| | H1 | H2 | H3 | | C1 | C2 | C3 |
|---|---|---|---|---|---|---|---|
| Fcp[kW/C] | 2.29 | 0.42 | 0.54 | Fcp[kW/C] | 0.93 | 1.56 | 0.45 |
| Tin[C] | 159 | 267 | 340 | Tin[C] | 26 | 100 | 60 |
| Tout[C] | 25 | 79 | 90 | Tout[C] | 148 | 260 | 178 |

**1. Build the grand composite curve, and**

**Use HRAT = 10 C**

The prime of hot and cold lines:

| | H1 | H2 | H3 | C1 | C2 | C3 |
|---|---|---|---|---|---|---|
| Fcp[kW/C] | 2.29 | 0.42 | 0.54 | 0.93 | 1.56 | 0.45 |
| 340 | | | \| | | | |
| 267 | | \| | \| | | | |
| 260 | | \| | \| | | \| | |
| 178 | | \| | \| | | \| | \| |
| 159 | \| | \| | \| | | \| | \| |
| 148 | \| | \| | \| | \| | \| | \| |
| 100 | \| | \| | \| | \| | \| | \| |
| 90 | \| | \| | \| | \| | | \| |
| 79 | \| | \| | | \| | | \| |
| 60 | \| | | | \| | | \| |
| 26 | \| | | | \| | | |
| 25 | \| | | | | | |

Move the cold lines up 10 C without moving the hot lines :

| | H1 | H2 | H3 | C1 | C2 | C3 |
|---|---|---|---|---|---|---|
| Fcp[kW/C] | 2.29 | 0.42 | 0.54 | 0.93 | 1.56 | 0.45 |
| 340 | | | \| | | | |
| 270 | | | \| | | \| | |
| 267 | | \| | \| | | \| | |
| 188 | | \| | \| | | \| | \| |
| 159 | \| | \| | \| | | \| | \| |
| 158 | \| | \| | \| | \| | \| | \| |
| 110 | \| | \| | \| | \| | \| | \| |
| 90 | \| | \| | \| | \| | | \| |
| 79 | \| | \| | | \| | | \| |
| 70 | \| | | | \| | | \| |
| 36 | \| | | | \| | | |
| 25 | \| | | | | | |

Build a Pinch Tableau below with cold lines plus 5 C and hot lines minus 5 C:

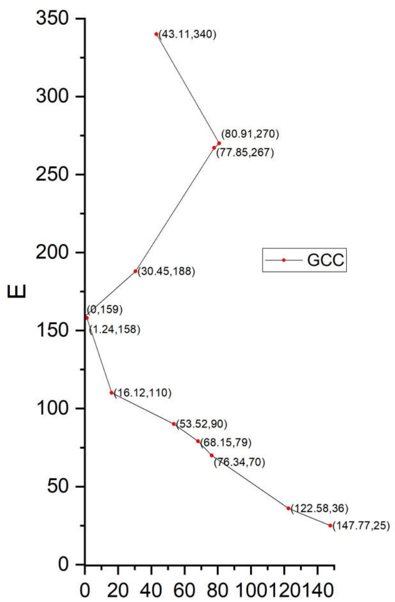
| Tcut | Tstart | Tend | Fcp | | dH | | cascade | cascade updated |
|---|---|---|---|---|---|---|---|---|
| 340 | 340 | 270 | 0.54 | H3 | 37.8 | s | 37.8 | 80.91 |
| 270 | 270 | 267 | -1.02 | H3-C2 | -3.06 | d | 34.74 | 77.85 |
| 267 | 267 | 188 | -0.6 | H2+H3-C2 | -47.4 | d | -12.66 | 30.45 |
| 188 | 188 | 159 | -1.05 | H2+H3-C2-C3 | -30.45 | d | -43.11 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 159 | 159 | 158 | 1.24 | H1+H2+H3-C2-C3 | 1.24 | s | -41.87 | 1.24 |
| 158 | 158 | 110 | 0.31 | H1+H2+H3-C1-C2-C3 | 14.88 | s | -26.99 | 16.12 |
| 110 | 110 | 90 | 1.87 | H1+H2+H3-C1-C3 | 37.4 | s | 10.41 | 53.52 |
| 90 | 90 | 79 | 1.33 | H1+H2-C1-C3 | 14.63 | s | 25.04 | 68.15 |
| 79 | 79 | 70 | 0.91 | H1-C1-C3 | 8.19 | s | 33.23 | 76.34 |
| 70 | 70 | 36 | 1.36 | H1-C1 | 46.24 | s | 79.47 | 122.58 |
| 36 | 36 | 25 | 2.29 | H1 | 25.19 | s | 104.66 | 147.77 |
| 25 | | | | | | | | |

