Pinch Technology Second Generation

Analysis with crisscross optimisation prior to design

Design with loop optimisation for minimum area and minimum cost

Example Case 4

Example from Linnhoff and Ahmad ï The 9SP aromatics plant

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Case 4 ï Example from Linnhoff and Ahmad ï The 9SP aromatics plant

Case 4 is the 9SP ñaromaticsò problem first presented by Linnhoff and Ahmad in 1990. The data are given in Table 4.1, together with optimised shift contributions.

Description -	Tsupply °C	Ttarget °C	Heat kW	DT-shift K	U*f kW/K,m²	mcp kW/K
H1	327	40	28700	0	0.50	100
H2	220	160	9600	1	0.40	160
H3	220	60	9600	12	0.14	60
H4	160	45	46000	4	0.30	400
C1	100	300	20000	4	0.35	100
C2	35	164	9030	0	0.70	70
C3	85	138	18550	2	0.50	350
C4	60	170	6600	12	0.14	60
C5	140	300	32000	0	0.60	200
Heating	330	250	24000	0	0.50	
Cooling	15	30	31720	0	0.50	

Heating : 60/kW, year

Cooling : 6/kW, year

HEX Cost : (2000 + 70 x Area)/year

Table 4.1

The effect of crisscross on the results of trade-off between energy and capital is shown in Fig.4.1.

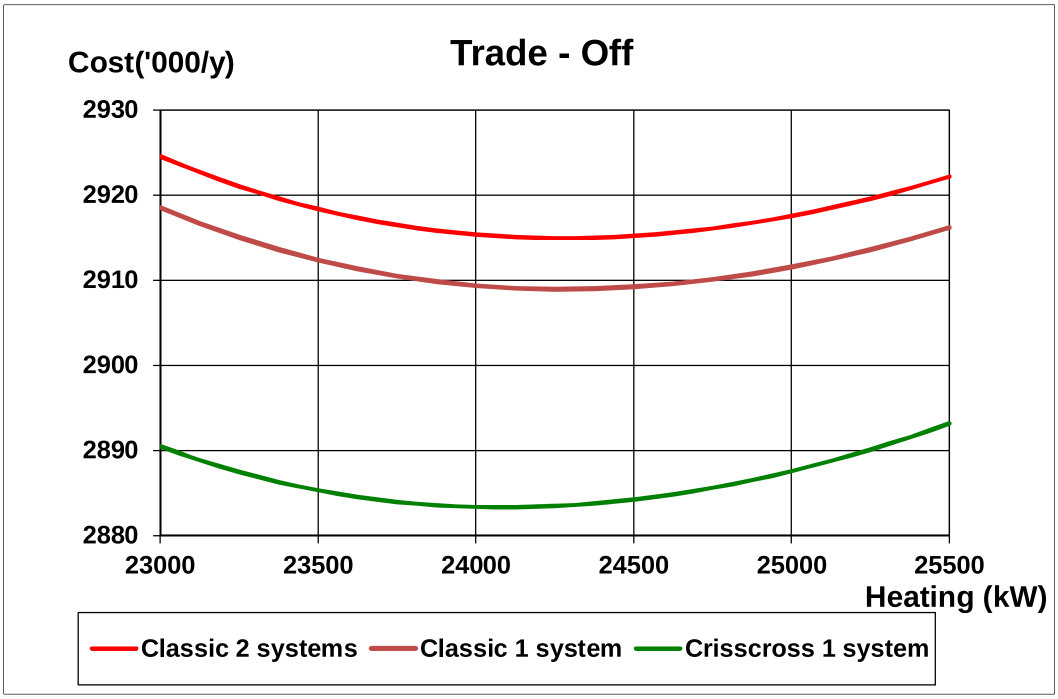


Fig. 4.1

The results of the study can be compared with published solutions in Table 4.2, for networks with a number of units from 18 to 10.

Example 9SP						
	QHot(MW)	Area (m²)	Cost ('000)	# HEX	# splits	Smallest
Published Optimum Heat Exchanger Networks						
Linnhoff and Ahmad (1990) [1]	25.04	17993	2992	17	1	26.0
Zhu and O'Neill (1995) [1]			2969			
Lewin (1998) [1]			2945			
Liporace et al. (2001) [1]	25.75	16740	2940	13		10.0
Fieg et al. (2009) [1]	23.62	18420	2922.3	14	3	11.3
	23.46	18660	2924.9	12	1	10.6
Toffolo (2009)	23.68	18300	2920.1	15	4	13.3
	24.12	17970	2920.3	12	2	16.4
Avila-Diaz (2008)	23.77	18006	2904.3	13	2	9.9
This research	24.27	17242	2891.21	18	9	16.8
	24.28	17245	2889.88	17	8	16.9
	24.33	17204	2888.78	16	7	17.0
	24.37	17250	2891.85	15	5	14.2
	23.93	17702	2892.82	14	2	14.1
	24.10	17564	2892.41	13	2	13.8
	24.16	17642	2899.72	12	3	14.7
	24.10	17867	2909.64	11	1	8.8
	25.72	16920	2948.26	10	1	10.4
	25.75	16904	2948.76	10	0	10.8
[1] Best of ...						

Table 4.2

The corresponding optimum networks are shown in Figures 4.2 through Fig.4.11. A very large number of networks can be developed with a cost below 2900 kEUR with minimum approach temperatures (smallest DeltaT) in the network that still are significantly higher than in published solutions. As shown, targets calculated with conventional pinch analysis can be beaten and targets obtained after crisscross optimisation are much closer to what is achievable.

Remarkably, almost all low cost networks show one single heat exchanger (A5) on the streams H3 ï C4 with a temperature difference of 50K. For the given Heating duty, conventional pinch analysis would suggest a DeltaT of 24 K and would allocate a pinch violation of 1550 kW to this match. Crisscross optimisation would suggest a DeltaT of 41 K between H3 and C4 and a Cooler of 3012 kW on the cold end of H3. With crisscross optimisation, accepting heat exchanger A5 and a Cooler of 3000 kW on the cold end of H3, total surface area required would not increase but would even be 470 m² lower than with conventional pinch analysis, even with the same Heating duty; consequently, this match creates no pinch violation; the remaining average driving force at the pinch for all other matches (with a heat transfer coefficient that is more than three times that of the heat exchanger on the two streams H3C4) is still 21K.

The original superstructure resulting from the analysis was reduced from 17 integration bands to 5 (Table 4.3). Several sequences can be applied for said reduction, but they all lead to the same initial network.

