Module-04 : **Targeting**

Lecture-11: **PROBLEM TABLE ALGORITHM-1st Part**

Key words: Problem Table Algorithm, shifted temperature, composite curve, PTA,

For a given ΔT_{min}, Composite curves can be used to obtain energy targets. However, this will require the use graph paper. If the number of streams is large then this method becomes tedious. Thus, even though composite curves are useful in providing conceptual understanding of the process one needs a convenient computation algorithm. Linhoff and Flower, 1978 developed such an algorithm known as Problem Table Algorithm (PTA) for calculating pinch temperature and energy targets. This algorithm can be solved using computer.

Temperature Shifted Composite curves

Composite curves can be used to estimate minimum amount of hot and cold utilities . However if the number of streams are large then it can't be called a convenient method. Thus a computer based method is necessary to tackle the above problem. To lay the foundation of such a method, let us examine what will happen if hot composite curve is moved vertically down by $\Delta T_{min}/2$ and the cold composite is raised vertically up by an amount $\Delta T_{min}/2$ as in Fig.4.5 . Dotted lines show the modified hot and cold composite curves. It can be seen that the modified composite curve meet at a point (pinch point) as expected. Further, the quantity of minimum hot and cold utility remains unchanged. As depicted in Fig.4.4 it is not possible to transfer heat in a temperature interval horizontally as the ΔT available is zero. However, as shown Fig.4.5 it is possible to transfer heat between shifted composite curves horizontally as the temperature difference in a temperature interval is ΔT_{min}. The actual temperature of the shifted hot composite at the red dot(in "B") is T_1 and that of the blue dot (in "B") is T1-ΔT_{min} and thus the temperature between these two dots which are in the same level of temperature (after shifting) is ΔT_{min}. This argument is valid for all temperature intervals and thus the horizontal heat transfer is possible in a temperature interval if the hot composite is shifted downward by an amount $\Delta T_{min}/2$ and cold composite is shifted vertically upward by an amount $\Delta T_{min}/2$.

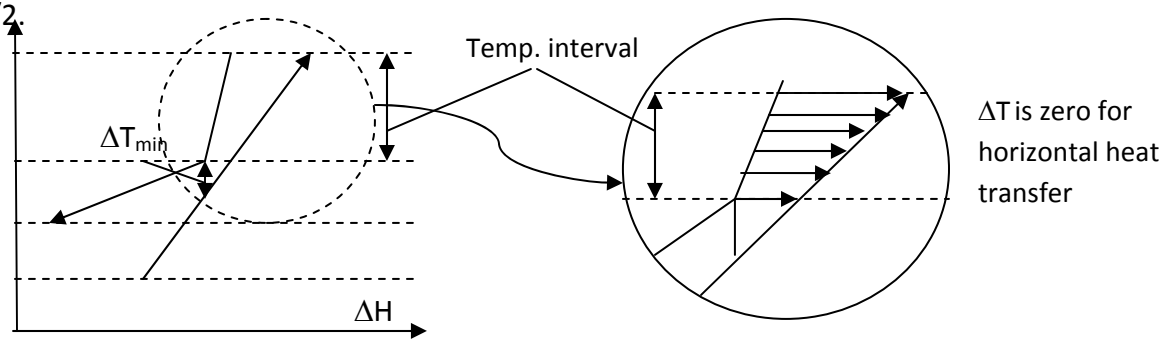


Fig.4.4 Horizontal heat transfer between hot composite and cold composite in above the pinch area

