Synthesis of Heat Exchanger Networks with Equal Heat Transfer Coefficients

Case 7 - Example from Ciric et al. modified by Bochenek et al.

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The data set of Example Case 7 is from Ciric and Floudas, modified by Bochenek et al (Table 7.1).

Table 7.1

Tsupply K	Ttarget K	Heat kW	DT-shift K	U*f kW/K,m²	Descript. -
500	350	1501.5		1.60	H1
450	350	1200.0		1.60	H2
400	320	640.8		1.60	H3
300	480	1620.0		1.60	C1
340	420	800.0		1.60	C2
340	400	480.0		1.60	C3
540	540	0.0		1.60	Heating
300	320	442.3		1.60	Cooling

Cost data

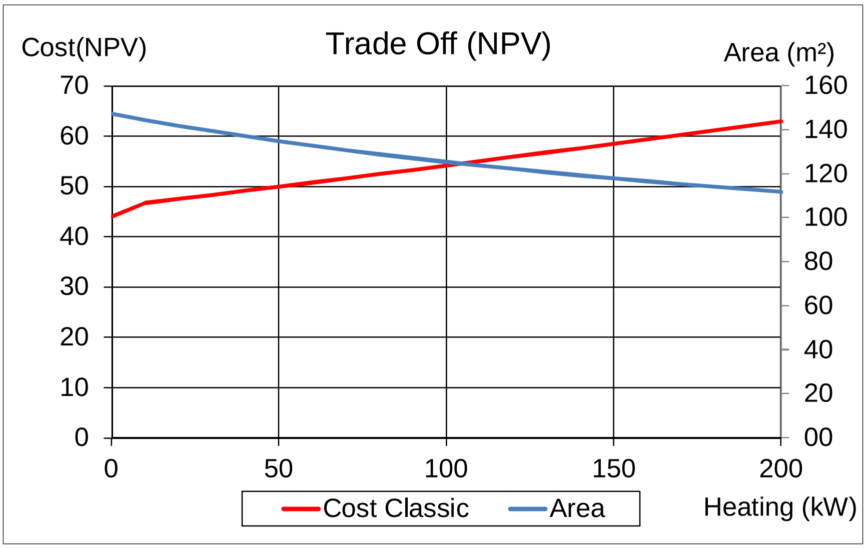
Heating : 80/kW,year Cooling : 20/kW,year

HEX 4000 + 1200 x Area $^{0.6}$ annuity 0.4794

Trade-off between energy and capital (Figure 7.1) indicates that the cost is minimum with no hot utility input, which turns the case into a threshold problem as reflected in the given data set.

Targeted area is 147.19 m²; assuming one single system the minimum number of heat exchanger units is 6.

Figure 7.1



The Grid Diagram generated during the analysis has a superstructure with 8 bands containing 24 units (Table 7.3). This can easily be reduced to 4 bands with 13 units requiring 149.54 m² (Table 7.4).

Since all heat transfer coefficients are the same, there is no criterion for generating one single optimum initial network using LP. Band 2 allows 6 different load distributions and band 3 allows 18 different distributions which, combined, results into 54 alternatives with the same minimum surface area and with at least 40 different structures with area costs varying between 54866 and 56212. The resulting structure from LP targeting for minimum area will depend on the underlying software algorithms themselves, on the sequence of the input streams and, eventually, on forbidden matches between streams. Three categories of results have been identified:

- Initial networks with congruency between bands 1 and 2 and 3 (example Figure 7.1)
- Initial networks with congruency between bands 2 and 3 (example Figure 7.5)
- Initial networks with no congruency between the mentioned bands (not pursued).

The initial network of Figure 7.1 was obtained using a loop analysis and optimization program targeting minimum area; it was further optimized using a simulation sheet in Excel, resulting into the optimum network with 2 stream splits as shown in Figure 7.2, with 1 stream split as shown in Figure 7.3 and without stream splits as shown in Figure 7.4.

The initial network as shown in Figure 7.5 was obtained using a loop analysis and optimization program targeting minimum cost; further development led to the network without stream splits as shown in Figure 7.6, which is a second best solution without stream splits. A summary of the results is shown and compared with results from literature in Table 7.2 below.