Process : 9SP aromatics

	area	#HEX	AreaCost
Heatit	17557.68	12	1253.04
Design	17769.56	20	1281.87

N°	Tsupply °C	Ttarget °C	Heat kW	Shift K	Stream -	U*f kW/m²,K	mcp kW/K	1	2	3	4	5	
10	330	250	24000	0	Heating	0.50	300.00	330.00	250.00				
1	327	40	28700	0	H1	0.50	100.00	327.00	250.00	161.31	120.89	98.21	40.00
2	220	160	9600	1	H2	0.40	160.00		220.00	160.00			
3	220	60	9600	12	H3	0.14	60.00		220.00	178.00	110.00	110.00	60.00
4	160	45	46000	4	H4	0.30	400.00			160.00	123.53	102.25	45.00
5	100	300	20000	4	C1	0.35	100.00	300.00	191.67	135.11	100.00		
6	35	164	9030	0	C2	0.70	70.00		164.00	140.00	104.00	35.00	
7	85	138	18550	2	C3	0.50	350.00			138.00	102.00	85.00	
8	60	170	6600	12	C4	0.14	60.00		170.00	128.00	60.00	60.00	
9	140	300	32000	0	C5	0.60	200.00	300.00	195.67	140.00			
11	15	30	31720	0	Cooling	0.50	2114.67					30.00	15.00

Table 4.3

Using the Grid Diagram of Table 4.3, an initial network was generated by LP targeting minimum surface area. This network was optimised for minimum cost in an Excel simulation flow sheet and further processed as shown in Table 4.4 with most of the steps leading to optimum networks. The network with minimum annual cost has 16 heat exchanger units for a cost of 2888.92 kEUR (Fig.4.4).

Series starting with 5 integration bands and 18 HEX		QHot(MW)	Area (m²)	Cost ('000)	# HEX	# splits	Smallest DeltaT(K)
Designit basis 5 bands		24.00	17770	2910.19	18	9	16.9
optimise Heating and splits		24.27	17242	2891.21	18	9	16.8
↳ merge splits H4		24.28	17245	2889.88	17	8	16.9
eliminate A13	(2)	24.33	17201	2890.29	17	8	17.0
eliminate A11		24.33	17204	2888.78	16	7	17.0
swap A2-A3 cold side & eliminate A2		24.37	17250	2891.85	15	5	14.2
merge load A1 into A3 trough heating loop	(2)	24.47	17213	2894.25	14	4	11.8
↳ eliminate A5	(2)	24.19	17515	2895.19	13	3	16.5
eliminate A12		24.16	17642	2899.72	12	3	14.7
eliminate A8		24.10	17867	2909.64	11	1	8.8
eliminate H1 and A8 and A12		25.72	16920	2948.26	10	1	10.4
eliminate split		25.75	16904	2948.76	10	0	10.8
Alternative route 1							
keep small HEX (Ax) on hot side H3		23.93	17702	2892.82	14	2	14.1
eliminate Ax		24.10	17564	2892.41	13	2	13.8
Alternative route 2							
match streams with same or comparable mcp's (H1-C1 / H3-C4 /H4-C3) followed by tick-off procedure on the rest		25.75	16904	2948.76	10	0	10.8

(2) Near optimum

Table 4.4

The first optimised network with 18 units is shown in Fig.4.2.

The ñAlternative route 2òis the fastest route to the simplest network with the minimum number of units (10) and does not require any sophisticated program at all; the difference with the lowest cost network is only 2%.

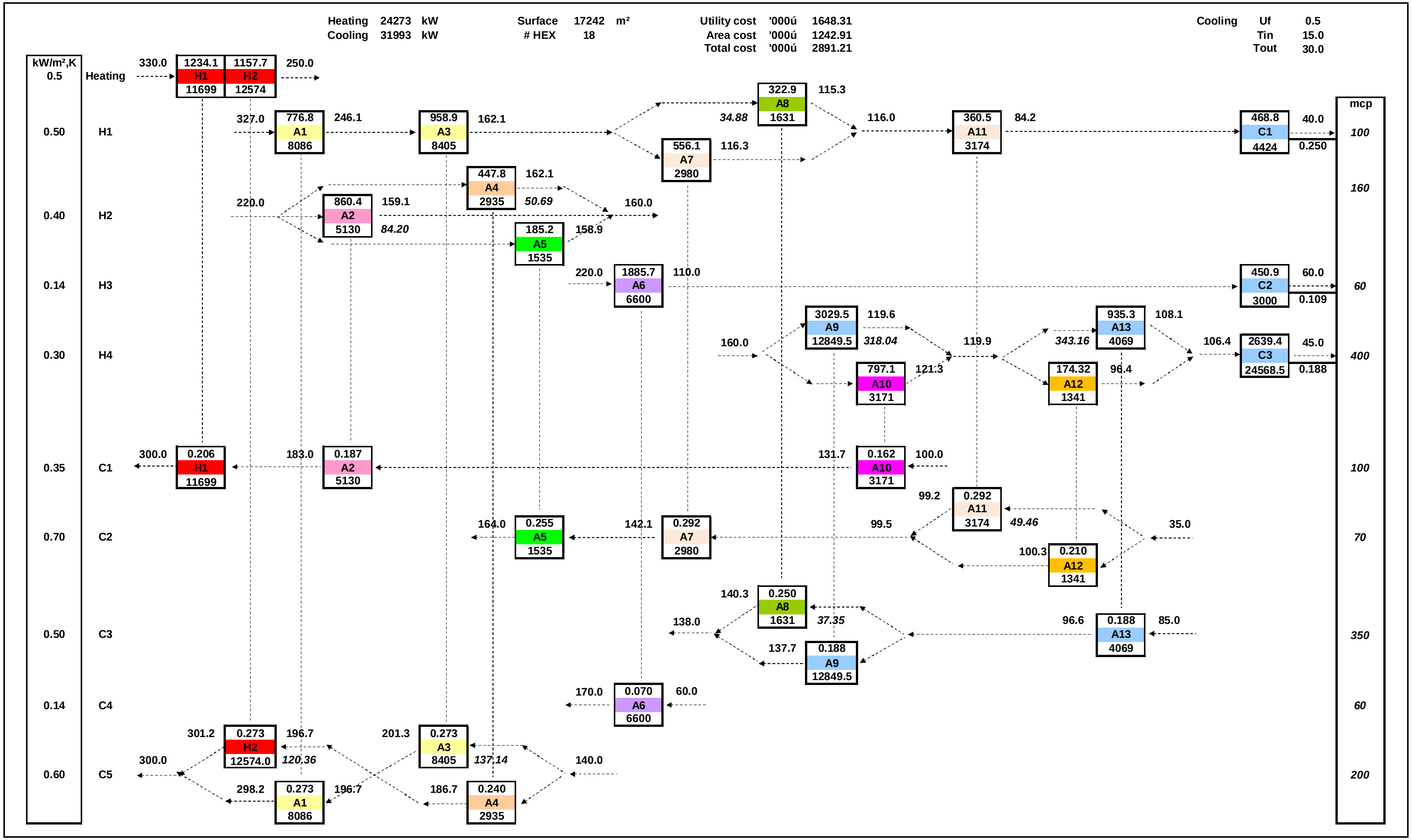

Heating 24273 kW
Cooling 31993 kW
Surface 17242 m²
HEX 18
Utility cost '000ú 1648.31
Area cost '000ú 1242.91
Total cost '000ú 2891.21
Cooling Uf 0.5
Tin 15.0
Tout 30.0
kW/m²,K
mcp
Heating
H1
H2
H3
H4
C1
C2
C3
C4
C5