d:deficit ; s:surplus

Then we use the last line and the first line to build the grand composite curve, mind that the data in the two lines are mismatched, with the first temperature ( T = 340 C ) matched the $\Delta H$ =(-43.11)*(-1)=43.11 kW

| T | $\Delta H$ |
|---|---|
| 340 | 43.11 |
| 270 | 80.91 |
| 267 | 77.85 |
| 188 | 30.45 |
| 159 | 0 |
| 158 | 1.24 |
| 110 | 16.12 |
| 90 | 53.52 |
| 79 | 68.15 |
| 70 | 76.34 |
| 36 | 122.58 |
| 25 | 147.77 |

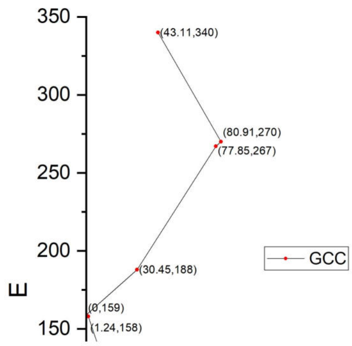



**a) Maximize low price steam usage. Consider steam at 3 pressures (20, 250 and 600 psia or higher if needed).**

For the GCC line above the pinch temperature(average pinch T = 154 C), the total heating utility can be got from the curve on the right. $Q_H$ = 43.11-0 kW = 43.11 kW. $T_{Hmax}$ =209.1 C. $T_{hot\ pinch}$ = 154 C.

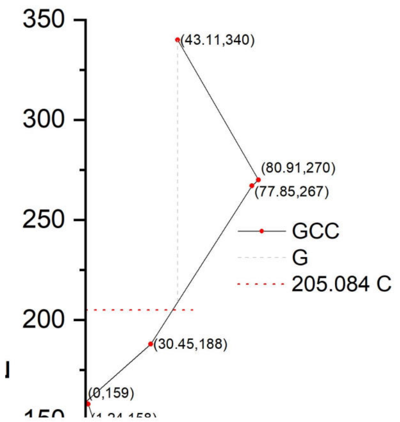
$T_{Hmax}$ : The highest temperature of the heat flux that has to participate in external heat transfer.

For steams at 3 pressures at 20, 250 and 600 psia, we can easily get the corresponding temperature from Aspen Plus:




| psia | kPa | C |
|---|---|---|
| 20 | 137.8952 | 108.895 |
| 250 | 1723.69 | 205.084 |
| 600 | 4136.856 | 252.471 |

It can be easily found that the steam of 20 psia cannot be used for the heating because its temperature is lower than $T_{hot\ pinch}$. As to the steams of 250 psia and 600 psia, both of the corresponding temperature is higher than the $T_{hot\ pinch}$ , but $T_{Hmax}$ is higher than 205.084 C, the temperature of 250 psia steam, but lower than 252.471 C, the temperature of 600 psia steam.
So for the task to "maximize low price steam usage", we have to use both the steams of 250 psia and 600 psia by dividing the heating line into 2 parts at the T = 205.084 C, because the lower the steam pressure is, the cheaper it is.