Table 7.2

Results	Area	Cost	splits
Targets	147.19	43.89	
Bochenek	168.99	48.64	1
X Luo	163.95	43.08	3
Declercq	152.27	42.17	2
	157.43	42.32	1
	183.81	43.52	0

Table 7.3

Process : 3H+3C

	area	#HEX	AreaCost
Heatit	147.19	6	35.05
Design	147.19	24	83.00

		DeltaTS	20.0		25.6		28.2		30.9		25.2		28.7		42.7		42.3		20.0
N°	Description	DeltaQ		500.5		39.5		380.0		681.0		939.0		180.0		382.0		240.3	
------------------------			1		2		3		4		5		6		7		8		
1	H1		500.00		450.00		448.21		430.94		400.00		368.72		362.72		350.00		
2	H2				450.00		448.21		430.94		400.00		368.72		362.72		350.00		
3	H3										400.00		368.72		362.72		350.00		320.00
4	C1		480.00		424.39		420.00		400.00		374.78		340.00		320.00		307.72		300.00
5	C2						420.00		400.00		374.78		340.00						
6	C3								400.00		374.78		340.00						
7	Cooling														320.00		307.72		300.00

Table 7.4

Process : 3H+3C Ciric

	Area	#HEX	AreaCost
Heatit	147.19	6	35.05
Design	149.54	13	55.87

N°	Descriptio	DeltaTS	20.0		25.6		25.2		28.7		20.0
	-	DeltaQ		500.5		1100.5		939.0		802.3	
------------------------			1		2		3		4		
1	H1		500.00		450.00		400.00		363.52		350.00
2	H2				450.00		400.00		368.72		350.00
3	H3						400.00		375.22		320.00
4	C1		480.00		424.39		374.78		340.00		300.00
5	C2				420.00		374.78		340.00		
6	C3				400.00		374.78		340.00		
7	Cooling								320.00		300.00

