		

Coil	Tube Strut $Sp=Tp/3$																						
Tubes	Profile	flat																					
	D_h	3.68mm																					
	Rows	4																					
	Tubes/row	19/18/19/18																					
	Pitch(transverse)	12mm																					
	Total Tubes	74																					
	Tube Material	Brass (Tin Flux)																					
Struts	Type	PPA																					
	Density	6.3 fpi																					
	Pitch	4mm																					
	Material	Copper																					
	Thickness	0.076mm																					
Coil Dimensions	Width	760mm																					
	Height	260mm																					
	Face Area	0.1976 sq m																					
	Depth	58mm																					
	A_o	6.52sq m																					
<table border="1" style="width:100%; height:100%;"> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table>																							
<p>Tube Strut $Sp=Tp/3$</p>																							

Coil	Delta Winglet Vortex Generator	
Tubes	Profile	flat
	D_h	3.68mm
	Rows	4
	Tubes/row	19/18/19/18
	Pitch(transverse)	12mm
	Total Tubes	74
	Tube Material	Brass (Tin Flux)
Fins	Type	DWVG: Flow Up
	Density	9 fpi
	Pitch	2.82mm
	Material	Copper
	Thickness	0.076mm
Coil Dimensions	Width	760mm
	Height	260mm
	Face Area	0.1976 sq m
	Depth	58mm
	A_o	8.60sq m



Delta Winglet Flow Up: $x=-3\text{mm}$

Appendix III Fluent Specifications and BC's

Category	Setting	Comments
Solver	Segregated	(Implicit)
Discretization	Finite Volume	
Numerical Scheme	Second order upwind	
Pressure-Velocity coupling	SIMPLE, PISO	
Viscous Model	Realizable $k-\varepsilon$, <i>LES</i>	$CFL \leq 1$
Wall treatment	Enhanced wall treatment	$y^+ \leq 5$
Boundary Condition	Type	Value/Material
Inlet	Velocity Inlet	6.3, 4.8, 2.9m/s, I=5%
Outlet	Pressure Outlet	0 Pa, I=15%
Top	Periodic	-
Bottom	Periodic	-
Sides	Periodic	-
Struts (thick)	Wall, solid	Brass: 1.2mm
Struts (thin)	Wall, shell conduction	Copper: 0.5mm
Fins	Wall, shell conduction	Copper: 0.076mm
Louvres	Wall, shell conduction	Copper: 0.076mm
Louvre sides	Wall, shell conduction	Copper: 0.02mm
Delta Winglets	Wall, shell conduction	Copper: 0.076mm
Delta Wings	Wall, shell conduction	PVC: 0.5mm
Tubes	Wall, constant temperature	284.5K

Appendix IV Coil Test Data

The shaded cells have been selected as sample results for an uncertainty calculation which is performed in Section 3.2.1.7.

COIL TEST RESULTS		Coil:		4row11					
Coil Specs		Tube Specs			Fin Specs			Surface Areas	
Width	760	Rows	4	Pitch L	12.2	Fpi	11	Total	10.17
Height	260	Tubes	74	Pitch T	12.2	Fin d	0.076	Fins	8.68
Depth	58	Dh	3.63	Tube t	0.2	Fin k	401	Tubes	1.49
	Air side				Water side				
Venturi DP	flow kg/s	on coil temp	off coil temp	Delta Pa	flow L/min	flow kg/s	on coil temp	off coil temp	Delta Kpa
200	0.67	39.48	22.42	60.37	40	0.67	11.74	15.69	1.97
200	0.67	39.50	21.60	60.12	60	1.01	11.56	14.29	4.73
200	0.67	39.59	20.95	60.64	80	1.35	11.48	13.60	9.10
200	0.67	39.87	20.26	60.24	100	1.68	11.47	13.26	14.14
200	0.67	39.56	19.56	59.49	120	2.00	11.43	12.99	21.11
600	1.10	39.33	25.66	134.18	40	0.66	11.51	16.51	1.34
600	1.10	39.33	24.88	134.33	60	1.00	11.61	15.14	3.87
600	1.10	39.34	24.12	134.16	80	1.35	11.56	14.29	8.18
600	1.11	39.36	23.27	133.60	100	1.68	11.59	13.99	13.32
600	1.10	39.36	22.64	132.68	120	2.01	11.83	13.94	20.17
1000	1.41	39.45	27.21	198.08	40	0.66	11.09	16.77	1.22
1000	1.42	39.47	26.58	197.92	60	1.01	11.67	15.56	4.29
1000	1.40	39.46	25.94	197.97	80	1.34	11.73	14.81	7.79
1000	1.41	39.46	25.01	197.54	100	1.68	12.09	14.81	13.36
1000	1.41	39.42	24.17	195.92	120	2.02	11.48	13.98	20.50