Fig.4.2

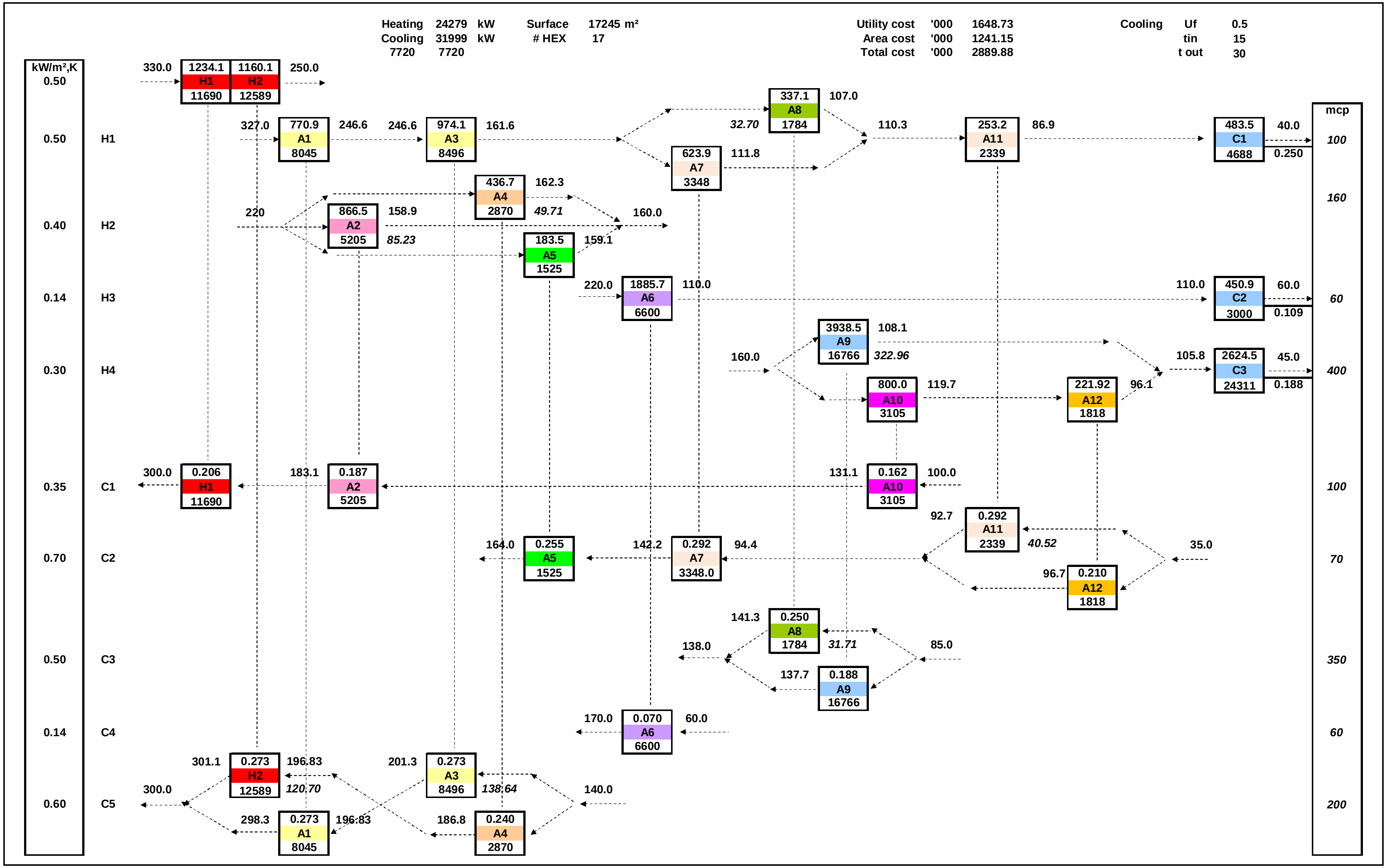

Heating 24279 kW
Cooling 31999 kW
7720 7720
Surface 17245 m²
HEX 17
Utility cost '000 1648.73
Area cost '000 1241.15
Total cost '000 2889.88
Cooling Uf 0.5
tin 15
t out 30
kW/m²,K
mcp
H1
H2
H3
H4
C1
C2
C3
C4
C5
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
C1
C2
C3

