PINCHCO

Pinch analysis with crisscross optimization prior to design

Heat exchanger network synthesis based on optimized input data sets

Case 14 ï Multiple Utilities Example from Shenoy et al.

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Case 14 is a 3 streams example with 3 hot utilities and 1 cold utility. It was used to show the effect of using multiple utilities by Shenoy, Ponce-Ortega et al and Huang & Karimi.

The data set is shown in Table 14.1, cost figures in Table 14.2.

Table 14.1

Stream Data						
Tsupply °C	Ttarget °C	Heat kW	Shift K	U*f :W/m²,I	Descrip -	mcp kW/K
105	25	800	10	0.50	H1	10.00
185	35	750	10	0.50	H2	5.00
25	185	1200	10	0.50	C1	7.50
210	209		10	5.00	HP Steam	
160	159		10	5.00	MP Steam	
130	129		10	5.00	LP Steam	
5	6			2.60	Cooling	

Table 14.2

Utility costs		**Capital cost**	
	ú/kW,year	HEX =	800 ú/m²
HP steam	160.00	annuiity	0.298
MP steam	110.00	Cost/year	238.4 ú/m²,year
LP steam	50.00		
Cooling	10.00		

A first assessment of the steam requirements for a few values of a global DTMin leads to Table 14.3. It is obvious that a global DTMin of 20 K will be a good starting point; the best result is obtained with a DTMin of 19.5 K.

Table 14.3

Cost in '000	Trade-off with Global DTMin			Best
DTMin (K)	15.0	20.0	25.0	19.5
HP steam	175.0	212.5	250.0	208.75
MP steam	75.0	75.0	75.0	75.00
LP steam	62.5	62.5	62.5	62.50
Cooling	662.5	700.0	737.5	696.25
Cost	98.240	96.919	98.200	96.906

The Grand Composite is shown in Figure 14.1.

It also appears from the data in Table 14.3 that only the HP Steam target is changing with changing DTMin. Therefore, the global DTMin parameter is not suited for carrying out a reliable trade-off between energy and capital in case of multiple utilities.

Although for this simple case no further trade-off is required for developing the optimum network, an appropriate procedure will be followed in order to illustrate the effect of specific stream dependent DTMin contributions. Trade-off is done with the heating loads as parameter, one by one, in a sequence from low to high. For each utility, the optimum load will be defined by the minimum cost. This process will be repeated a number of times until sufficient convergence is reached.

The result of 11 runs with Steam loads as parameter is shown in Table 14.4. Convergence is reached on a cost figure of 96 365.

Table 14.4

Cost in '000	**Trade-off steps - heating loads as parameters**					
	Start	I	II	III	IV	V
HP steam	212.5	210	208	206.5	205.5	205.9
MP steam	75	57.5	52.0	50.0	50	50.5
LP steam	62.5	87.5	106.0	115.0	118.8	119.5
Cooling	700.0	705.0	716.0	721.5	724.3	725.9
Cost	96.919	96.547	96.401	96.371	96.366	96.366

Cost in '000	**Trade-off steps - heating loads as parameters**					
	VI	VII	VIII	IX	X	XI
HP steam	205.15	204.6	204.2	203.95	203.75	203.6
MP steam	50.40	50.8	51.3	51.7	52.1	52.3
LP steam	118.75	119.65	119.8	119.7	119.6	119.4
Cooling	724.30	725.1	725.30	725.35	725.35	725.30
Cost	96.366	96.365	96.365	96.365	96.365	96.365

The Grand Composite is shown in Figure 14.2 and corresponds with a global DTMin of 15.79 K.

The result of 11 runs with crisscross optimization is shown in Table 14.5. Convergence is reached on a value of 96 044 after 11 steps. It can be demonstrated that, from practical point of view, this is also the lowest value that is achievable with any procedure in the targeting stage; the ultimate values are shown in the column marked with **+)** in Table 14.5.

The Grand Composite, quite similar to the previous one, is shown in Figure 14.3 and corresponds with a global DTMin of 17.66 K with shift corrections of -6 K for MP Steam and LP Steam. Shift corrections could be further refined to -5.99 K for MP Steam and -5.88 K for LP Steam, with only negligible improvements, however.

For this example, the cost targets obtained by the different methods do not differ very much from what is achievable in the targeting stage; the distribution of the steam load targets, however, is quite different. From the comparison in Table 14.6, it is clear that for the steam load targets in the classic approach with DTMin as parameter, the errors for MP and LP steam are unacceptable. The results with trade-off using steam loads as parameter are much closer to the achievable optimum; the results of trade-off using steam loads combined with crisscross optimization are right on target for the cost and deviations in steam loads are less than 1%.

Table 14.5

Cost in '000		Trade-off steps - heating loads as parameters					
		Differentiated DTMin contributions					
	DTMin	Start	I	II	III	IV	V
HP steam	0	212.5	210	207.5	205	203.5	202.5
MP steam	-6	75	57.5	50.0	49.0	49.5	51.0
LP steam	-6	62.5	87.5	110.0	119.0	123.5	124.0
Cooling		700.0	705.0	717.5	723.0	726.5	727.5
Cost with crisscross		96.345	96.287	96.093	96.059	96.052	96.048

Cost in '000		Trade-off steps - heating loads as parameters						
		Differentiated DTMin contributions						
	DTMin	VI	VII	VIII	IX	X	XI	Đ
HP steam	0	201.0	200.6	200.25	199.95	199.80	199.70	199.50
MP steam	-6	52.0	53.2	54.05	54.65	55.00	55.25	55.80
LP steam	-6	124.0	124.3	123.45	122.95	122.65	122.45	122.00
Cooling		727.0	728.1	727.75	727.55	727.45	727.40	727.30
Cost with crisscross		96.047	96.046	96.045	96.044	96.044	96.044	96.044