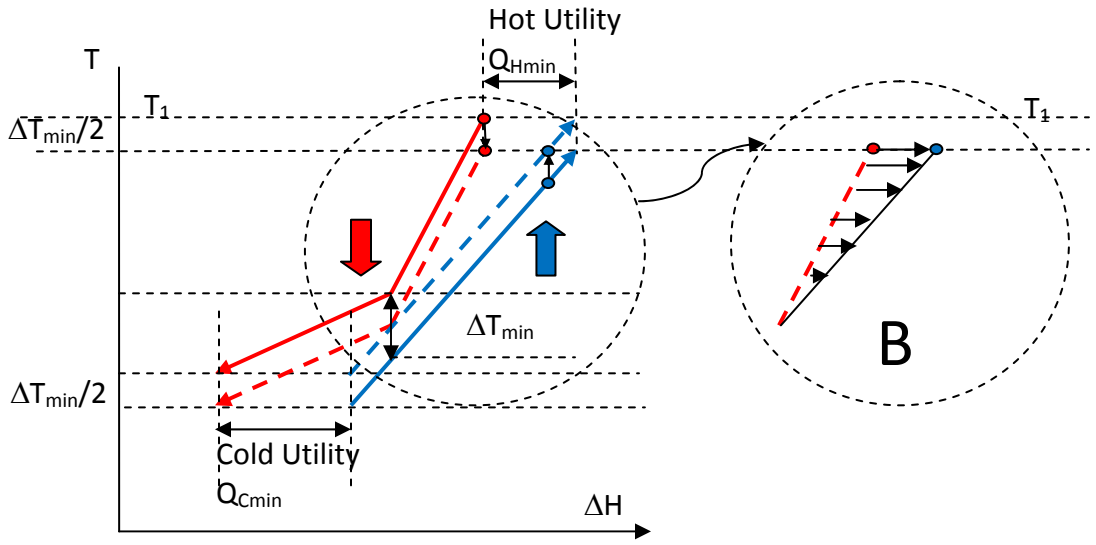


Fig. 4.5 Shifting of hot composite vertically down by $\Delta T_{min}/2$ and cold composite vertically up by $\Delta T_{min}/2$

Thus the shifting technique thus developed can be effectively used to develop a strategy to compute energy targets without constructing hot and cold composite curves.

For developing PTA, following steps are undertaken:

Step-1: Set up shifted temperature intervals using the stream supply and target temperatures by subtracting $\Delta T_{min}/2$ from hot streams and adding $\Delta T_{min}/2$ to the cold streams. The genesis of the above process is shown in Fig.4.5.

Step-2: In each shifted temperature interval, ΔT_i, compute an energy balance using Eq.4.2:

$$\Delta H_i = [\sum CP_C - \sum CP_H]_i \Delta T_i \qquad \ldots 4.2$$

Where ΔH_i is the heat balance for the temperature interval i and ΔT_i is the temperature difference in interval i. ΣCP_C and ΣCP_H are cumulative CP of all the cold streams present in the interval i and cumulative CP of all the hot streams present in this interval respectively. If the heat required by the cold streams in this interval is more than the heat available with hot streams then ΔH is positive which means that this temperature interval has heat deficiency. If the reverse is true then ΔH is negative meaning that heat is surplus in this temperature interval and can be transferred to a temperature interval which is lower in temperature than the present interval. The present sign convention is similar to the convention of thermodynamics. The heat

balance between each shifted temperature interval allows maximum heat recovery within the interval. However, heat recovery should also be allowed amongst temperature intervals keeping in mind that heat can flow from higher to lower temperature levels.

Step-3: Cascade any surplus heat available down the temperature scale from one interval to other. This is possible as any surplus heat available from hot streams in an interval is hot enough to be supplied to the next interval down where there is a heat deficit due to the heat requirement of cold streams. It should be remembered that heat can not be transferred up the temperature scale. During this process one can find that heat flows from some intervals are negative which shows an infeasible heat transfer. Thus to make the cascade feasible, sufficient heat must be transferred from hot utility down the cascade so that the values of heat flows at least become zero.

This basic approach can be developed into a algorithm know as Problem Table Algorithm (PTA). This algorithm and remaining steps of it is explained using an example.

For example, let us consider the four stream problem given below: -

Table 4.2 Four stream problem for PTA for ΔT_{min} equal to 10°C.

Stream Serial No.	Stream Type	CP (KW / K)	Actual Temperatures		Shifted Temperatures	
			T_s (^{0}C)	T_t (^{0}C)	T_s (^{0}C)	T_t (^{0}C)
1	Cold	2.25	20	135	25	140
2	Hot	3	170	60	165	55
3	Cold	4.25	80	140	85	145
4	Hot	2	150	30	145	25

Note: For shifted temperature deduct $\Delta T_{min}/2$ from both target and supply temperatures of hot stream and add $\Delta T_{min}/2$ to both target and supply temperatures of cold stream.

Table 4.2 shows a hot and cold stream with actual temperatures as well as the same with shifted temperatures.

Next, plot the streams in a schematic representation on a vertical temperature scale with interval boundaries superimposed (as shifted temperatures) and arrange shifted temperatures from maximum to minimum a shown in Fig.4.6.

The Fig.4.6 shows the schematic representation of above streams on a vertical temperature interval.