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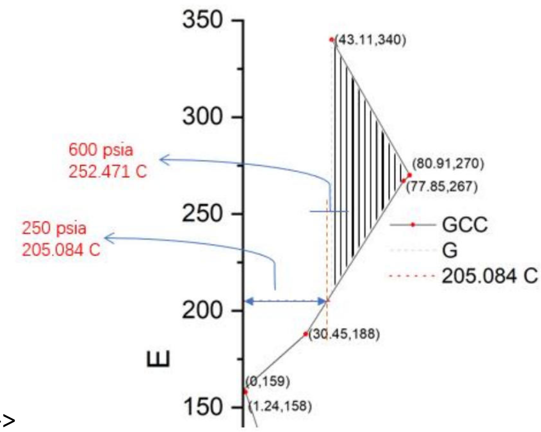
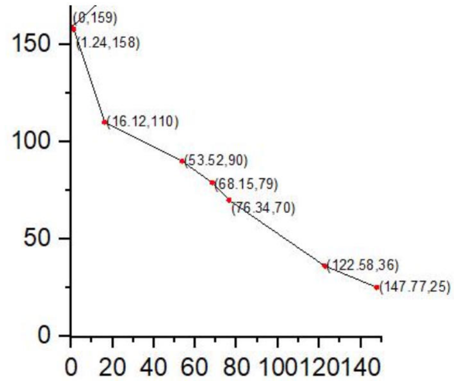



**b) Minimum Water usage (Water provided at 15 ℃)**

For the GCC line below the pinch temperature(hot pinch T = 159 C), the total cooling utility can be got from the curve on the right. $Q_C$ = 147.77-0 kW = 147.77 kW. $T_{Cmin}$ =25 C. $T_{hot\ pinch}$ = 154 C.

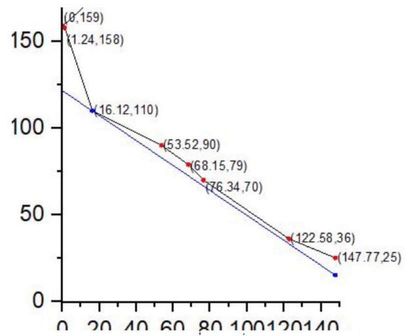



$T_{Cmin}$ : The lowest temperature of the cooling flux that has to participate in external heat transfer, which must be higher than or equal to the temperature of cooling water.

The cooling water has a lower temperature (T = 15 C) than $T_{Cmin}$ , meet the requirement.

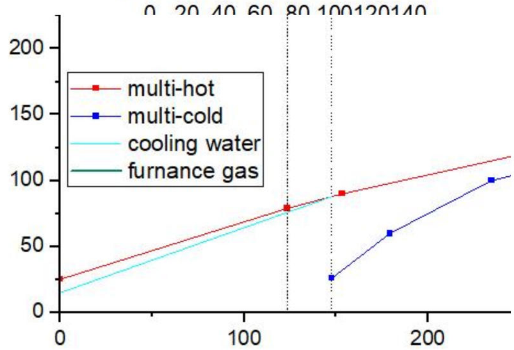
So we can get three highest ending temperature of CW respectively from GCC, CC and experience.

From GCC, we try to draw a line that is exactly tangent to the cold flow line with a start T = 15 C.




We can get the absolute value of slope $k1 = \frac{110-15}{147.77-16.12} = 0.722\ \frac{K}{kW}$ , and the CW highest T is T1 = 121.6 C.

From CC, we try to draw a line that intersects exactly the point at the multi-hot line's highest T which has an external heat exchanging. Then there is another largest absolute value of slope $k2 = \frac{87.9-15}{147.77-0} = 0.493\ \frac{K}{kW}$ , and the CW highest T is T2 = 87.9 C.



From experience, the cooling water has to be below 45 C, which is a extra limitation of the CW highest T. Then we get T3 = 45 C.

As to meet all requirement from the three situations, we final choose the T3 = 45 C.

So the final slope used to get minimum CW flowrate is $k3 = \frac{45-15}{147.77-0} = 0.203\ \frac{\mathrm{K}}{\mathrm{kW}}$ .