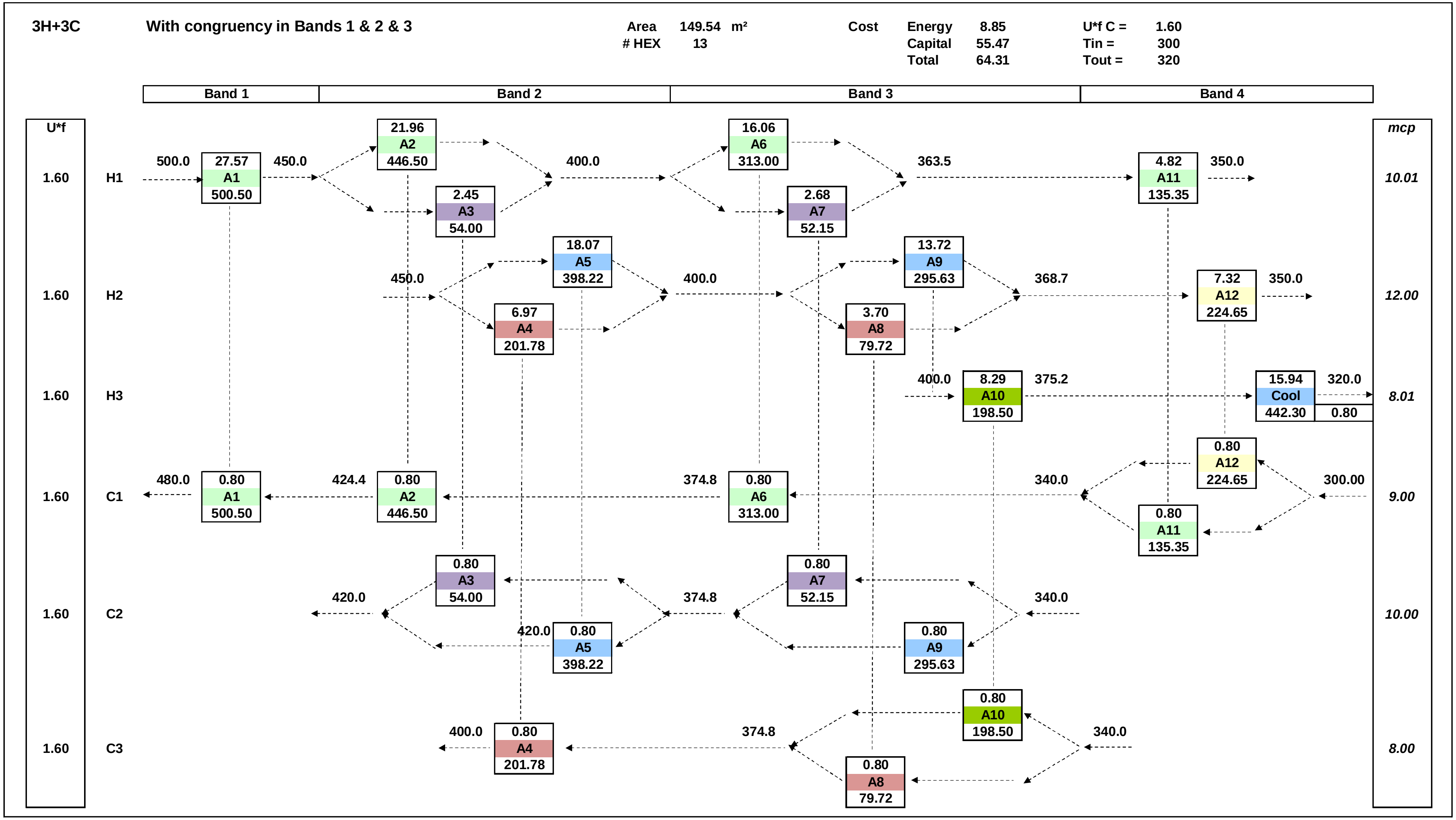

3H+3C
With congruency in Bands 1 & 2 & 3
Area 149.54 m²
HEX 13
Cost
Energy 8.85
Capital 55.47
Total 64.31
U*f C = 1.60
Tin = 300
Tout = 320
Band 1
Band 2
Band 3
Band 4
U*f
mcp
H1
H2
H3
C1
C2
C3
1.60
10.01
12.00
8.01
9.00
10.00
8.00
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
Cool