Table 14.6

		Parameter	DTMin		Steam loads		Steam loads	
		Trade-off target	**Classic**	**deviation**	**Classic**	**deviation**	**Crisscross**	**deviation**
HP steam	kW	199.5	208.8	4.7%	203.6	2.1%	199.70	0.10%
MP steam	kW	55.8	75.0	34.4%	52.3	-6.3%	55.25	-0.99%
LP steam	kW	122.0	62.5	-48.8%	119.4	-2.1%	122.45	0.37%
Cost	'000	96.044	96.906	0.9%	96.366	0.3%	96.044	0.0%

The grid diagrams for the classic approach and for the analysis with crisscross optimization are shown in Table 14.8. It can easily be seen that the HEN structures will be identical and in both cases the targets are fully achievable. The classic grid leads to a network with 12 units and a cost of 96,919; the cost for the network using the crisscross grid is 96,046. Evolution of the networks will result in the same network with 10 units; this is the network with the lowest cost (96,041). This network can be simplified further with the view to reducing the number of units at a marginally higher cost. The best networks with and without splits are shown in Figures 14.4.

The results are summarized in Table 14.7 and compared with those of best published HENs (adjusted for correct heat exchanger DTLnM instead of approximations). The network with 7 units is identical with that of Ponce-Ortega.

Table 14.7

	HP Steam	MP Steam	LP Steam	Total steam	# HEX	# splits	Area	Cost
	kW	kW	kW	kW	-	-	m^2	'000
Shenoy	203.0	53.0	119.5	375.5	9	0	195.78	98.214
	240.0	0.0	135.5	375.5	7	0	193.87	98.649
Ponce-Ortega	238.7	0	151.3	390.0	7	0	184.09	97.043
Huang & Karimi	221.1	27.0	142.6	390.7	8	1	185.16	97.026
This work								
Targeting	199.7	55.3	122.45	377.4	-	-	187.16	96.044
Design	199.7	55.3	122.45	377.4	12	3	187.16	96.046
	199.2	56.0	122.1	377.3	10	1	187.21	96.041
	199.2	33.2	140.2	372.6	10	0	186.58	96.262
	199.3	55.9	135.2	390.4	9	0	186.04	96.552
	238.4	0	138.9	377.3	8	1	185.27	96.531
	238.4	0	145.1	383.5	8	0	184.64	96.752
	238.3	0	152.1	390.4	7	0	184.17	97.043