COIL TEST RESULTS			Coil: 4row09							
Coil Specs		Tube Specs			Fin Specs		Areas			
Width	760	Rows	4	Pitch L	12.2	Fpi	9	Total	8.60	
Height	260	Tubes	74	Pitch T	12.2	Fin d	0.076	Fins	7.10	
Depth	58	Dh	3.63	Tube t	0.2	Fin k	401	Tubes	1.50	
		Air side			Water side					
Venturi	flow	on coil	off coil	Delta	flow	flow	on coil	off coil	Delta	
DP	kg/s	temp	temp	Pa	L/min	kg/s	temp	temp	Kpa	
200	0.67	40.00	24.03	46.58	40	0.67	11.53	15.08	3.42	
200	0.67	39.89	23.24	46.68	60	1.00	11.44	14.00	6.51	
200	0.67	39.92	22.78	46.31	80	1.34	11.42	13.38	10.34	
200	0.67	39.94	21.74	47.31	100	1.68	11.44	13.09	16.08	
200	0.68	39.69	20.97	47.68	120	2.00	11.30	12.79	22.53	
600	1.10	39.89	27.48	106.27	40	0.67	11.51	16.07	3.41	
600	1.10	39.87	26.78	104.71	60	1.00	11.62	14.83	6.33	
600	1.10	39.88	26.08	106.45	80	1.35	11.54	14.03	10.29	
600	1.10	39.87	25.09	104.90	100	1.69	11.52	13.73	16.07	
600	1.10	39.85	24.27	105.40	120	2.01	11.48	13.44	22.79	
1000	1.40	39.56	28.79	160.09	40	0.67	11.77	16.72	2.33	
1000	1.41	39.56	28.03	159.13	60	1.00	11.72	15.25	4.66	
1000	1.40	39.57	27.35	159.97	80	1.35	11.50	14.30	9.04	
1000	1.41	39.71	26.59	159.53	100	1.68	11.79	14.25	14.40	
1000	1.41	39.93	26.14	159.37	120	2.01	11.63	13.91	20.89	

COIL TEST RESULTS				Coil: Tube Mesh (Both Directions)					
Coil Specs		Tube Specs				Fin Specs		Tube Areas	
Width	760	Rows	6	Pitch L	12.2	Fpi	Na	Total	3.17
Height	260	Tubes	300	Pitch T	10	Fin d	Na	Horiz.	1.58
Depth	73.2	Dh	3.68	Pitch V	10	Fin k	Na	Vert.	1.59
	Air side				Water side				
Venturi	flow	on coil	off coil	Delta	flow	flow	on coil	off coil	Delta
DP	kg/s	temp	temp	Pa	L/min	kg/s	temp	temp	Kpa
200	0.67	38.92	29.63	10.22	40	0.67	7.92	10.28	14.17
200	0.67	39.07	29.71	10.70	60	1.00	7.84	9.5	25.44
200	0.67	38.79	28.98	10.43	80	1.33	7.34	8.6	43.51
200	0.67	38.95	29.16	10.63	100	1.67	7.41	8.53	62.97
200	0.67	39.08	29.46	9.96	120	2.00	7.8	8.76	90.1
600	1.1	39.12	31.3	31.16	40	0.67	8.19	11.21	14.59
600	1.1	39.19	31.16	30.59	60	1.00	8.01	10.13	26.11
600	1.1	39.03	31.03	30.14	80	1.33	8.11	9.7	42.83
600	1.1	39.12	31.11	30.83	100	1.67	8	9.4	61.25
600	1.1	39.27	31.04	30.37	120	2.00	7.99	9.2	90.51
1000	1.41	39.16	31.95	50.21	40	0.67	7.89	11.34	15.13
1000	1.41	39.2	31.75	51.15	60	1.00	7.69	10.14	25.67
1000	1.41	39.18	31.79	50.53	80	1.33	8.02	9.88	43.13
1000	1.41	39.02	31.37	50.80	100	1.67	7.47	9.05	63.04
1000	1.41	39.25	31.73	49.84	120	2.00	8.07	9.41	89.91