Fig.4.3

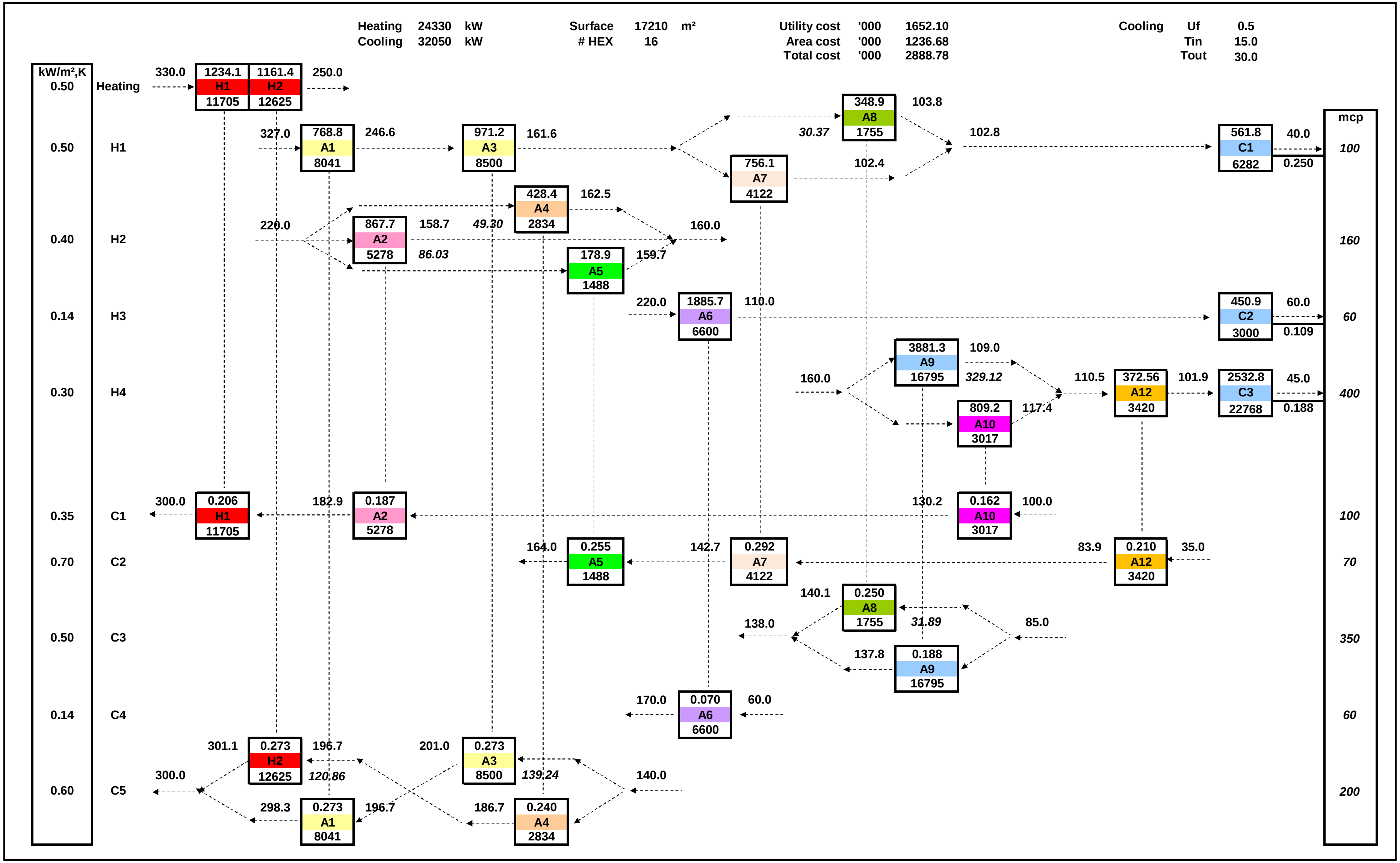
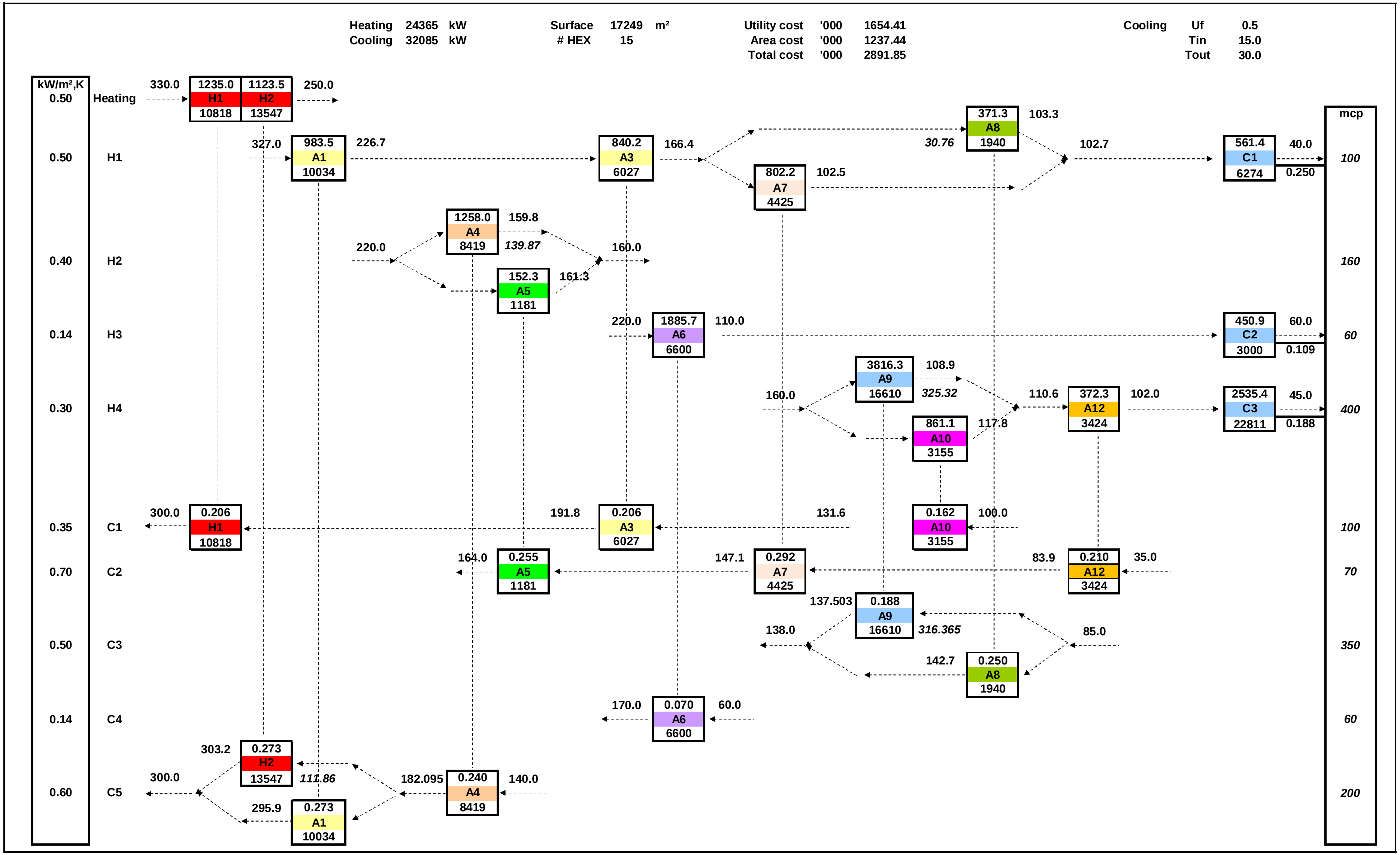

Heating 24330 kW
Cooling 32050 kW
Surface 17210 m²
HEX 16
Utility cost '000 1652.10
Area cost '000 1236.68
Total cost '000 2888.78
Cooling Uf 0.5
Tin 15.0
Tout 30.0
kW/m²,K
mcp
Heating
H1
H2
H3
H4
C1
C2
C3
C4
C5

Fig.4.4



Heating 24365 kW
Cooling 32085 kW
Surface 17249 m²
HEX 15
Utility cost '000 1654.41
Area cost '000 1237.44
Total cost '000 2891.85
Cooling Uf 0.5
Tin 15.0
Tout 30.0
kW/m²,K
Heating
H1
H2
H3
H4
C1
C2
C3
C4
C5
mcp