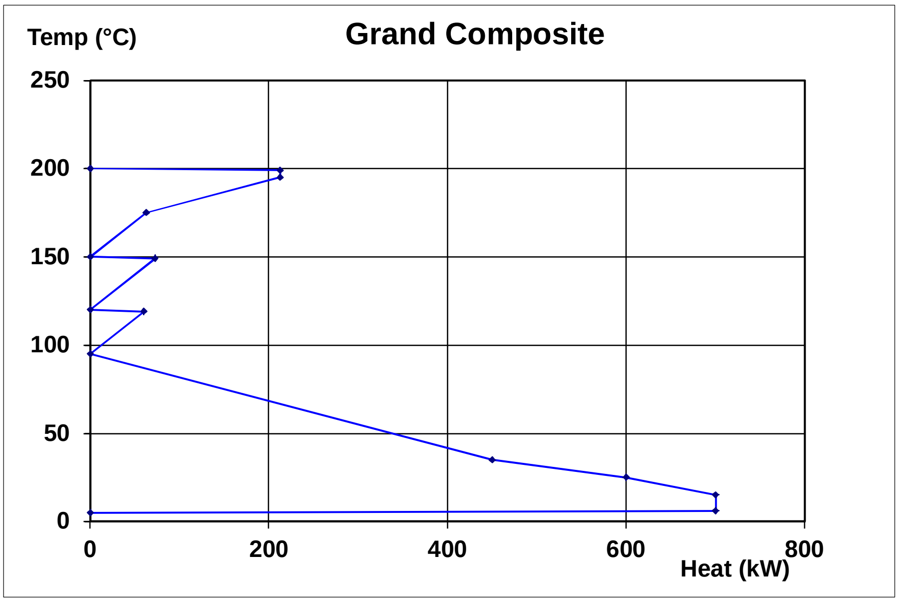


Figure 14.1

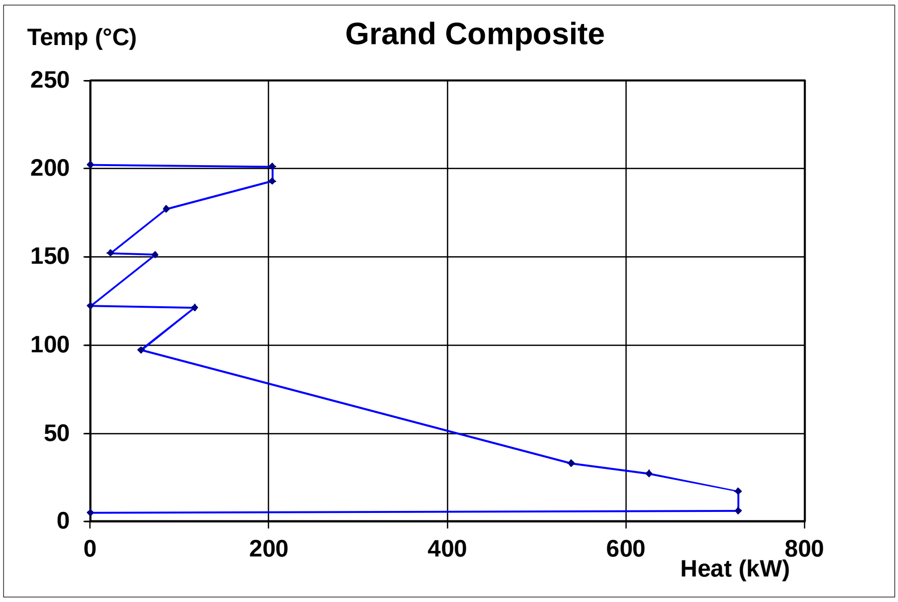


Figure 14.2

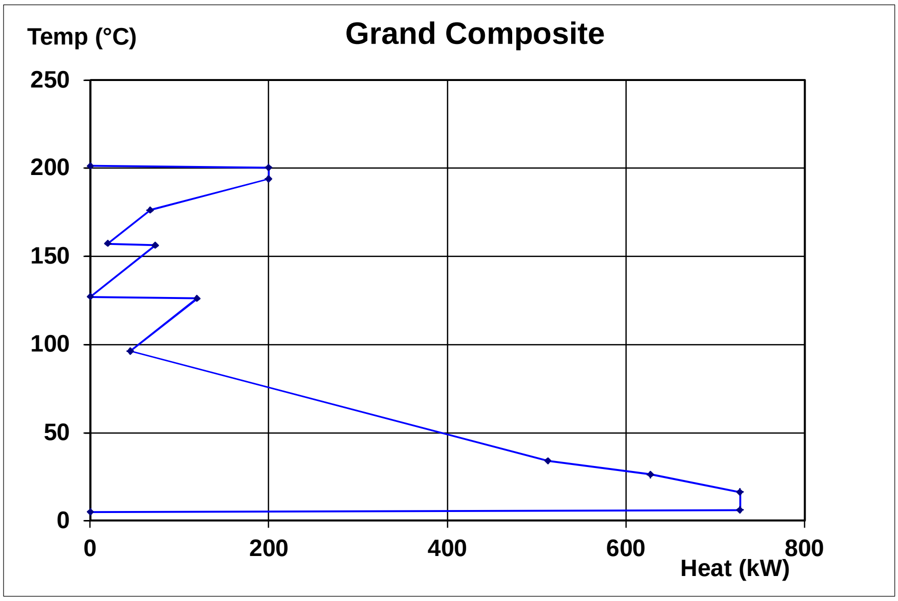


Figure 14.3

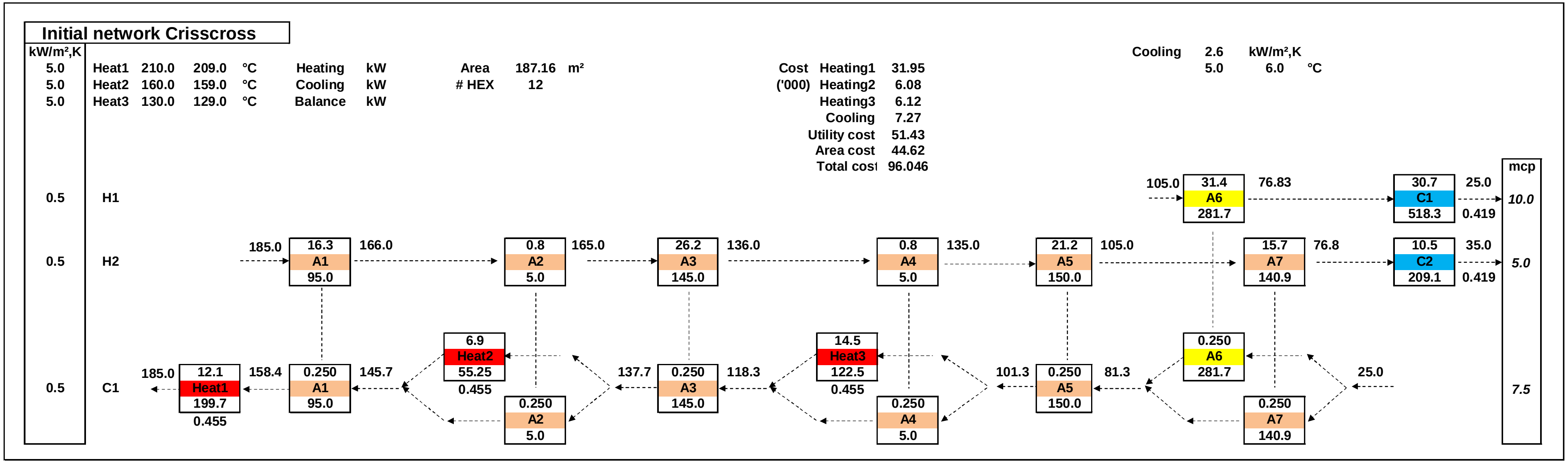
Table 14.8

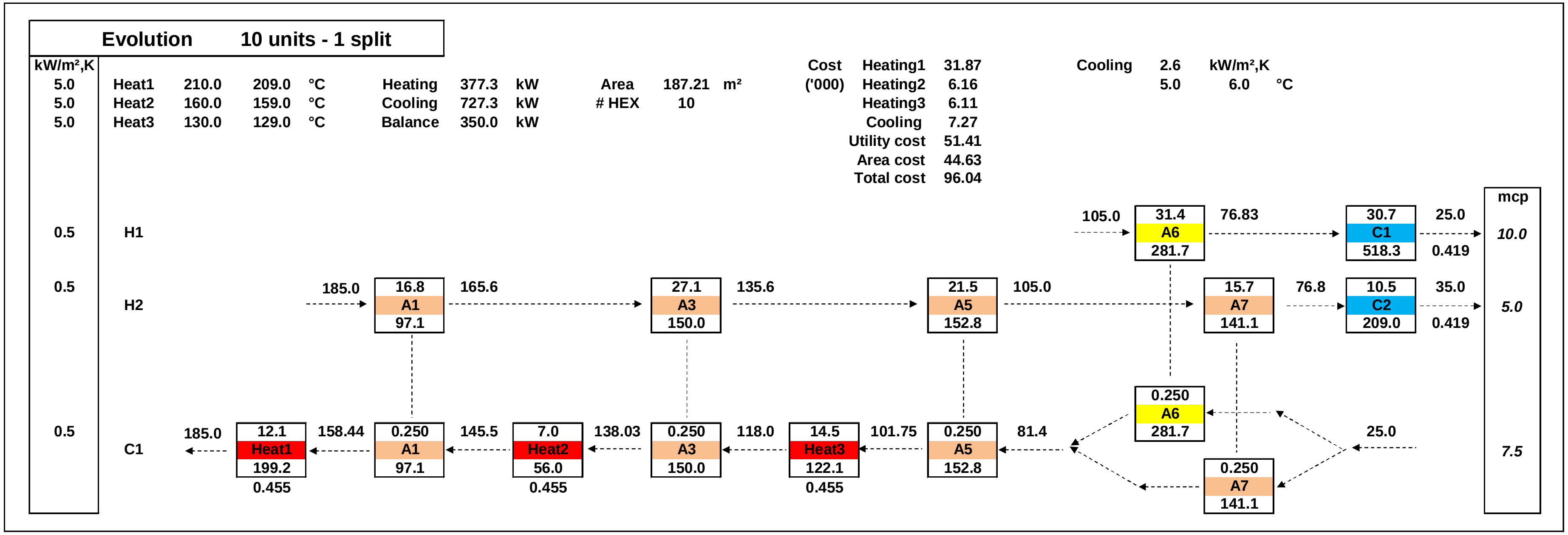
Description		1		2		3		4		5		6		7		8		9	
-	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C
HP Stean	210.0	**212.5**	209.0																
MP Stean					160.0	**75.0**	159.0												
LP Stean									130.0	**62.5**	129.0								
H1													105.0	**300.0**	75.0	**400.0**	35.0	**100.0**	25.0
H2			185.0	**125.0**	160.0	**5.0**	159.0	**145.0**	130.0	**5.0**	129.0	120.0	105.0	**150.0**	75.0	**200.0**	35.0		
C1	185.0	**212.5**	156.7	**125.0**	140.0	**80.0**	129.3	**145.0**	110.0	**67.5**	101.0	120.0	85.0	**450.0**	25.0				
Cooling															6.0	**600.0**	5.1	**100.0**	5.0