COIL TEST RESULTS		Coil: Tube Mesh (Horizontal Tubes)							
Coil Specs		Tube Specs				Fin Specs		Tube areas	
Width	760	Rows	3	Pitch L	12.2	Fpi	Na	Total	3.17
Height	260	Tubes	76	Pitch T	10	Fin d	Na	Horiz.	1.58
Depth	73.2	Dh	3.68	Pitch V	10	Fin k	Na	Vert.	1.59
	Air side				Water side				
Venturi DP	flow kg/s	on coil temp	off coil temp	Delta Pa	flow L/min	flow kg/s	on coil temp	off coil temp	Delta Kpa
200	0.67	39.18	32.12	10.35	40	0.67	5.31	6.94	13.51
200	0.67	39.19	31.99	10.42	60	1.00	5.32	6.47	27.61
200	0.67	39.18	31.96	10.54	80	1.33	5.41	6.35	50.40
200	0.67	39.16	31.99	10.59	100	1.67	5.61	6.47	75.11
200	0.67	39.27	31.98	10.50	120	2.00	5.91	6.70	113.83
600	1.10	39.33	34.20	30.65	40	0.67	7.59	9.51	13.38
600	1.10	39.36	33.98	30.69	60	1.00	7.04	8.46	27.98
600	1.10	39.39	33.88	30.53	80	1.33	6.70	7.86	49.97
600	1.10	39.39	33.77	30.37	100	1.67	6.45	7.53	74.88
600	1.10	39.37	33.60	30.52	120	2.00	6.30	7.31	111.97
1000	1.41	39.28	34.76	49.47	40	0.67	7.76	9.97	13.65
1000	1.41	39.22	34.59	50.34	60	1.00	7.64	9.21	27.83
1000	1.41	39.15	34.43	49.53	80	1.33	7.59	8.85	50.07
1000	1.41	38.90	34.28	49.67	100	1.67	7.53	8.66	75.14
1000	1.41	38.90	34.00	50.10	120	2.00	7.47	8.49	114.21

COIL TEST RESULTS		Coil:		Tube Mesh (Vertical Tubes)						
Coil Specs		Tube Specs			-		Fin Specs		Tube Areas	
Width	760	Rows	3	Pitch L	12.2	Fpi	Na	Total	3.17	
Height	260	Tubes	224	Pitch T	10	Fin d	Na	Horiz.	1.58	
Depth	73.2	Dh	3.68	Pitch V	10	Fin k	Na	Vert.	1.59	
		Air side				Water side				
Venturi	flow	on coil	off coil	Delta	flow	flow	on coil	off coil	Delta	
DP	kg/s	temp	temp	Pa	L/min	kg/s	temp	temp	Kpa	
200	0.67	39.18	31.96	10.79	40	0.67	6.23	7.84	15.81	
200	0.67	39.16	32.01	10.57	60	1.00	6.69	7.88	30.75	
200	0.67	39.17	31.94	10.93	80	1.33	6.58	7.54	52.43	
200	0.67	39.16	31.91	10.85	100	1.67	6.57	7.44	79.39	
200	0.67	39.16	32.00	10.74	120	2.00	7.03	7.83	114.14	
600	1.10	39.44	33.86	31.14	40	0.67	7.78	9.79	16.11	
600	1.10	39.39	33.79	31.26	60	1.00	7.84	9.29	30.31	
600	1.10	39.37	33.73	30.33	80	1.33	7.69	8.88	52.97	
600	1.10	39.39	33.75	30.58	100	1.67	7.97	8.99	78.15	
600	1.10	39.33	33.74	31.28	120	2.00	8.05	8.97	114.34	
1000	1.41	39.29	34.36	49.39	40	0.67	7.98	10.35	16.26	
1000	1.41	39.16	34.23	50.18	60	1.00	8.01	9.70	31.50	
1000	1.41	39.02	34.13	50.55	80	1.33	8.09	9.44	52.55	
1000	1.41	38.87	34.00	49.38	100	1.67	8.16	9.30	78.58	
1000	1.41	38.58	33.88	50.61	120	2.00	8.14	9.16	115.28	