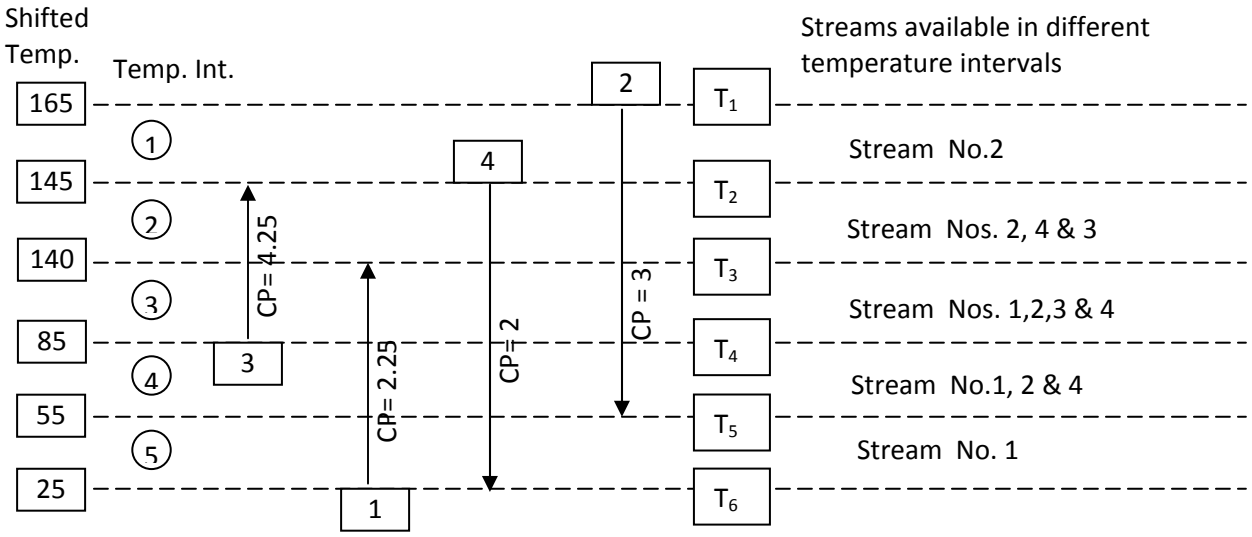


Fig.4.6 Schematic representation of stream population on a vertical temperature scale with interval boundaries superimposed

In the above diagram, in interval number 2, which is between shifted temperatures 145°C and 140°C, two hot streams, streams No. 2 & 4 are operating having actual temperature from 150°C to 145°C, and one cold stream, stream No. 3 having actual temperature from 135°C to 140°C is operating. It should be noted that the actual temperature difference between hot and cold stream is ΔT_{min} equal to 10°C. Thus, setting up of intervals in this way guarantees that full heat interchange (horizontally) within this interval is possible. This fact is also true for other temperature intervals. A heat balance in each interval shows that each interval will have either a net surplus or net deficit of heat as dictated by enthalpy balance, but never both. Knowing the stream population in each interval (from Fig.4.6), enthalpy balances can easily be calculated for each temperature interval using Eq. 4.3:

$$\Delta H_i = [\sum CP_C - \sum CP_H]_i \Delta T_i = (T_i - T_{i+1}) * [\sum CP_C - \sum CP_H]_i \quad \text{.... 4.3}$$

This equation is valid for any interval i. The computed heat balance in all the temperature intervals are shown in the Table 4.3, the last column of which indicates whether the interval is in heat surplus or heat deficit.

Table 4.3 Temperature interval heat balance

	Interval Number i	$T_i - T_{i+1}$	$\sum CP_C - \sum CP_H$ (kW / ^{0}C)	ΔH (kW)	Surplus or Deficit

T_1 = 165					
	1	165-145 = 20	0-3 = -3	-60	**Surplus**
T_2 = 145					
	2	145-140 = 5	4.25-2-3 = -0.75	-3.75	**Surplus**
T_3 = 140					
	3	140-85= 55	4.25+2.25-2-3 = 1.5	82.5	**Deficit**
T_4 = 85					
	4	85-55 = 30	2.25-2-3 = -2.75	-82.5	**Surplus**
T_5 =55					
	5	55-25 = 30	2.25-2 = 0.25	7.5	**Deficit**
T_6 = 25					

The temperature interval heat balance based on horizontal transfer of heat given in Table 4.3 is shown schematically in Fig.4.7.