Figure 7.1

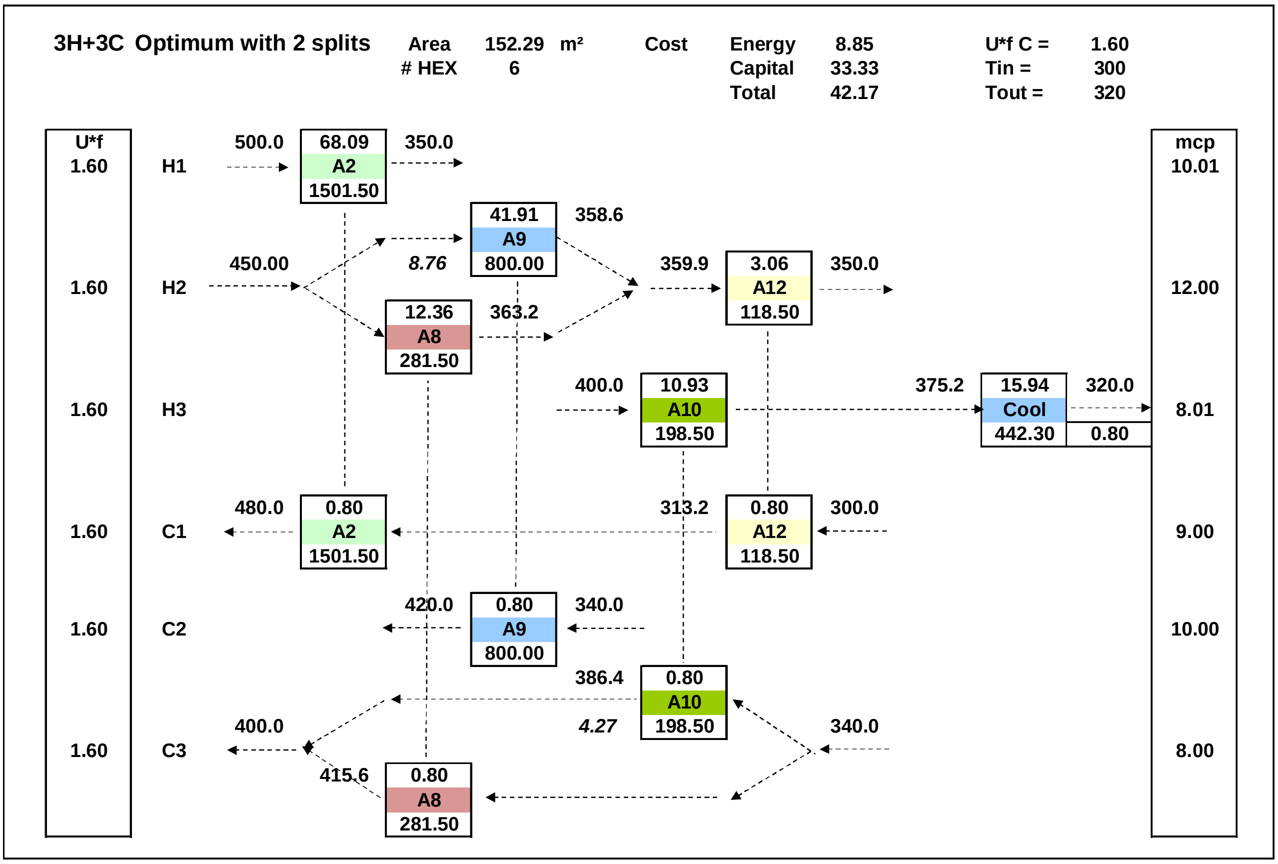


Figure 7.2

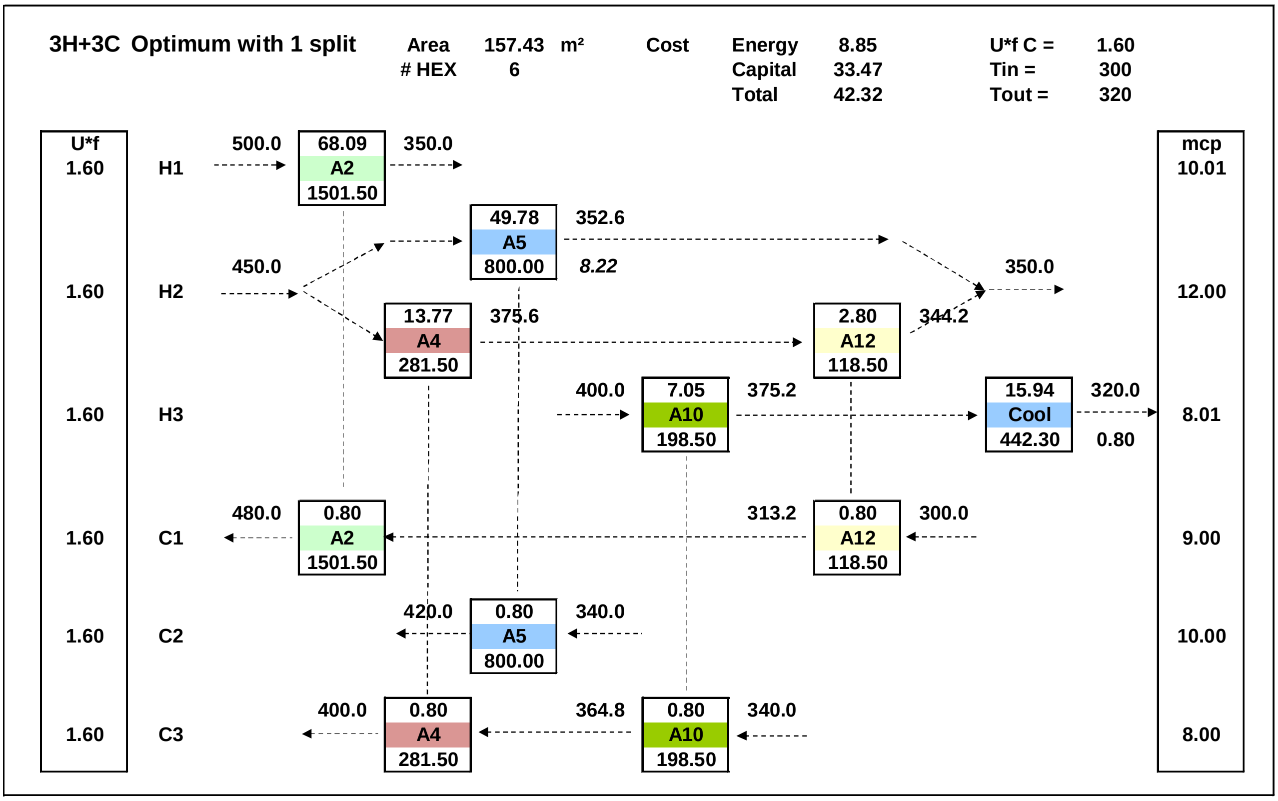


Figure 7.3

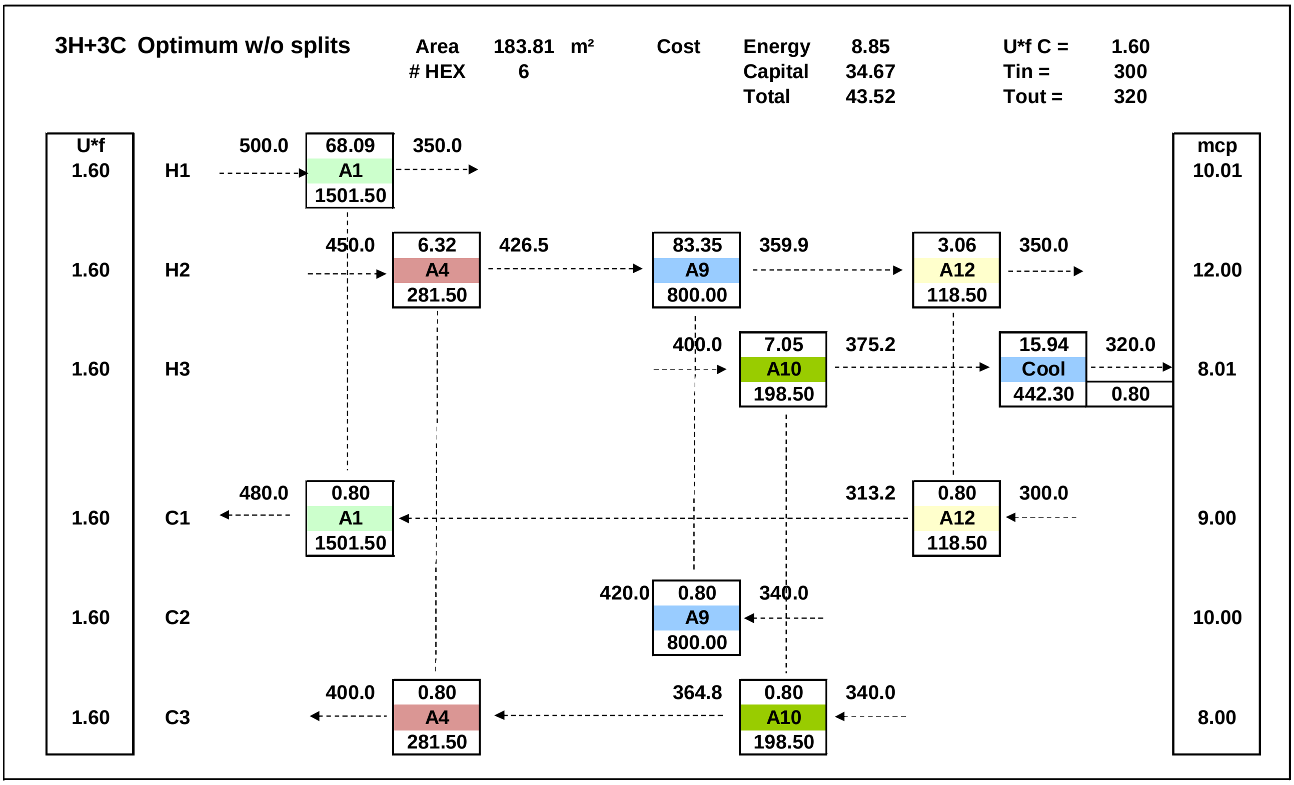

3H+3C Optimum w/o splits
Area 183.81 m²
HEX 6
Cost
Energy 8.85
Capital 34.67
Total 43.52
U*f C = 1.60
Tin = 300
Tout = 320
U*f
1.60
1.60
1.60
1.60
1.60
1.60
H1
H2
H3
C1
C2
C3
mcp
10.01
12.00
8.01
9.00
10.00
8.00
500.0
68.09
A1
1501.50
350.0
450.0
6.32
A4
281.50
426.5
83.35
A9
800.00
359.9
3.06
A12
118.50
350.0
400.0
7.05
A10
198.50
375.2
15.94
Cool
442.30
320.0
0.80
480.0
0.80
A1
1501.50
313.2
0.80
A12
118.50
300.0
420.0
0.80
A9
800.00
340.0
400.0
0.80
A4
281.50
364.8
0.80
A10
198.50
340.0