Then we get the minimum CW flowrate $F = \frac{1}{k3\times cp} = \frac{1}{0.203\times 4.187}\ \frac{\mathrm{kW}}{\mathrm{K}\times \mathrm{kJ}/(\mathrm{kg}\times \mathrm{K})} = 1.176\ \mathrm{kg/s}$

**c) Fired Heater energy consumption and maximum efficiency.**

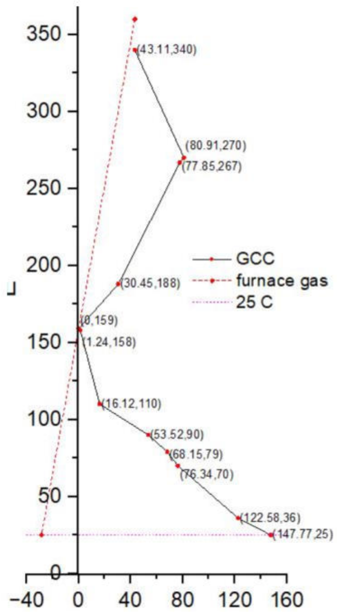
As we are not given the detail information of the furnace gas, which means we can never get the accurate data of $T_{FZ}$ without assuming something, so let's just choose a suitable entrance temperature of furnace gas.

From GCC, we get the lowest entrance temperature of furnace gas is T = 340 C. Let us pick an entrance T = 360 C.

So heat transferred to fluid is $Q_T = Q_H$ = 43.11-0 kW = 43.11 kW.

With the ambient T = 25 C, we get the smallest stack loss at picked $T_{FZ}$ , $Q_L = \frac{43.11-0}{340-159} \times (159-25)$ kW = 28.74 kW.

So the total consumption of fired heater energy is $Q_{Total} = Q_T + Q_L$ = 43.11+28.74 kW = 71.85 kW, and maximum efficiency $E\% = Q_T / Q_{Total}$ *100% = 60%




**2. Perform Supertargeting**

Use U=0.1kW/(m²℃)

Cost of Energy : $C_E = c_Q Qh_{min}$ $c_Q$=30 RMB/MMBTU

Cost of cooling Water : $C_{cw} = c_w Qc_{min}$ $c_w$=20 RMB/1000 Gallons

Cost of Capital: $C_{ca} = N_{min}[c_f + d(A_{min})^e]$ $c_f$=120000RMB d=3500RMB e=0.5

Total Annualized Cost: $TAC = C_{ca}/n + C_E + C_{cw}$ n=10 years

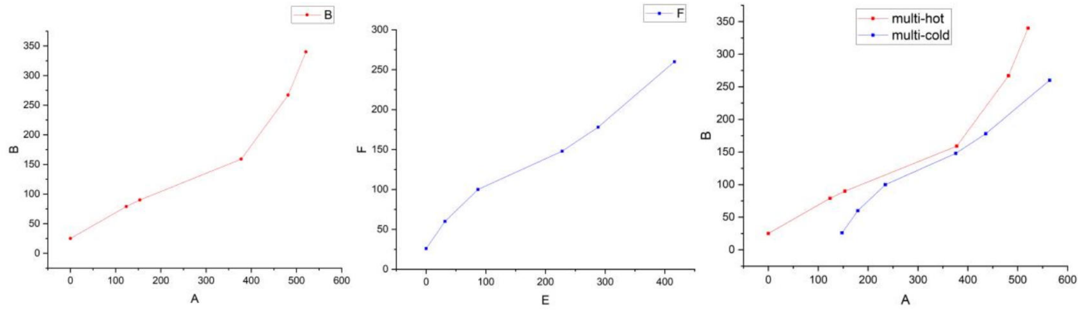
Use HRAT from 10 C to 45 C.