COIL TEST RESULTS		Coil: Strut Pitch (Sp=Pt)							
Coil Specs		Tube Specs			Fin Specs			Areas	
Width	760	Rows	4	Pitch L	12.2	Fpi	2	Total	3.20
Height	260	Tubes	74	Pitch T	12.2	Fin d	1.2	Fins	1.81
Depth	61	Dh	3.68	Tube thk	0.2	Fin k	111	Tubes	1.39
		Air side			Water side				
Reading No	flow kg/s	on coil temp	off coil temp	Delta Pa	flow L/min	flow kg/s	on coil temp	off coil temp	Delta Kpa
200	0.68	39.79	31.46	19.52	40	0.67	11.52	13.54	5.25
200	0.68	39.78	31.19	19.84	60	1.01	11.18	12.58	8.49
200	0.67	39.80	31.16	19.58	80	1.34	11.76	12.80	12.53
200	0.67	39.81	30.87	19.77	100	1.68	11.61	12.49	18.37
200	0.67	39.23	30.21	19.71	120	2.02	11.50	12.23	25.77
600	1.10	39.43	32.56	50.94	40	0.67	11.30	13.90	4.94
600	1.09	39.43	32.36	51.89	60	1.09	11.57	13.35	8.01
600	1.10	39.42	32.09	51.60	80	1.34	10.99	12.39	12.62
600	1.10	39.43	31.83	53.39	100	1.68	11.25	12.42	18.59
600	1.10	39.43	31.64	52.69	120	2.01	11.25	12.25	25.52
1000	1.40	39.54	33.34	81.74	40	0.67	11.09	14.09	4.79
1000	1.40	39.54	33.11	81.86	60	1.01	11.22	13.27	7.73
1000	1.41	39.54	32.95	82.37	80	1.35	11.26	12.86	12.52
1000	1.41	39.54	32.68	82.42	100	1.68	11.36	12.69	18.40
1000	1.40	39.55	32.45	82.85	120	2.02	11.33	12.50	25.35
1900	1.92	39.68	34.41	147.00	40	0.66	11.62	15.04	4.85
1900	1.92	39.68	34.17	146.49	60	1.00	11.56	13.96	8.09
1900	1.92	39.68	33.94	146.84	80	1.35	11.55	13.38	12.77
1900	1.92	39.68	33.61	146.52	100	1.68	11.51	13.09	18.09
1900	1.93	39.68	33.33	147.75	120	2.02	11.31	12.70	25.70
2800	2.28	39.76	34.88	203.87	40	0.66	11.70	15.44	5.29
2800	2.29	39.75	34.56	205.05	60	1.01	11.51	14.14	8.07
2800	2.28	39.76	34.28	208.38	80	1.34	11.46	13.52	12.48
2800	2.28	39.75	33.95	206.43	100	1.68	11.73	13.52	18.36
2800	2.28	39.82	33.73	213.40	120	2.01	11.67	13.26	25.29