Fig.4.5

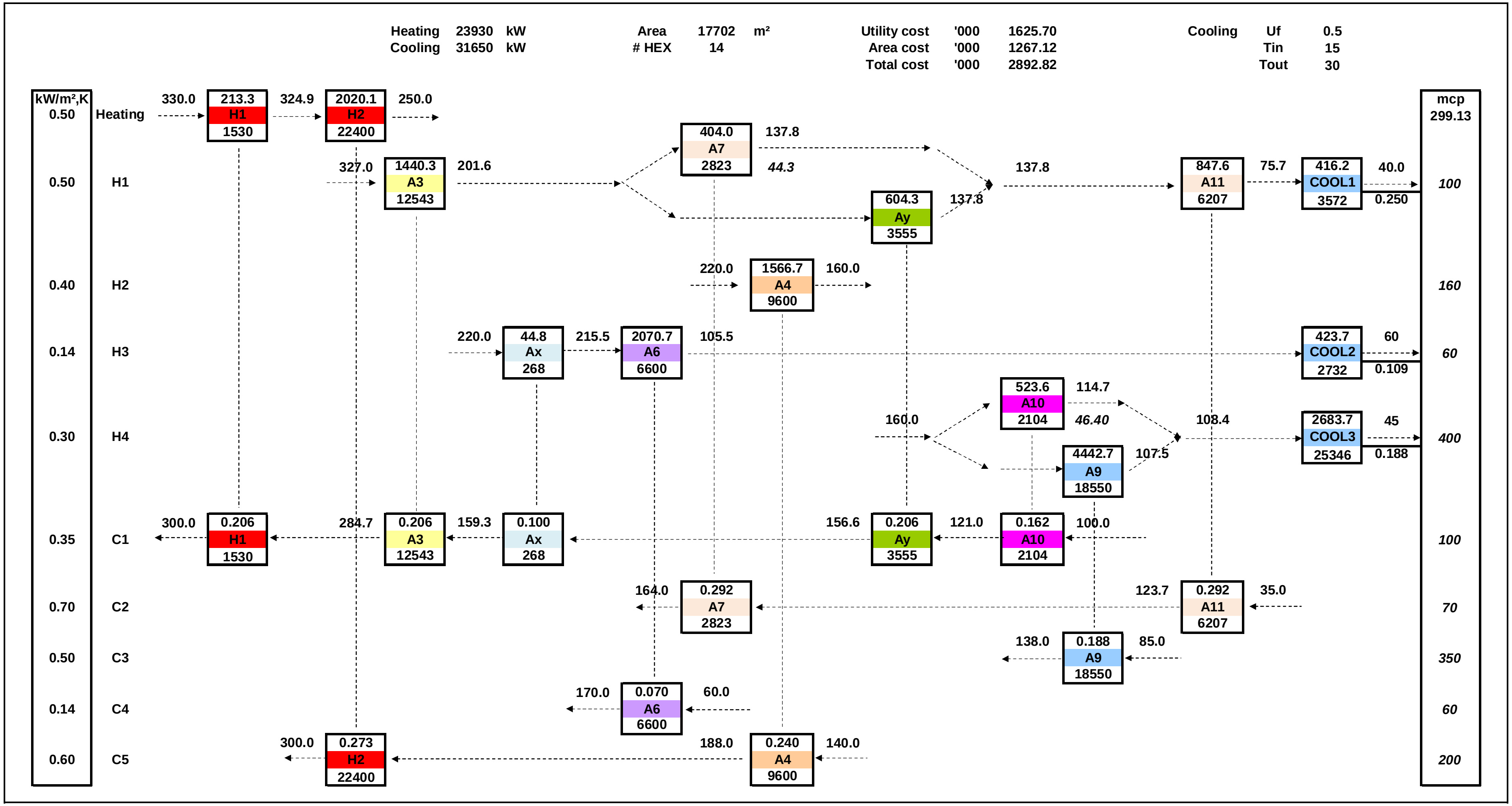

Heating 23930 kW
Cooling 31650 kW
Area 17702 m²
HEX 14
Utility cost '000 1625.70
Area cost '000 1267.12
Total cost '000 2892.82
Cooling Uf 0.5
Tin 15
Tout 30
kW/m²,K
mcp
299.13
Heating
H1
H2
H3
H4
C1
C2
C3
C4
C5
H1
H2
A3
A7
Ay
A4
Ax
A6
A10
A9
A11
COOL1
COOL2
COOL3