**0)build the hot and cold composite curves**

| | Tcut | Tstart | Tend | Fcp | dH | cascade | | X | Y |
|---|---|---|---|---|---|---|---|---|---|
| | 340 | 340 | 267 | 0.54 | 39.42 | 520.82 | | 520.82 | 340 |
| | 267 | 267 | 159 | 0.96 | 103.68 | 481.4 | | 481.4 | 267 |
| hot | 159 | 159 | 90 | 3.25 | 224.25 | 377.72 | -> | 377.72 | 159 |
| | 90 | 90 | 79 | 2.71 | 29.81 | 153.47 | | 153.47 | 90 |
| | 79 | 79 | 25 | 2.29 | 123.66 | 123.66 | | 123.66 | 79 |
| | 25 | | | | | | | 0 | 25 |
| | 260 | 260 | 178 | 1.56 | 127.92 | 416.16 | | 416.16 | 260 |
| | 178 | 178 | 148 | 2.01 | 60.3 | 288.24 | | 288.24 | 178 |
| cold | 148 | 148 | 100 | 2.94 | 141.12 | 227.94 | -> | 227.94 | 148 |
| | 100 | 100 | 60 | 1.38 | 55.2 | 86.82 | | 86.82 | 100 |
| | 60 | 60 | 26 | 0.93 | 31.62 | 31.62 | | 31.62 | 60 |

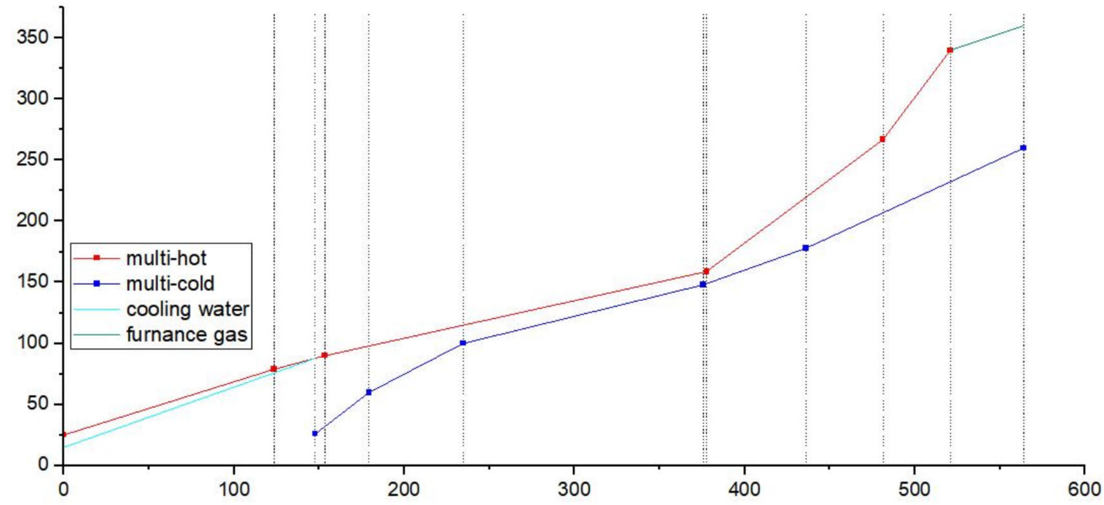
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 26 | | | | | | | 0 | 26 |

As to HRAT = 10 C, we already get the value =147.77 kW which is added to the multi-cold line from 1.a.




a)Taking the case of HRAT=10 C as an example to carry out specific calculations.

Let us assume that the CW line has a ending temperature of 45 C(the ending T is obtained by 1.b. ) and the furnace gas line has a ending temperature of 340 C. (We have already assumed the furnace gas T at entrance is 360 C in 1.c. )




| interval | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q point | 0 | 123.7 | 147.8 | 153.5 | 179.4 | 234.6 | 375.7 | 377.7 | 436.0 | 481.4 | 520.8 | 563.9 |
| dQ | | 123.7 | 24.1 | 5.7 | 25.9 | 55.2 | 141.1 | 2.0 | 58.3 | 45.4 | 39.4 | 43.1 |
| T of H | 25.0 | 79.0 | 87.9 | 90.0 | 98.0 | 115.0 | 158.4 | 159.0 | 219.7 | 267.0 | 340.0 | |
| T of C | | | 26.0 | 32.1 | 60.0 | 100.0 | 148.0 | 149.0 | 178.0 | 207.1 | 232.4 | 260.0 |