COIL TEST RESULTS		Coil: Strut Pitch (Sp=Pt/2)							
Coil Specs		Tube Specs			Fin Specs			Areas	
Width	760	Rows	4	Pitch L	12.2	Fpi	4.1	Total	4.86
Height	260	Tubes	74	Pitch T	12.2	Fin d	0.5	Fins	3.45
Depth	61	Dh	3.68	Tube thk	0.02	Fin k	401	Tubes	1.42
	Air side				Water side				
Venturi DP	flow kg/s	on coil temp	off coil temp	Delta Pa	flow L/min	flow kg/s	on coil temp	off coil temp	Delta Kpa
200	0.67	39.70	28.57	18.76	40	0.67	10.93	13.69	3.47
200	0.67	39.64	28.24	19.22	60	1.00	11.08	13.00	6.09
200	0.67	39.56	27.92	19.52	80	1.34	11.24	12.72	11.28
200	0.67	39.38	27.29	19.87	100	1.68	11.33	12.52	17.54
200	0.68	39.05	26.82	21.06	120	2.00	11.24	12.27	25.34
600	1.10	39.70	30.91	46.65	40	0.67	11.66	15.15	3.25
600	1.10	40.05	30.70	47.04	60	1.00	11.48	13.97	6.61
600	1.10	40.03	30.30	46.63	80	1.33	11.38	13.34	10.68
600	1.10	39.99	29.59	47.44	100	1.68	11.38	13.04	17.43
600	1.10	39.92	29.20	47.73	120	2.02	11.76	13.20	25.52
1000	1.40	39.68	31.86	72.83	40	0.66	11.72	15.65	3.08
1000	1.41	39.68	31.41	72.73	60	1.01	11.49	14.23	6.48
1000	1.40	39.66	30.97	72.93	80	1.34	11.44	13.59	11.31
1000	1.41	39.65	30.30	73.51	100	1.68	11.45	13.31	17.56
1000	1.41	39.66	29.93	72.67	120	2.02	11.64	13.25	25.35
1900	1.91	39.77	33.00	130.23	40	0.67	11.65	16.19	3.53
1900	1.92	39.77	32.54	131.65	60	1.01	11.50	14.73	6.64
1900	1.92	39.77	32.10	129.66	80	1.34	11.34	13.91	11.12
1900	1.92	39.76	31.41	129.83	100	1.68	11.50	13.75	17.64
1900	1.92	39.75	30.97	129.38	120	2.02	11.55	13.54	25.46
2800	2.32	39.84	33.64	183.75	40	0.68	11.46	16.42	3.37
2800	2.32	39.84	33.17	186.20	60	1.00	11.24	14.84	6.41
2800	2.31	39.84	32.78	183.54	80	1.35	11.47	14.27	11.09
2800	2.32	39.84	32.15	183.50	100	1.69	12.01	14.47	17.85
2800	2.31	39.82	31.69	183.48	120	2.01	11.93	14.09	25.49

COIL TEST RESULTS		Coil: Strut Pitch (Sp=Pt/3)							
Coil Specs		Tube Specs			Fin Specs			Areas	
Width	760	Rows	4	Pitch L	12.2	Fpi	6	Total	6.52
Height	260	Tubes	74	Pitch T	12.2	Fin d	0.076	Fins	5.00
Depth	61	Dh	3.68	Tube thk	0.2	Fin k	401	Tubes	1.51
Air side					Water side				
Venturi DP	flow kg/s	on coil temp	off coil temp	Delta Pa	flow L/min	flow kg/s	on coil temp	off coil temp	Delta Kpa
200	0.67	39.10	27.73	20.09	40	0.66	8.64	11.06	2.21
200	0.67	39.09	27.54	20.59	60	1.00	9.06	10.66	5.92
200	0.67	39.09	27.42	20.17	80	1.36	9.46	10.64	9.94
200	0.67	39.13	27.20	19.82	100	1.68	9.88	10.87	14.44
200	0.67	39.19	27.06	19.94	120	2.03	10.48	11.31	20.77
600	1.09	39.36	30.79	47.01	40	0.66	10.99	14.05	2.05
600	1.10	39.32	30.32	47.19	60	1.02	10.75	12.82	4.71
600	1.10	39.31	30.00	45.74	80	1.38	10.71	12.27	8.35
600	1.10	39.33	29.48	46.33	100	1.71	10.90	12.22	13.76
600	1.10	39.35	29.17	46.25	120	2.03	11.16	12.34	20.54
1000	1.41	39.44	31.90	70.81	40	0.66	11.52	14.94	2.07
1000	1.41	39.44	31.52	71.17	60	1.00	11.54	13.91	4.85
1000	1.40	39.42	31.20	71.43	80	1.33	11.51	13.32	8.90
1000	1.40	39.40	30.81	70.63	100	1.57	11.48	13.10	12.41
1000	1.40	39.31	30.10	70.37	120	2.02	11.42	12.78	20.88
1900	1.92	39.65	33.14	119.17	40	0.68	11.73	15.58	2.36
1900	1.91	39.65	32.75	119.11	60	1.00	11.58	14.33	4.87
1900	1.92	39.65	32.42	119.44	80	1.34	11.50	13.65	8.81
1900	1.92	39.64	31.86	117.36	100	1.66	11.49	13.40	13.63
1900	1.92	39.63	31.32	118.56	120	2.04	11.43	13.10	21.10
2800	2.33	39.73	33.84	164.30	40	0.67	11.84	16.05	2.51
2800	2.31	39.73	33.46	164.20	60	1.00	11.62	14.65	4.48
2800	2.32	39.73	33.12	165.58	80	1.35	11.55	13.89	8.18
2800	2.31	39.73	32.49	163.73	100	1.69	11.56	13.60	13.51
2800	2.32	39.74	32.04	164.67	120	2.02	11.45	13.26	20.46