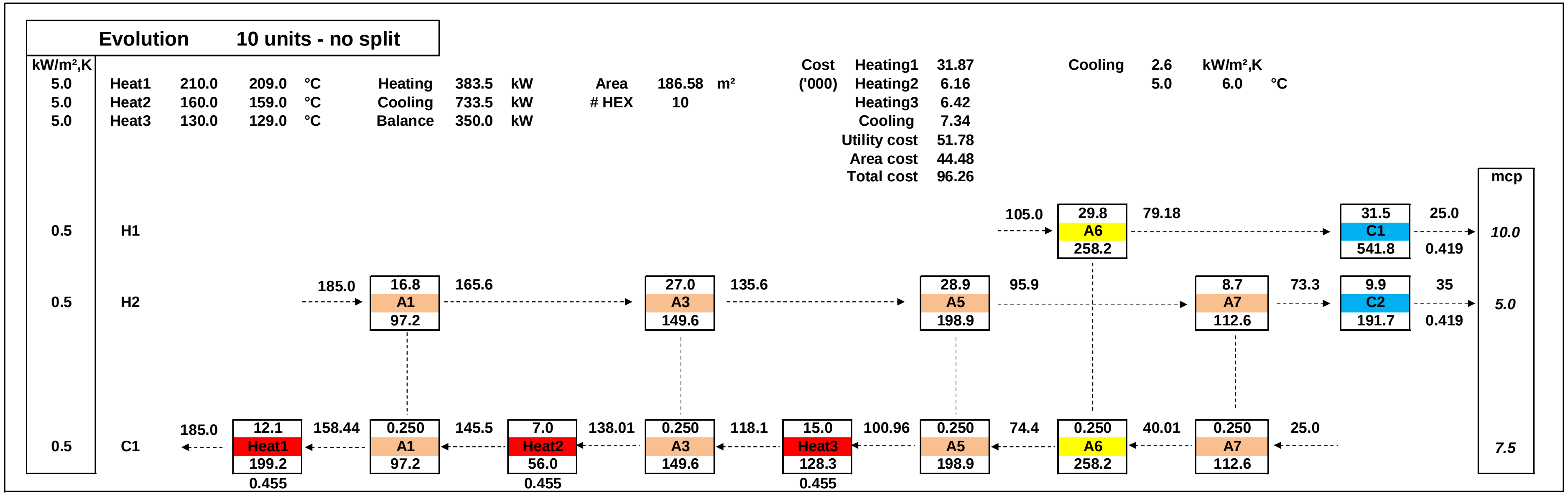
Crisscross

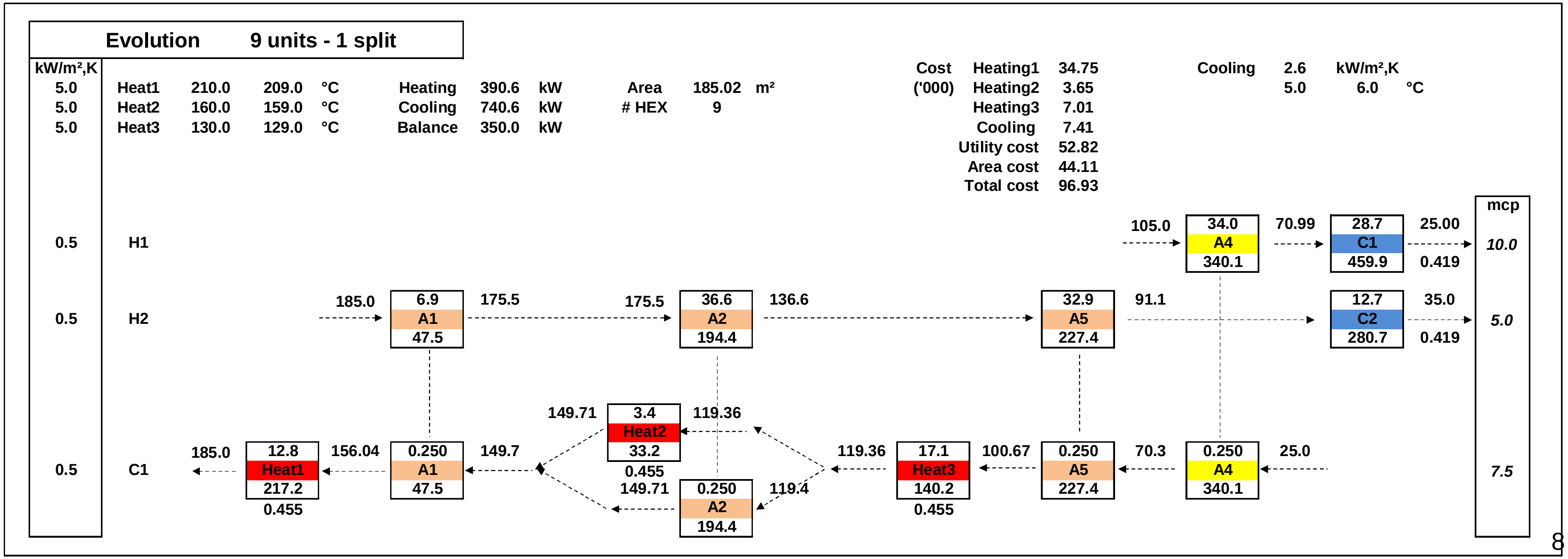
Description		1		2		3		4		5		6		7		8		9	
-	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C	kW	°C
HP Stean	210.0	**199.7**	209.0																
MP Stean					160.0	**55.25**	159.0												
LP Steam									130.0	**122.5**	129.0								
H1													105.0	**281.7**	76.8	**418.3**	35.0	**100.0**	25.0
H2			185.0	**95.0**	166.0	**5.0**	165.0	**145.0**	136.0	**5.0**	135.0	**150.0**	105.0	**140.9**	76.8	**209.2**	35.0		
C1	185.0	**199.7**	158.4	**95.0**	145.7	**60.25**	137.7	**145.0**	118.3	**127.5**	101.3	**150.0**	81.3	**422.6**	25.0				
Cooling															6.0	**627.5**	5.1	**100.0**	5.0