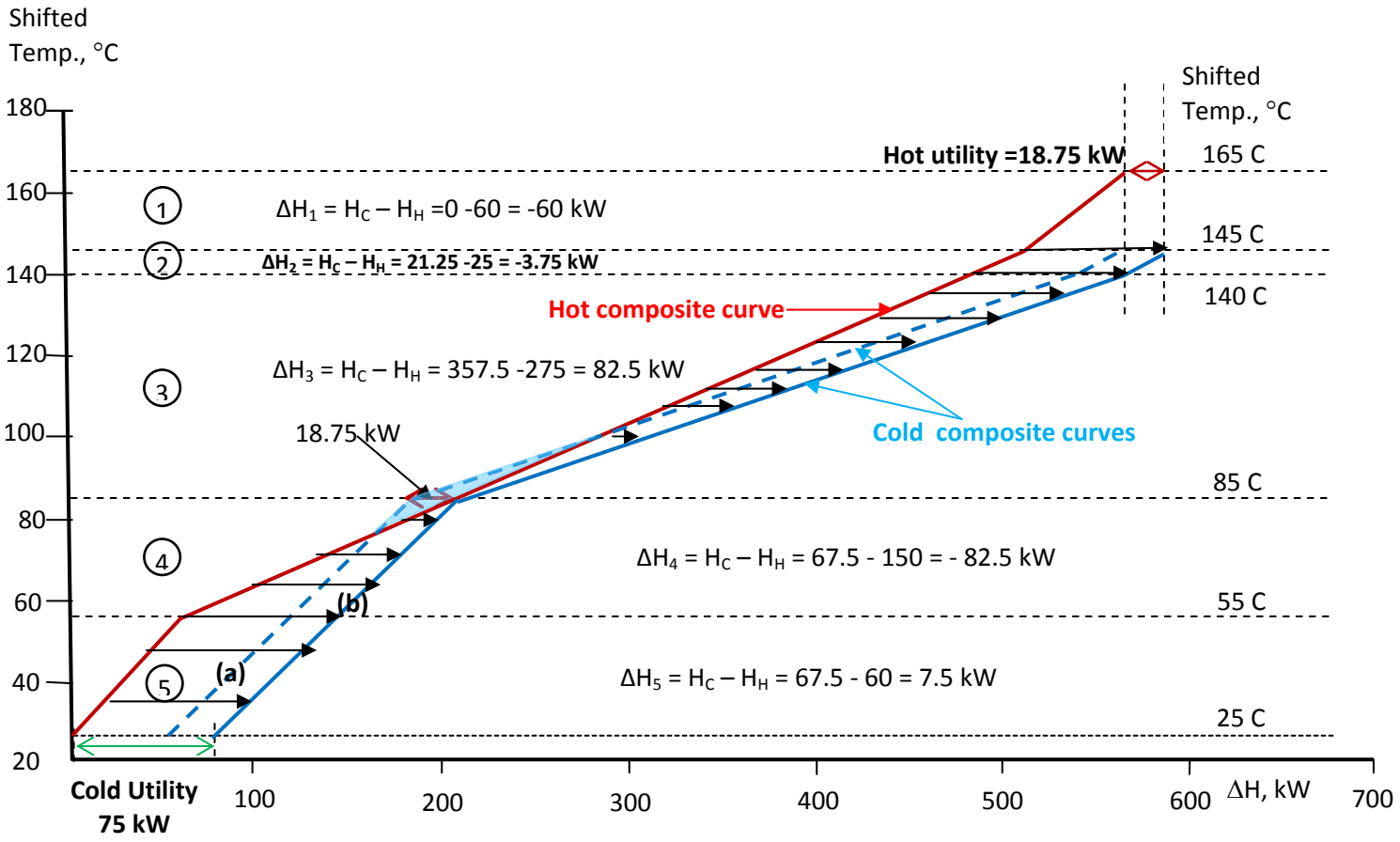
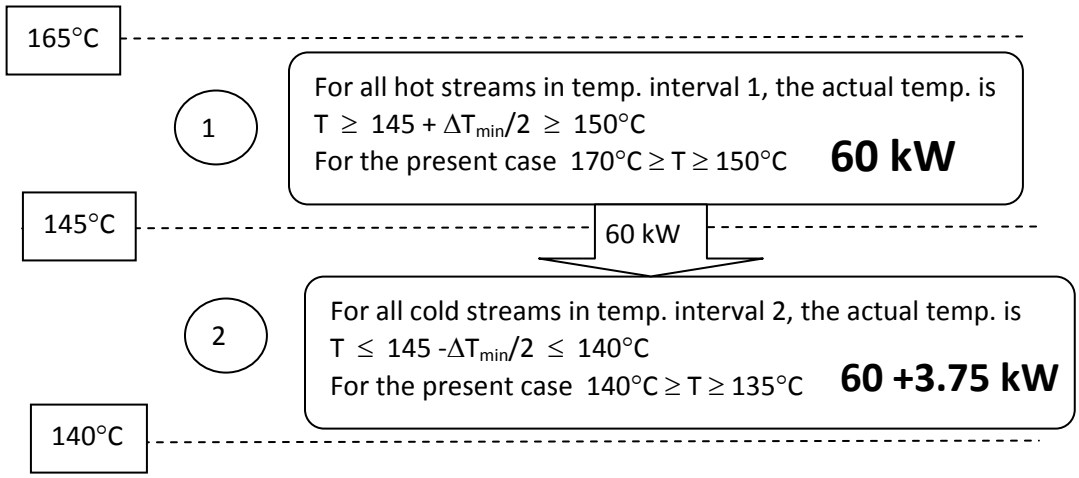
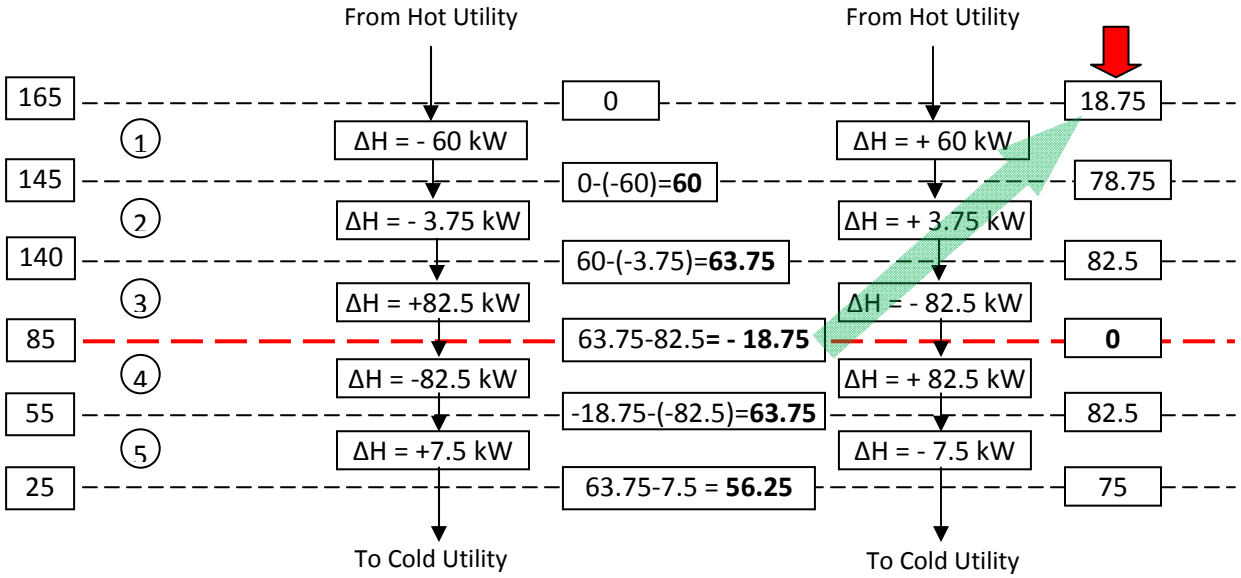