Fig.4.6

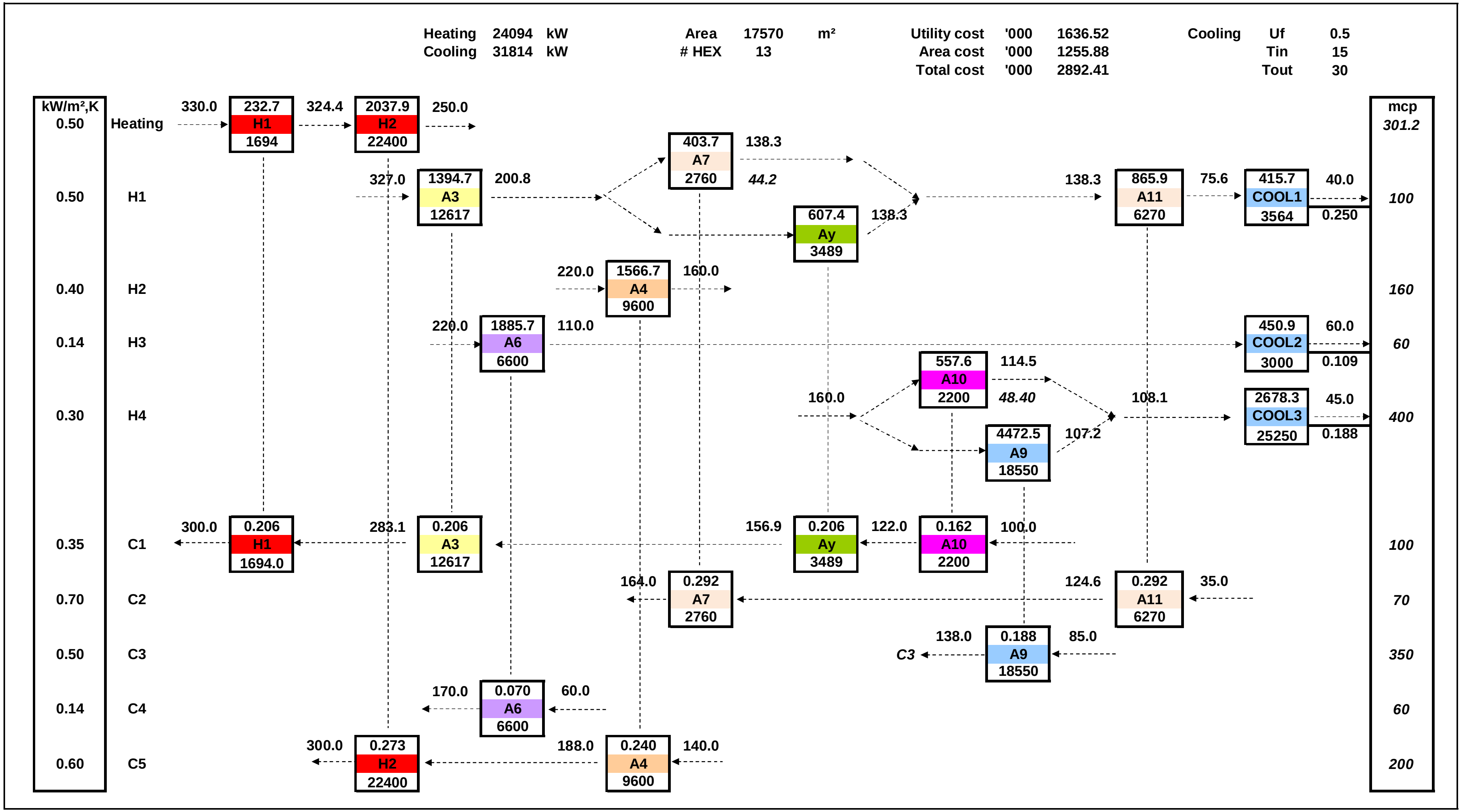

Heating 24094 kW
Cooling 31814 kW
Area 17570 m²
HEX 13
Utility cost '000 1636.52
Area cost '000 1255.88
Total cost '000 2892.41
Cooling Uf 0.5
Tin 15
Tout 30
kW/m²,K
mcp
301.2
0.50 Heating
0.50 H1
0.40 H2
0.14 H3
0.30 H4
0.35 C1
0.70 C2
0.50 C3
0.14 C4
0.60 C5
100
160
60
400
100
70
350
60
200
330.0
232.7 H1 1694
324.4
2037.9 H2 22400
250.0
403.7 A7 2760
138.3
44.2
327.0
1394.7 A3 12617
200.8
607.4 Ay 3489
138.3
138.3
865.9 A11 6270
75.6
415.7 COOL1 3564
40.0
0.250
220.0
1566.7 A4 9600
160.0
220.0
1885.7 A6 6600
110.0
450.9 COOL2 3000
60.0
0.109
557.6 A10 2200
114.5
48.40
160.0
108.1
2678.3 COOL3 25250
45.0
0.188
4472.5 A9 18550
107.2
300.0
0.206 H1 1694.0
283.1
0.206 A3 12617
156.9
0.206 Ay 3489
122.0
0.162 A10 2200
100.0
164.0
0.292 A7 2760
124.6
0.292 A11 6270
35.0
138.0
C3
0.188 A9 18550
85.0
170.0
0.070 A6 6600
60.0
300.0
0.273 H2 22400
188.0
0.240 A4 9600
140.0

Fig.4.7

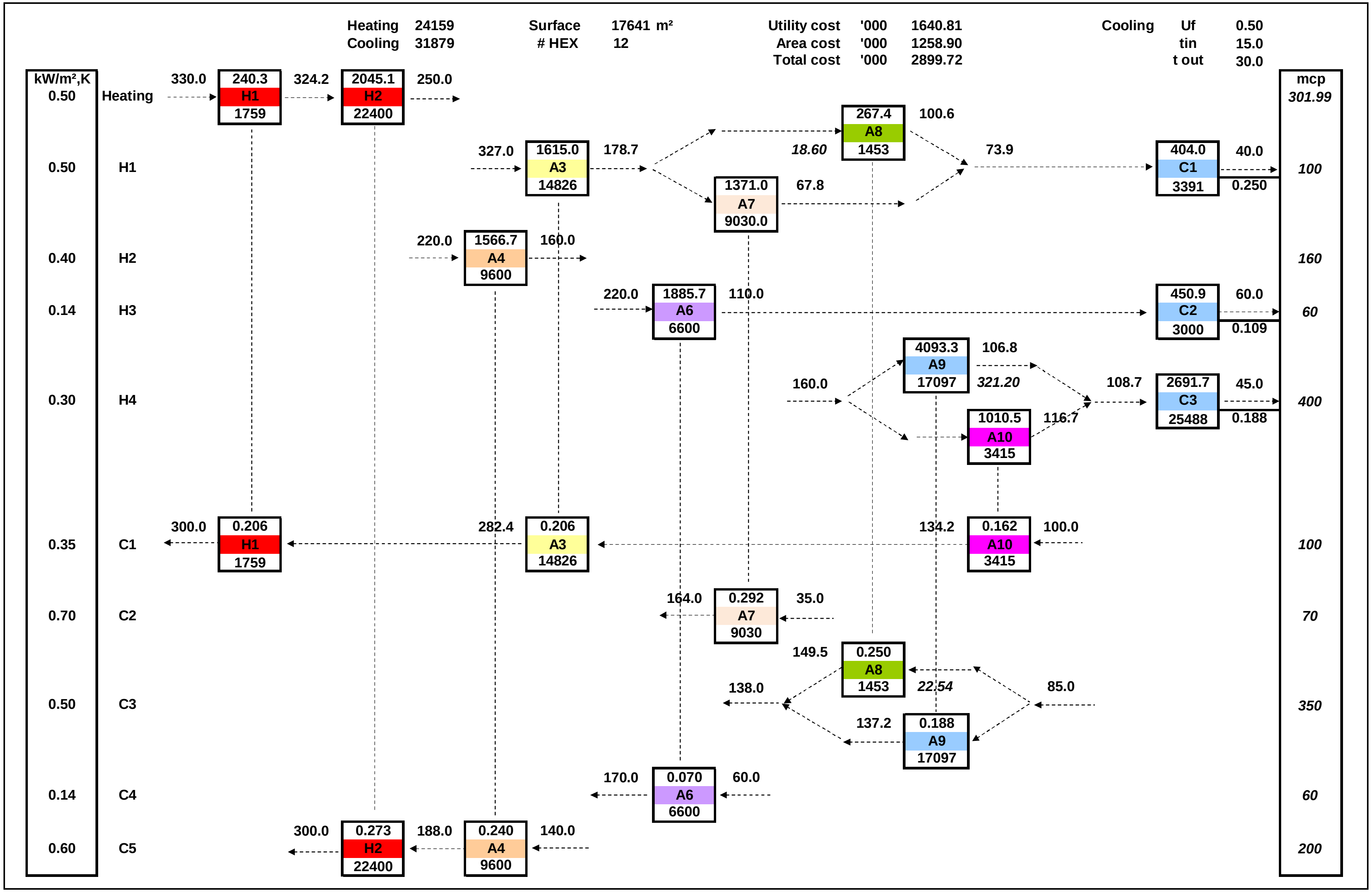

Heating 24159
Cooling 31879
Surface 17641 m²
HEX 12
Utility cost '000 1640.81
Area cost '000 1258.90
Total cost '000 2899.72
Cooling Uf 0.50
tin 15.0
t out 30.0
kW/m²,K
mcp
301.99
Heating
H1
H2
H3
H4
C1
C2
C3
C4
C5
A3
A4
A6
A7
A8
A9
A10
H1
H2
C1
C2
C3