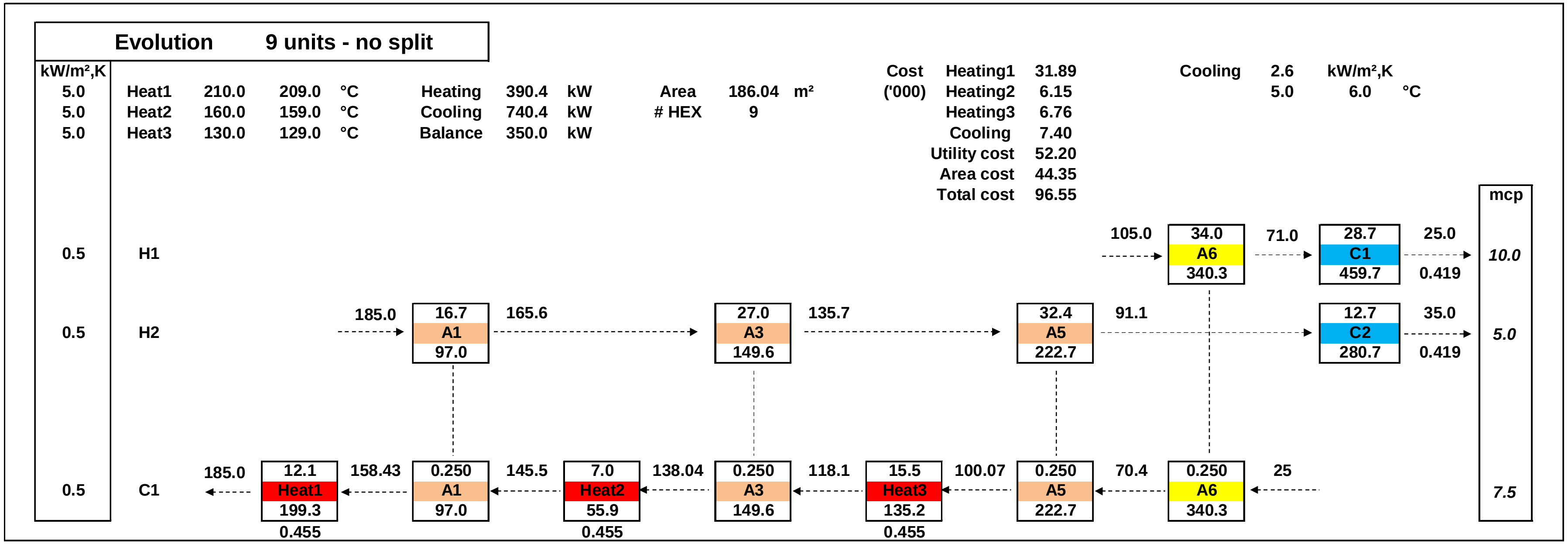
Figures 14.4 Heat Exchanger Networks

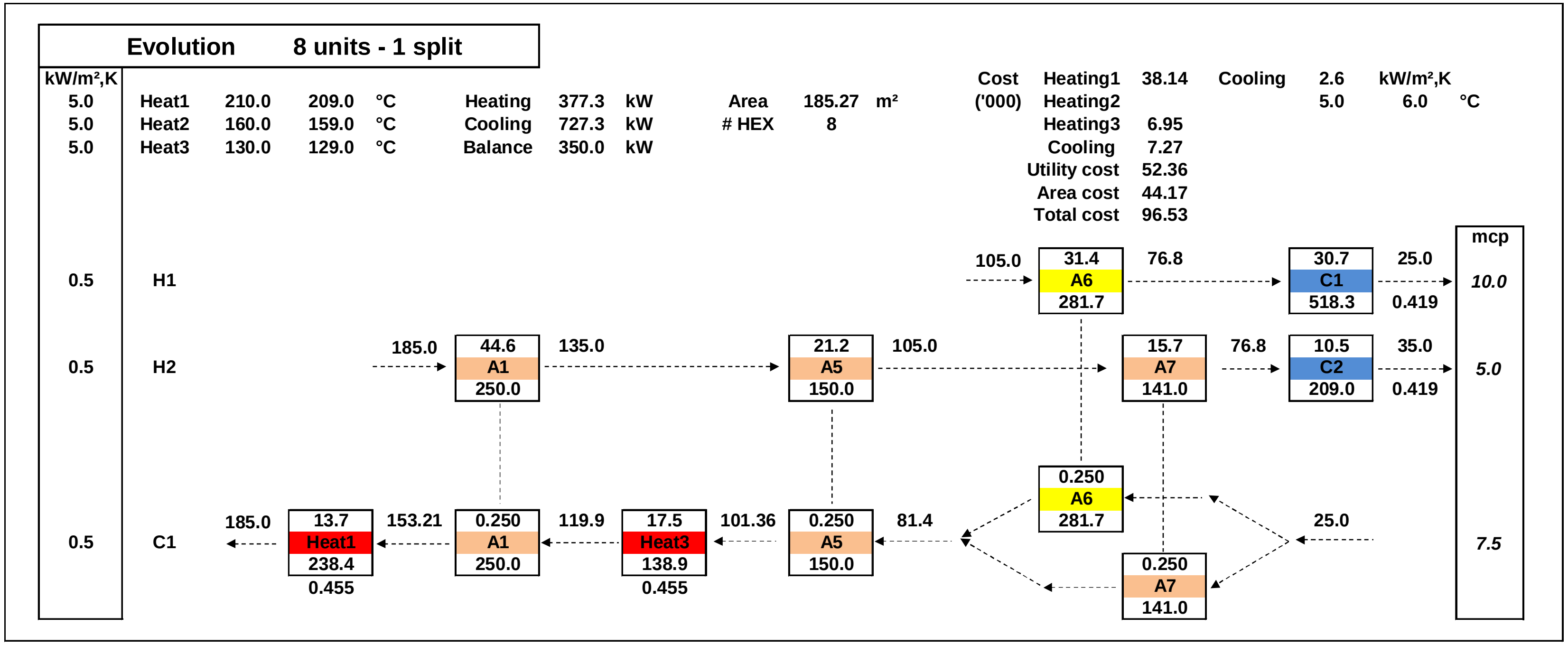


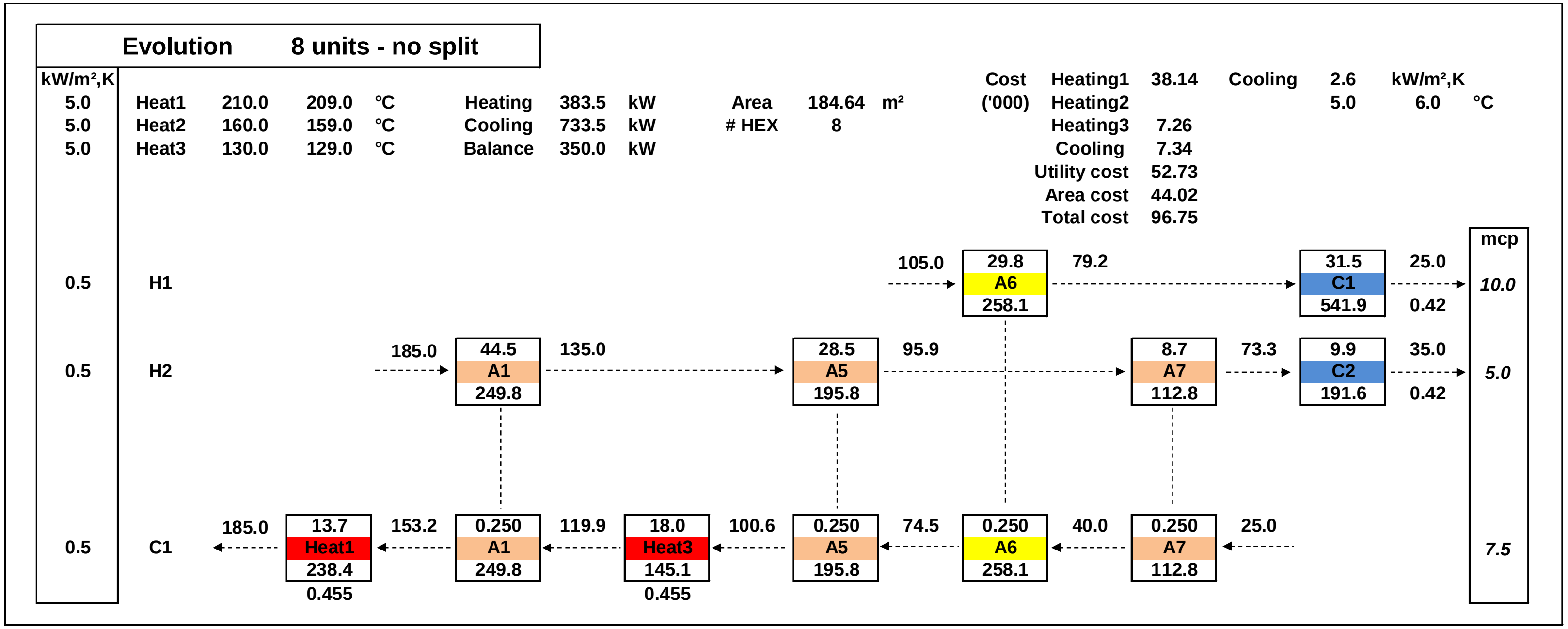


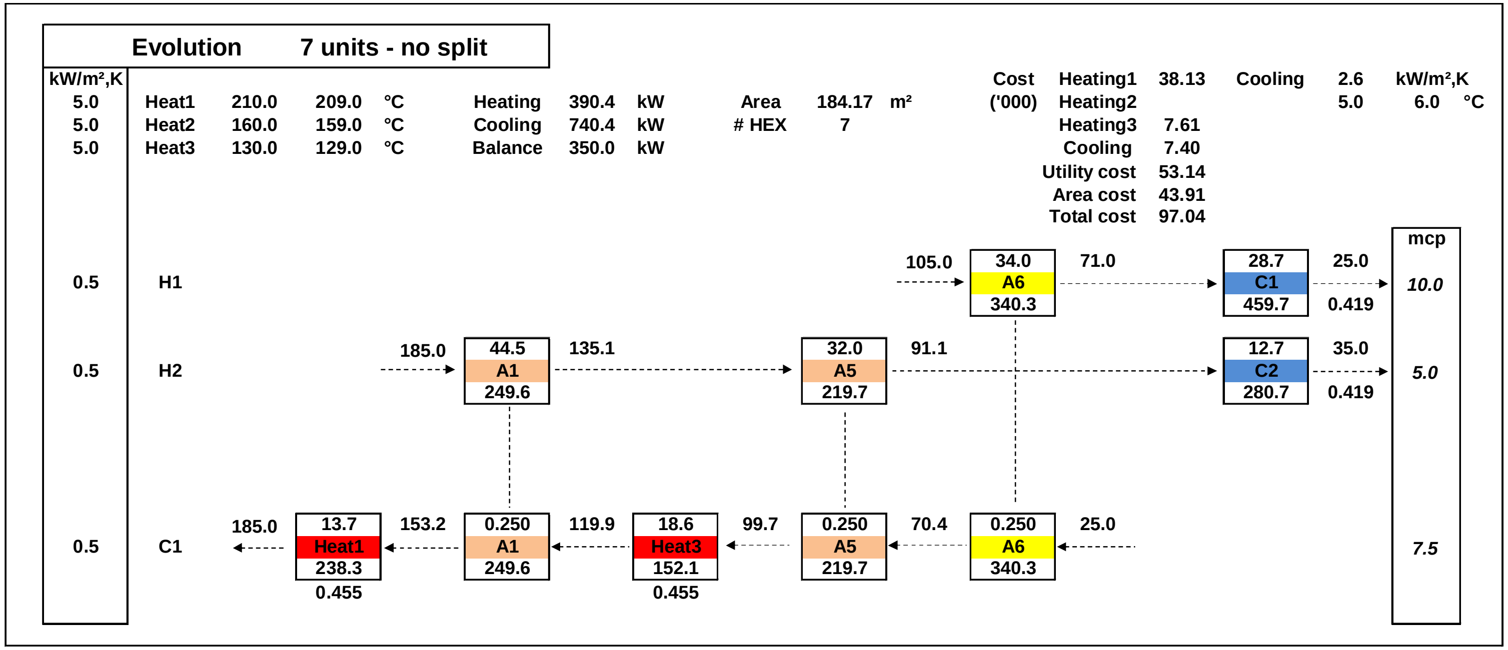

Evolution 10 units - no split
kW/m²,K
5.0 Heat1 210.0 209.0 °C
5.0 Heat2 160.0 159.0 °C
5.0 Heat3 130.0 129.0 °C
Heating 383.5 kW
Cooling 733.5 kW
Balance 350.0 kW
Area 186.58 m²
HEX 10
Cost ('000) Heating1 31.87
Heating2 6.16
Heating3 6.42
Cooling 7.34
Utility cost 51.78
Area cost 44.48
Total cost 96.26
Cooling 2.6 kW/m²,K
5.0 6.0 °C
mcp
0.5 H1 105.0 29.8 A6 258.2 79.18 31.5 C1 541.8 25.0 0.419 10.0
0.5 H2 185.0 16.8 A1 97.2 165.6 27.0 A3 149.6 135.6 28.9 A5 198.9 95.9 8.7 A7 112.6 73.3 9.9 C2 191.7 35 0.419 5.0
0.5 C1 185.0 12.1 Heat1 199.2 0.455 158.44 0.250 A1 97.2 145.5 7.0 Heat2 56.0 0.455 138.01 0.250 A3 149.6 118.1 15.0 Heat3 128.3 0.455 100.96 0.250 A5 198.9 74.4 0.250 A6 258.2 40.01 0.250 A7 112.6 25.0 7.5