Figure 7.4

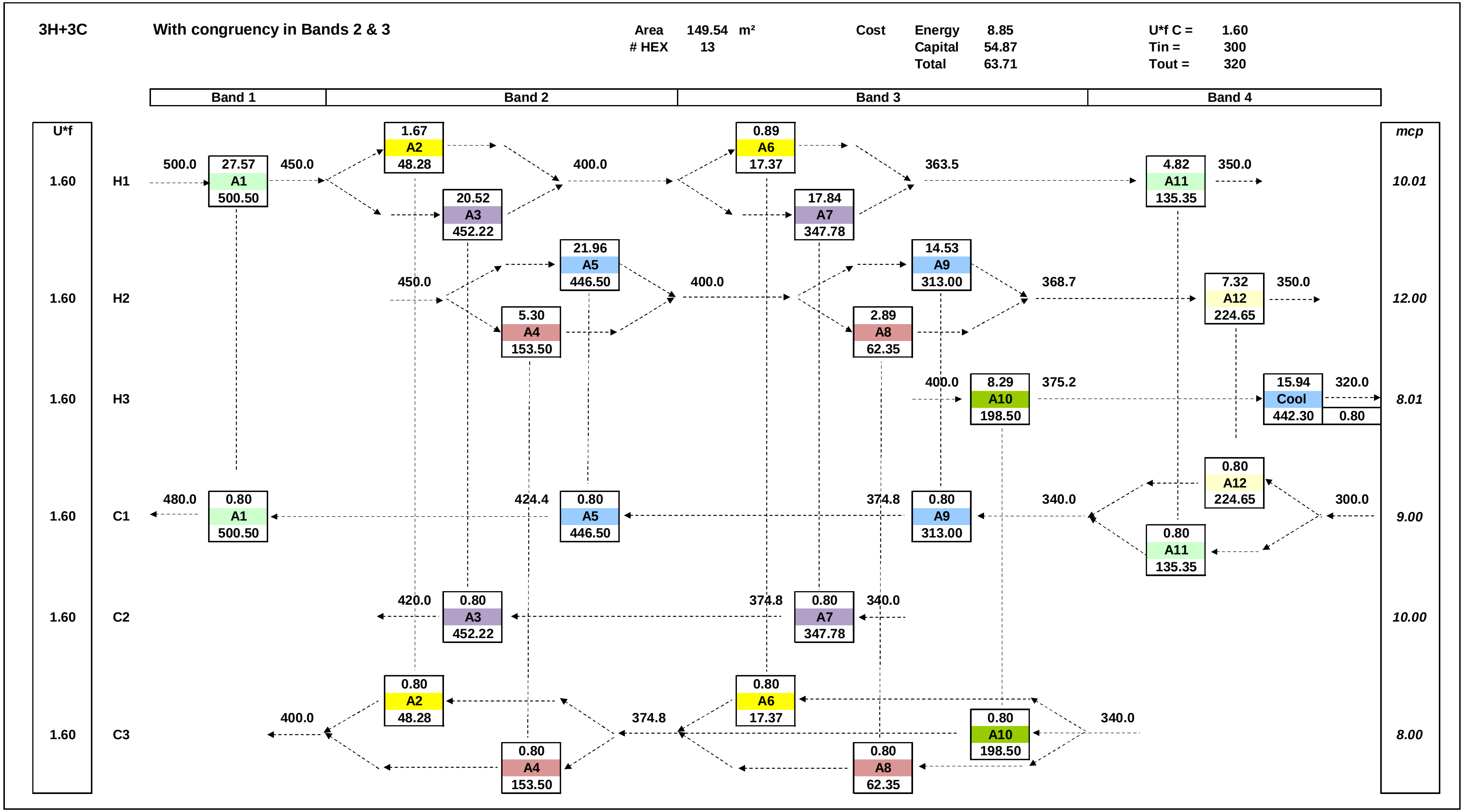

3H+3C
With congruency in Bands 2 & 3
Area 149.54 m²
HEX 13
Cost
Energy 8.85
Capital 54.87
Total 63.71
U*f C = 1.60
Tin = 300
Tout = 320
Band 1
Band 2
Band 3
Band 4
U*f
mcp
H1
H2
H3
C1
C2
C3
1.60
10.01
12.00
8.01
9.00
10.00
8.00
500.0
450.0
400.0
363.5
350.0
450.0
400.0
368.7
400.0
375.2
320.0
480.0
424.4
374.8
340.0
300.0
420.0
374.8
340.0
400.0
374.8
340.0
27.57
A1
500.50
1.67
A2
48.28
20.52
A3
452.22
21.96
A5
446.50
5.30
A4
153.50
0.89
A6
17.37
17.84
A7
347.78
14.53
A9
313.00
2.89
A8
62.35
8.29
A10
198.50
4.82
A11
135.35
7.32
A12
224.65
15.94
Cool
442.30
0.80