COIL TEST RESULTS			Coil: DWVG						
Coil Specs		Tube Specs			Fin Specs		Areas		
Width	760	Rows	4	Pitch L	12.2	Fpi	9	Total	8.60
Height	260	Tubes	74	Pitch T	12.2	Fin d	0.076	Fins	7.10
Depth	58	Dh	3.63	Tube thk	0.2	Fin k	401	Tubes	1.50
	Air side				Water side				
Reading No	flow kg/s	on coil temp	off coil temp	Delta Pa	flow L/min	flow kg/s	on coil temp	off coil temp	Delta Kpa
200	0.67	39.81	26.22	22.60	40	0.66	11.05	14.08	3.95
200	0.67	40.04	25.89	22.75	60	1.01	11.32	13.41	7.55
200	0.68	39.87	25.31	23.25	80	1.34	11.01	12.61	12.53
200	0.67	39.84	24.57	22.77	100	1.68	10.94	12.28	18.85
200	0.68	40.07	24.21	22.78	120	2.01	11.35	12.53	26.61
600	1.09	39.92	29.18	55.97	40	0.68	11.61	15.48	3.87
600	1.10	39.90	28.63	55.77	60	1.01	11.48	14.23	7.23
600	1.10	39.91	28.15	56.09	80	1.35	11.44	13.57	12.50
600	1.10	39.87	27.45	56.13	100	1.67	11.68	13.52	18.58
600	1.10	39.91	26.79	55.80	120	2.00	11.64	13.25	26.10
1000	1.40	39.82	30.37	87.25	40	0.67	11.61	15.99	4.06
1000	1.40	39.78	29.77	87.08	60	1.02	11.50	14.58	7.53
1000	1.41	39.80	29.25	87.07	80	1.35	11.45	13.91	12.49
1000	1.40	39.84	28.50	86.18	100	1.67	11.54	13.68	18.51
1000	1.40	40.14	27.94	86.65	120	2.01	11.35	13.30	26.03
1400	1.65	39.93	31.22	115.70	40	0.67	11.60	16.38	3.58
1400	1.65	39.95	30.61	115.82	60	1.00	11.52	14.92	7.45
1400	1.65	39.96	30.12	114.77	80	1.34	11.54	14.18	12.52
1400	1.65	39.95	29.27	114.35	100	1.68	11.63	13.96	18.86
1400	1.65	39.94	28.63	114.01	120	2.01	11.71	13.79	26.61
1800	1.87	40.01	31.86	142.67	40	0.68	11.63	16.59	3.73
1800	1.87	40.02	31.26	143.21	60	1.01	11.66	15.21	7.00
1800	1.87	40.02	30.78	142.85	80	1.34	11.49	14.32	12.00
1800	1.87	40.00	29.96	142.04	100	1.68	11.87	14.33	18.14
1800	1.87	40.00	29.27	141.85	120	2.01	11.85	14.05	26.10

Appendix V Measurement Uncertainty Analysis

The following Table extract is taken from the coil test results for the louvre fin coil having 11fpi in Appendix IV.