| interval | Q | $T_{H1}$ | $T_{H2}$ | $T_{C1}$ | $T_{C2}$ | $dT_{min}$ | A |
|---|---|---|---|---|---|---|---|
| 1 | 123.66 | 79.00 | 25.00 | 15.00 | 40.10 | 21.27 | 58.13 |
| 2 | 24.11 | 87.90 | 79.00 | 40.10 | 45.00 | 40.86 | 5.90 |
| 3 | 5.7 | 90.00 | 87.90 | 26.00 | 32.13 | 59.86 | 0.95 |
| 4 | 25.92 | 97.98 | 90.00 | 32.13 | 60.00 | 47.23 | 5.49 |
| 5 | 55.2 | 114.96 | 97.98 | 60.00 | 100.00 | 24.71 | 22.34 |
| 6 | 141.12 | 158.38 | 114.96 | 100.00 | 148.00 | 12.53 | 112.61 |
| 7 | 2.01 | 159.00 | 158.38 | 148.00 | 149.00 | 10.19 | 1.97 |
| 8 | 58.29 | 219.72 | 159.00 | 149.00 | 178.00 | 22.21 | 26.25 |
| 9 | 45.39 | 267.00 | 219.72 | 178.00 | 207.10 | 50.26 | 9.03 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10 | 39.42 | 340.00 | 267.00 | 207.10 | 232.37 | 81.45 | 4.84 |
| 11 | 43.11 | 360.00 | 340.00 | 232.37 | 260.00 | 103.77 | 4.15 |

Total Area = 251.67 $m^2$

from the figure on the right, we can get $N_{min}$ :

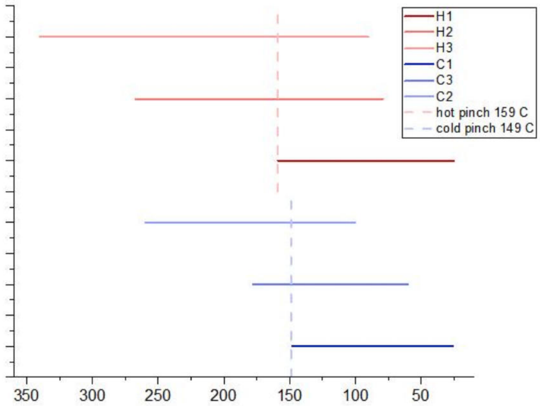
$(S\text{-}P)_{above\ pinch}$:

S=5(4 streams + 1 utility), P=1

$(S\text{-}P)_{below\ pinch}$:

S=7(6 streams + 1 utility), P=1

$N_{min} = (S\text{-}P)_{above\ pinch} + (S\text{-}P)_{below\ pinch} = (5-1)+(7-1)=10$




Cost of Utility :

$Qh_{min}$ = 43.11 kW = 4.09e-5 MMBTU/s          1 MMBTU=1054 MJ

$C_E = c_Q Qh_{min}$ = 30*4.09e-5 RMB/s = 1.23e-3 RMB/s       $c_Q$ = 30 RMB/MMBTU

$$F = \frac{Q}{cp \cdot \Delta T} = \frac{147.77}{4.187 \times (45-15)}\ kg/s = 1.176\ kg/s$$

$Qc_{min} = \frac{F}{\rho} = \frac{1.176}{998.95}\ m^3/s$ =1.178e-3 $m^3/s$ = 0.259 Gallon/s          1 Gallon = 4.546 L

$C_{cw} = c_w Qc_{min}$ =  20*0.259e-3 RMB/s =5.18e-3 RMB/s    $c_w$ = 20 RMB/1000 Gallons

$C_u = C_E + C_{cw}$ = 6.41e-3 RMB/s

Cost of Capital: $C_{ca} = N_{min}[c_f+d(A_{min})^e]$ =  10*(120000+3500*251.67^0.5) RMB = 1755243.51 RMB

$c_f$=120000RMB        d=3500RMB     e=0.5

Total Annualized Cost :