Figure 7.5

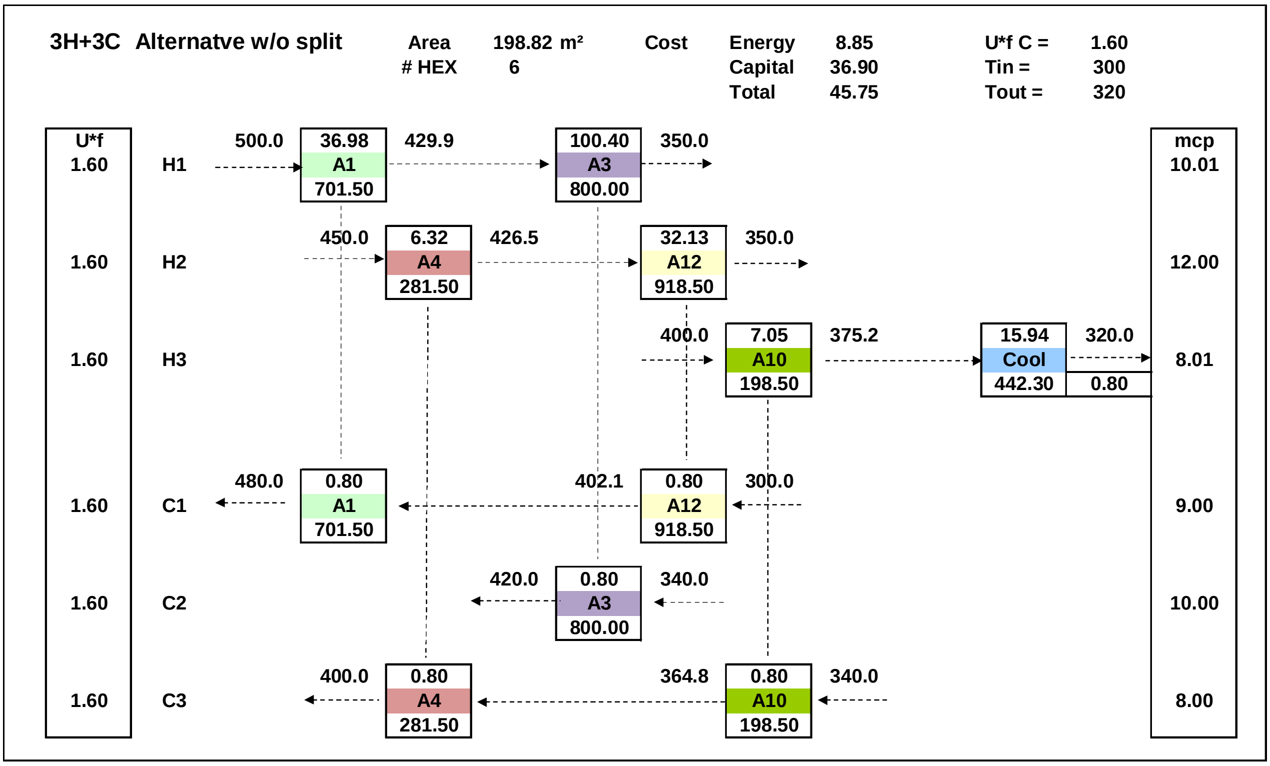

3H+3C Alternatve w/o split
Area 198.82 m²
HEX 6
Cost
Energy 8.85
Capital 36.90
Total 45.75
U*f C = 1.60
Tin = 300
Tout = 320
U*f
1.60
1.60
1.60
1.60
1.60
1.60
H1
H2
H3
C1
C2
C3
mcp
10.01
12.00
8.01
9.00
10.00
8.00
500.0
36.98
A1
701.50
429.9
100.40
A3
800.00
350.0
450.0
6.32
A4
281.50
426.5
32.13
A12
918.50
350.0
400.0
7.05
A10
198.50
375.2
15.94
Cool
442.30
320.0
0.80
480.0
0.80
A1
701.50
402.1
0.80
A12
918.50
300.0
420.0
0.80
A3
800.00
340.0
400.0
0.80
A4
281.50
364.8
0.80
A10
198.50
340.0

Figure 7.6