COIL TEST RESULTS		Coil:		4row11					
		Air side			Water side				
Venturi DP	flow kg/s	on coil temp	off coil temp	Delta Pa	flow L/min	flow kg/s	on coil temp	off coil temp	Delta Kpa
200	0.67	39.48	22.42	60.37	40	0.67	11.74	15.69	1.97
1000	1.41	39.42	24.17	195.92	120	2.02	11.48	13.98	20.50

From Equation(1.1)

$$e_R = \left[\left(\frac{\partial R}{\partial x_1} e_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} e_2 \right)^2 + \dots + \left(\frac{\partial R}{\partial x_n} e_n \right)^2 \right]^{\frac{1}{2}}$$

Recall that the uncertainties in the measured variables are:

- air flow rate: +/- 0.5%
- water flow rate: +/- 1%
- air & water temperatures: +/- 0.1°C

1. For the case of the minimum fluid flow rates and considering the air heat transfer.

$$\dot{Q} = \dot{m}_a c_{pa} (T_{a_{in}} - T_{a_{out}})$$

$$\frac{\partial \dot{Q}_a}{\partial \dot{m}_a} = c_{pa} (T_{a_{in}} - T_{a_{out}}) = 1004.9(39.48 - 22.42) = 17143.59$$

$$\frac{\partial \dot{Q}_a}{\partial T_{a_{in}}} = \dot{m}_a c_{pa} = 0.61 \times 1004.9 = 673.28$$

$$\frac{\partial \dot{Q}_a}{\partial T_{a_{out}}} = -\dot{m}_a c_{pa} = -673.28$$

$$e_{\dot{Q}_a} = \left[(17143.59 \times 0.00335)^2 + (673.28 \times 0.1)^2 + (-673.28 \times 0.1)^2 \right]^{\frac{1}{2}} = 111.20$$

$$\therefore \%error = \frac{111.20}{11486.01} = 0.97\%$$

For the water heat transfer

$$\dot{Q}_w = \dot{m}_w c_{pw} (Tw_{out} - Tw_{in})$$

$$\frac{\partial \dot{Q}_w}{\partial \dot{m}_w} = c_{pw} (Tw_{out} - Tw_{in}) = 4224.96(15.69 - 11.74) = 16688.59$$

$$\frac{\partial \dot{Q}_w}{\partial Tw_{out}} = \dot{m}_w c_{pw} = 0.67 \times 4224.96 = 2830.72$$

$$\frac{\partial \dot{Q}_w}{\partial Tw_{in}} = -\dot{m}_w c_{pw} = -2830.72$$

$$e_{\dot{Q}_w} = [(16688.59 \times 0.0067)^2 + (2830.72 \times 0.1)^2 + (-2830.72 \times 0.1)^2]^{\frac{1}{2}} = 415.65$$

$$\therefore \%error = \frac{415.65}{11097.92} = 3.75\%$$

2. For the case of the maximum fluid flow rates and considering the air heat transfer.

$$\frac{\partial \dot{Q}_a}{\partial \dot{m}_a} = C_{pa} (Ta_{in} - Ta_{out}) = 1004.9(39.42 - 24.17) = 15324.73$$

$$\frac{\partial \dot{Q}_a}{\partial Ta_{in}} = \dot{m}_a C_{pa} = 1.41 \times 1004.9 = 1416.91$$

$$\frac{\partial \dot{Q}_a}{\partial Ta_{out}} = -\dot{m}_a C_{pa} = -1416.91$$

$$e_{\dot{Q}_a} = [(15324.73 \times 0.0071)^2 + (1416.91 \times 0.1)^2 + (-1416.91 \times 0.1)^2]^{\frac{1}{2}} = 228.02$$

$$\therefore \%error = \frac{228.02}{21607.34} = 1.06\%$$

For the water heat transfer

$$\dot{Q}_w = \dot{m}_w c_{pw} (T_{w_{out}} - T_{w_{in}})$$

$$\frac{\partial \dot{Q}_w}{\partial \dot{m}_w} = c_{pw} (T_{w_{out}} - T_{w_{in}}) = 4223.43(13.98 - 11.48) = 10558.58$$

$$\frac{\partial \dot{Q}_w}{\partial T_{w_{out}}} = \dot{m}_w c_{pw} = 2.02 \times 4223.43 = 8531.33$$

$$\frac{\partial \dot{Q}_w}{\partial T_{w_{in}}} = -\dot{m}_w c_{pw} = -8531.33$$

$$e_{\dot{Q}_w} = [(16688.59 \times 0.0067)^2 + (2830.72 \times 0.1)^2 + (-2830.72 \times 0.1)^2]^{\frac{1}{2}} = 2450.44$$

$$\therefore \%error = \frac{2450.44}{21288.67} = 11.5\%$$