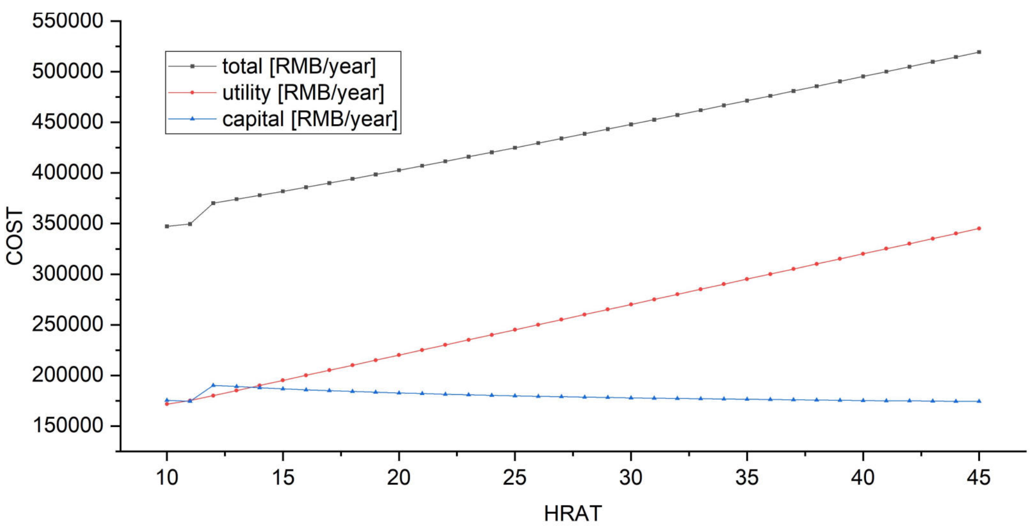
Assmue annualized working time is 310 days with 24 hr/day.

TAC = $C_{ca}/n+C_E+C_{cw}$ = 1755243.51/10+6.41e-3*310*24*3600 RMB =347163 RMB/year

n=10 years

b)calculate the $C_u$, $C_{ca}$, TAC at different HRAT and list the results in the table in the attached list of 2.c. Draw three lines of the $C_u$, $C_{ca}$, TAC with changing HRAT as the horizontal coordinate.

With HRAT changing continuously by 1 C, we will find at HRAT = 11 C and 12 C there is a change in the number of exchangers.



**In conclusion, finally we pick HRAT = 10 C as the result for supertargeting.**

c)the table metioned in 2.b.

And for convenience, I made an excel sheet to depart HRAT into different segments. I cut the HRAT into different intervals when the temperature turning points of the hot and cold fluid arrangement sequence changes.