Fig.4.8

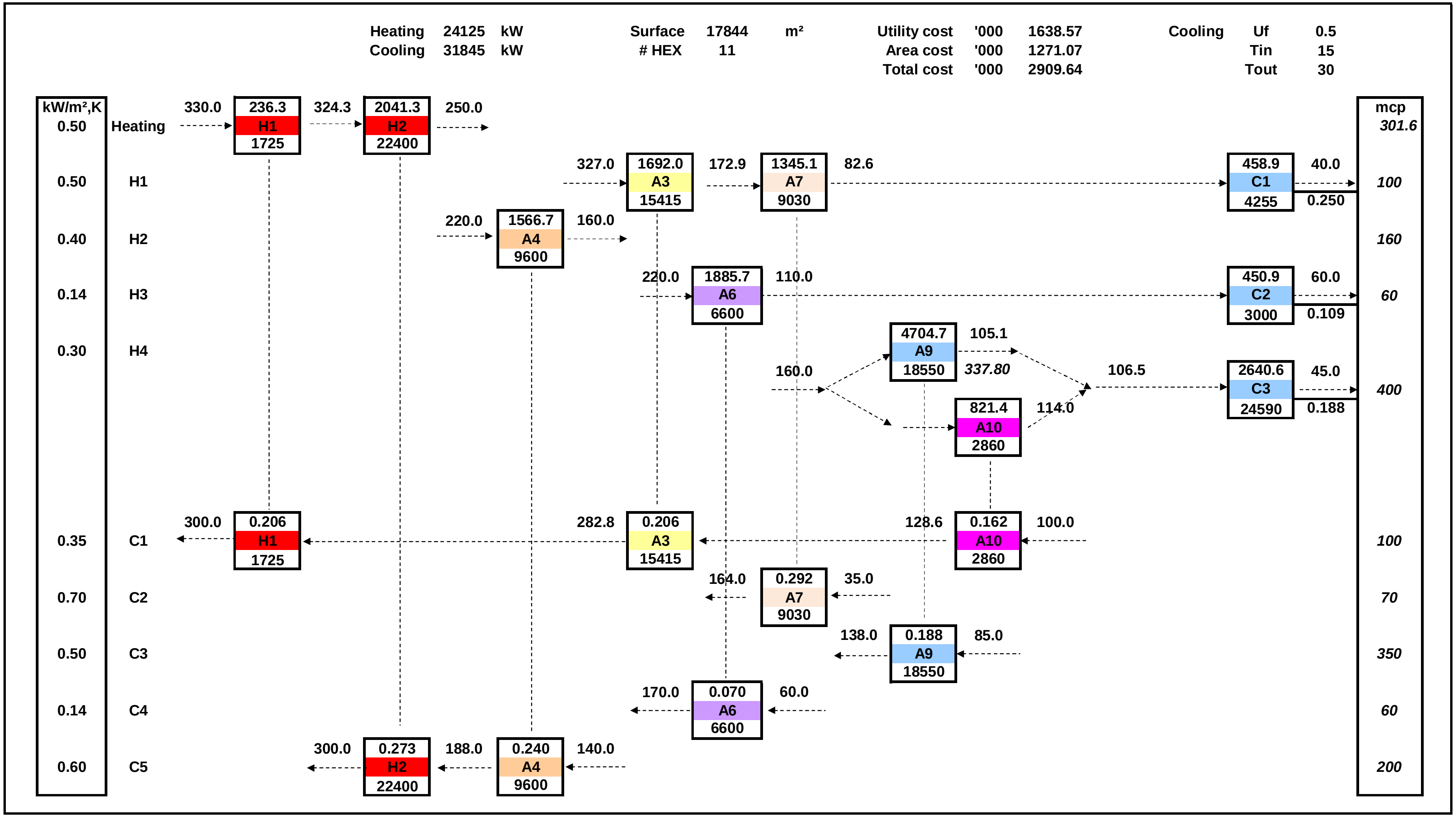
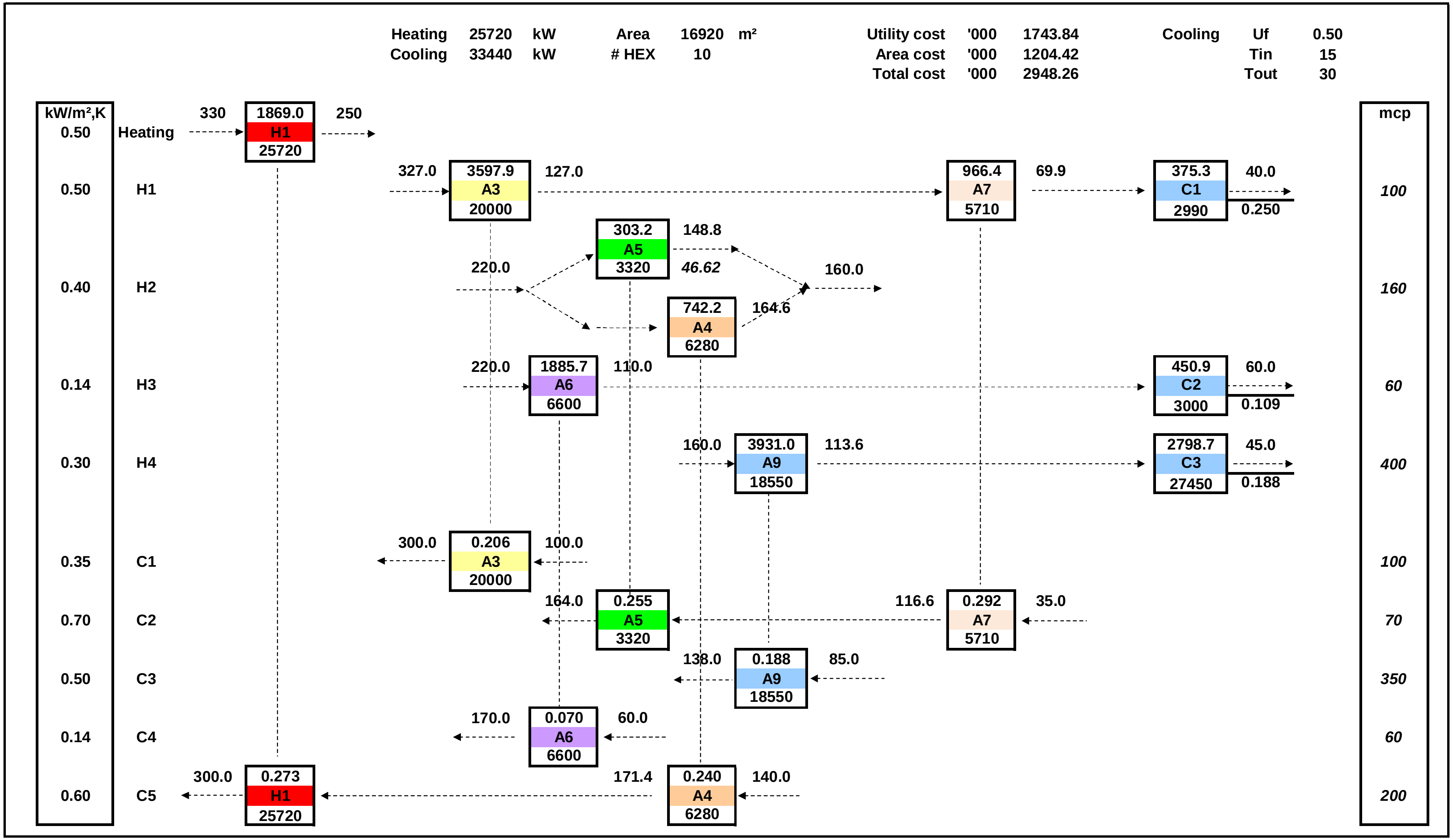