Evolution 9 units - 1 split
kW/m²,K
5.0 Heat1 210.0 209.0 °C
5.0 Heat2 160.0 159.0 °C
5.0 Heat3 130.0 129.0 °C
Heating 390.6 kW
Cooling 740.6 kW
Balance 350.0 kW
Area 185.02 m²
HEX 9
Cost ('000) Heating1 34.75
Heating2 3.65
Heating3 7.01
Cooling 7.41
Utility cost 52.82
Area cost 44.11
Total cost 96.93
Cooling 2.6 kW/m²,K
5.0 6.0 °C
mcp
0.5 H1 105.0 34.0 A4 340.1 70.99 28.7 C1 459.9 25.00 0.419 10.0
0.5 H2 185.0 6.9 A1 47.5 175.5 175.5 36.6 A2 194.4 136.6 32.9 A5 227.4 91.1 12.7 C2 280.7 35.0 0.419 5.0
0.5 C1 185.0 12.8 Heat1 217.2 0.455 156.04 0.250 A1 47.5 149.7 149.71 3.4 Heat2 33.2 0.455 119.36 149.71 0.250 A2 194.4 119.4 119.36 17.1 Heat3 140.2 0.455 100.67 0.250 A5 227.4 70.3 0.250 A4 340.1 25.0 7.5


Evolution 9 units - no split
kW/m²,K
5.0 Heat1 210.0 209.0 °C
5.0 Heat2 160.0 159.0 °C
5.0 Heat3 130.0 129.0 °C
Heating 390.4 kW
Cooling 740.4 kW
Balance 350.0 kW
Area 186.04 m²
HEX 9
Cost ('000)
Heating1 31.89
Heating2 6.15
Heating3 6.76
Cooling 7.40
Utility cost 52.20
Area cost 44.35
Total cost 96.55
Cooling 2.6 5.0 kW/m²,K 6.0 °C
mcp
0.5 H1 10.0
0.5 H2 5.0
0.5 C1 7.5
105.0
34.0 A6 340.3
71.0
28.7 C1 459.7
25.0 0.419
185.0
16.7 A1 97.0
165.6
27.0 A3 149.6
135.7
32.4 A5 222.7
91.1
12.7 C2 280.7
35.0 0.419
185.0
12.1 Heat1 199.3 0.455
158.43
0.250 A1 97.0
145.5
7.0 Heat2 55.9 0.455
138.04
0.250 A3 149.6
118.1
15.5 Heat3 135.2 0.455
100.07
0.250 A5 222.7
70.4
0.250 A6 340.3
25


Evolution 8 units - 1 split
kW/m²,K
5.0 Heat1 210.0 209.0 °C
5.0 Heat2 160.0 159.0 °C
5.0 Heat3 130.0 129.0 °C
Heating 377.3 kW
Cooling 727.3 kW
Balance 350.0 kW
Area 185.27 m²
HEX 8
Cost ('000)
Heating1 38.14
Heating2
Heating3 6.95
Cooling 7.27
Utility cost 52.36
Area cost 44.17
Total cost 96.53
Cooling 2.6 5.0 kW/m²,K 6.0 °C
mcp
0.5 H1 10.0
0.5 H2 5.0
0.5 C1 7.5
105.0
31.4 A6 281.7
76.8
30.7 C1 518.3
25.0 0.419
185.0
44.6 A1 250.0
135.0
21.2 A5 150.0
105.0
15.7 A7 141.0
76.8
10.5 C2 209.0
35.0 0.419
185.0
13.7 Heat1 238.4 0.455
153.21
0.250 A1 250.0
119.9
17.5 Heat3 138.9 0.455
101.36
0.250 A5 150.0
81.4
0.250 A6 281.7
0.250 A7 141.0
25.0


Evolution 8 units - no split
kW/m²,K
5.0 Heat1 210.0 209.0 °C
5.0 Heat2 160.0 159.0 °C
5.0 Heat3 130.0 129.0 °C
Heating 383.5 kW
Cooling 733.5 kW
Balance 350.0 kW
Area 184.64 m²
HEX 8
Cost ('000)
Heating1 38.14
Heating2
Heating3 7.26
Cooling 7.34
Utility cost 52.73
Area cost 44.02
Total cost 96.75
Cooling 2.6 5.0
kW/m²,K 6.0 °C
mcp
0.5 H1 105.0 29.8 A6 258.1 79.2 31.5 C1 541.9 25.0 0.42 10.0
0.5 H2 185.0 44.5 A1 249.8 135.0 28.5 A5 195.8 95.9 8.7 A7 112.8 73.3 9.9 C2 191.6 35.0 0.42 5.0
0.5 C1 185.0 13.7 Heat1 238.4 0.455 153.2 0.250 A1 249.8 119.9 18.0 Heat3 145.1 0.455 100.6 0.250 A5 195.8 74.5 0.250 A6 258.1 40.0 0.250 A7 112.8 25.0 7.5


Evolution 7 units - no split
kW/m²,K
5.0 Heat1 210.0 209.0 °C
5.0 Heat2 160.0 159.0 °C
5.0 Heat3 130.0 129.0 °C
Heating 390.4 kW
Cooling 740.4 kW
Balance 350.0 kW
Area 184.17 m²
HEX 7
Cost ('000)
Heating1 38.13
Heating2
Heating3 7.61
Cooling 7.40
Utility cost 53.14
Area cost 43.91
Total cost 97.04
Cooling 2.6 5.0
kW/m²,K 6.0 °C
mcp
0.5 H1 105.0 34.0 A6 340.3 71.0 28.7 C1 459.7 25.0 0.419 10.0
0.5 H2 185.0 44.5 A1 249.6 135.1 32.0 A5 219.7 91.1 12.7 C2 280.7 35.0 0.419 5.0
0.5 C1 185.0 13.7 Heat1 238.3 0.455 153.2 0.250 A1 249.6 119.9 18.6 Heat3 152.1 0.455 99.7 0.250 A5 219.7 70.4 0.250 A6 340.3 25.0 7.5