| HRAT | TAC [ *e+5 ￥/year] | capital [*e+6 ￥/10 years] | utility [ *e+5 ￥/year] | A[$m^2$] | heating utility[kW] | cooling utility[kW] | Nmin | $C_{cw}$ [￥/s] | $C_E$ [￥/s] |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 3.47 | 1.76 | 1.72 | 251.67 | 43.11 | 147.77 | 10 | 5.18 | 1.23 |
| 11 | 3.50 | 1.74 | 1.75 | 242.33 | 45.12 | 149.78 | 10 | 5.25 | 1.28 |
| 12 | 3.70 | 1.90 | 1.80 | 227.33 | 48.06 | 152.72 | 11 | 5.35 | 1.37 |
| 13 | 3.74 | 1.89 | 1.85 | 219.95 | 51.0 | 155.66 | 11 | 5.46 | 1.45 |
| 14 | 3.78 | 1.88 | 1.90 | 210.84 | 53.94 | 158.6 | 11 | 5.56 | 1.54 |
| 15 | 3.82 | 1.87 | 1.95 | 202.78 | 56.88 | 161.54 | 11 | 5.66 | 1.62 |
| 16 | 3.86 | 1.86 | 2.00 | 195.59 | 59.82 | 164.48 | 11 | 5.77 | 1.70 |
| 17 | 3.90 | 1.85 | 2.05 | 189.14 | 62.76 | 167.42 | 11 | 5.87 | 1.79 |
| 18 | 3.94 | 1.84 | 2.10 | 183.32 | 65.7 | 170.36 | 11 | 5.97 | 1.87 |
| 19 | 3.98 | 1.83 | 2.15 | 178.05 | 68.64 | 173.3 | 11 | 6.08 | 1.95 |
| 20 | 4.03 | 1.83 | 2.20 | 173.25 | 71.58 | 176.24 | 11 | 6.18 | 2.04 |
| 21 | 4.07 | 1.82 | 2.25 | 168.86 | 74.52 | 179.18 | 11 | 6.28 | 2.12 |
| 22 | 4.12 | 1.81 | 2.30 | 164.84 | 77.46 | 182.12 | 11 | 6.39 | 2.21 |
| 23 | 4.16 | 1.81 | 2.35 | 161.13 | 80.4 | 185.06 | 11 | 6.49 | 2.29 |
| 24 | 4.20 | 1.80 | 2.40 | 157.72 | 83.34 | 188.0 | 11 | 6.59 | 2.37 |
| 25 | 4.25 | 1.80 | 2.45 | 154.56 | 86.28 | 190.94 | 11 | 6.69 | 2.46 |
| 26 | 4.30 | 1.79 | 2.50 | 151.63 | 89.22 | 193.88 | 11 | 6.80 | 2.54 |
| 27 | 4.34 | 1.79 | 2.55 | 148.91 | 92.16 | 196.82 | 11 | 6.90 | 2.62 |
| 28 | 4.39 | 1.79 | 2.60 | 146.37 | 95.1 | 199.76 | 11 | 7.00 | 2.71 |
| 29 | 4.43 | 1.78 | 2.65 | 144.01 | 98.04 | 202.7 | 11 | 7.11 | 2.79 |
| 30 | 4.48 | 1.78 | 2.70 | 141.80 | 100.98 | 205.64 | 11 | 7.21 | 2.87 |
| 31 | 4.53 | 1.78 | 2.75 | 139.73 | 103.92 | 208.58 | 11 | 7.31 | 2.96 |
| 32 | 4.57 | 1.77 | 2.80 | 137.79 | 106.86 | 211.52 | 11 | 7.42 | 3.04 |
| 33 | 4.62 | 1.77 | 2.85 | 135.96 | 109.8 | 214.46 | 11 | 7.52 | 3.13 |
| 34 | 4.67 | 1.77 | 2.90 | 134.25 | 112.74 | 217.4 | 11 | 7.62 | 3.21 |
| 35 | 4.71 | 1.76 | 2.95 | 132.64 | 115.68 | 220.34 | 11 | 7.73 | 3.29 |
| 36 | 4.76 | 1.76 | 3.00 | 131.12 | 118.62 | 223.28 | 11 | 7.83 | 3.38 |
| 37 | 4.81 | 1.76 | 3.05 | 129.69 | 121.56 | 226.22 | 11 | 7.93 | 3.46 |
| 38 | 4.86 | 1.76 | 3.10 | 128.34 | 124.5 | 229.16 | 11 | 8.03 | 3.54 |
| 39 | 4.91 | 1.75 | 3.15 | 127.06 | 127.44 | 232.1 | 11 | 8.14 | 3.63 |
| 40 | 4.95 | 1.75 | 3.20 | 125.85 | 130.38 | 235.04 | 11 | 8.24 | 3.71 |
| 41 | 5.00 | 1.75 | 3.25 | 124.71 | 133.32 | 237.98 | 11 | 8.34 | 3.80 |
| 42 | 5.05 | 1.75 | 3.30 | 123.62 | 136.26 | 240.92 | 11 | 8.45 | 3.88 |
| 43 | 5.10 | 1.75 | 3.35 | 122.60 | 139.2 | 243.86 | 11 | 8.55 | 3.96 |
| 44 | 5.15 | 1.74 | 3.40 | 121.62 | 142.14 | 246.8 | 11 | 8.65 | 4.05 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 45 | 5.19 | 1.74 | 3.45 | 120.70 | 145.08 | 249.74 | 11 | 8.76 | 4.13 |