Heating 24125 kW
Cooling 31845 kW
Surface 17844 m²
HEX 11
Utility cost '000 1638.57
Area cost '000 1271.07
Total cost '000 2909.64
Cooling Uf 0.5
Tin 15
Tout 30
kW/m²,K
mcp
Heating
H1
H2
H3
H4
C1
C2
C3
C4
C5

Fig.4.9



Heating 25720 kW
Cooling 33440 kW
Area 16920 m²
HEX 10
Utility cost '000 1743.84
Area cost '000 1204.42
Total cost '000 2948.26
Cooling Uf 0.50
Tin 15
Tout 30
kW/m²,K
mcp
0.50 Heating 330 1869.0 H1 25720 250
0.50 H1 327.0 3597.9 A3 20000 127.0 966.4 A7 5710 69.9 375.3 C1 2990 40.0 0.250 100
0.40 H2 220.0 303.2 A5 3320 148.8 46.62 742.2 A4 6280 164.6 160.0 160
0.14 H3 220.0 1885.7 A6 6600 110.0 450.9 C2 3000 60.0 0.109 60
0.30 H4 160.0 3931.0 A9 18550 113.6 2798.7 C3 27450 45.0 0.188 400
0.35 C1 300.0 0.206 A3 20000 100.0 100
0.70 C2 164.0 0.255 A5 3320 116.6 0.292 A7 5710 35.0 70
0.50 C3 138.0 0.188 A9 18550 85.0 350
0.14 C4 170.0 0.070 A6 6600 60.0 60
0.60 C5 300.0 0.273 H1 25720 171.4 0.240 A4 6280 140.0 200

Fig.4.10

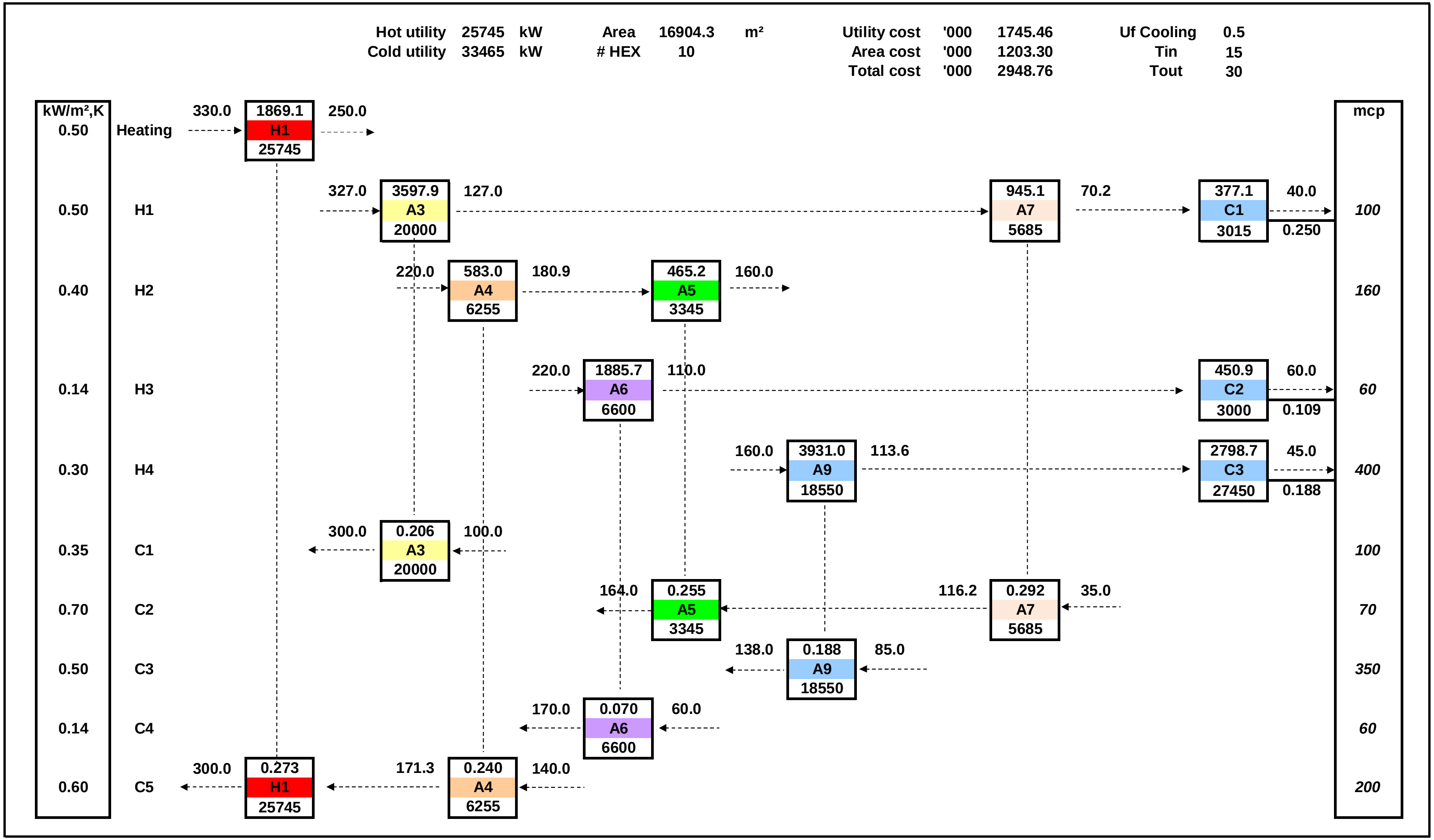

Hot utility 25745 kW
Cold utility 33465 kW
Area 16904.3 m²
HEX 10
Utility cost '000 1745.46
Area cost '000 1203.30
Total cost '000 2948.76
Uf Cooling 0.5
Tin 15
Tout 30
kW/m²,K
mcp
Heating
H1
H2
H3
H4
C1
C2
C3
C4
C5
A3
A4
A5
A6
A7
A9
C1
C2
C3

Fig.4.11