Fig.4.7 Graphical representation of the heat cascades used for PTA for problem given in Table 4.2

After constructing the Problem table and defining intervals with surplus and deficit of heat, the next step is to develop a heat cascade based on key feature of problem table that **any heat available in interval i is hot enough to supply any duty in interval i+1**. Now, the interval 1 has a surplus of 60 kW which can be transferred to the 2nd interval as the hot streams in interval 1 are at least ΔT_{min} higher in temperature scale(Fig.4.8(a)) than cold stream at interval 2. However, reverse of it which means natural transfer of heat from T_i interval to T_{i-1} interval is not feasible as per second law of thermodynamics. First assume no heat is supplied to the first interval from hot utility. In this, way a heat cascade can be set up as shown in the figure below:



(a)



(b)Transfer of cascade surplus heat from high to low temperature

(c)Add heat through hot utility to make all heat flow positive or at least zero

Fig.4.8 Problem table cascade

Initially, for the formulation of heat cascade we assume that no heat is supplied from the hot utility to the hottest interval. The first interval has a surplus heat of 60 kW, which is cascaded to the next interval. The second interval has a surplus of 3.75 kW, which leaves the heat cascaded from this interval to be 63.75 kW. In the third interval the process has a heat deficit of 82.5 kW, which leaves -18.75 kW to be cascaded to next interval. The Fourth interval has a heat surplus of 82.5 kW, which leaves 63.75 kW to be cascaded to next interval. The fifth and the last interval has a heat deficit of 7.5 kW which leaves 56.25 kW to be transferred to cold utility. From this cascade, we can see that from interval 3 to 4, -18.75 kW of heat is being transferred which is not thermodynamically feasible as, heat cannot be transferred up the temperature scale, to satisfy the heat demand. Thus the cascade shown in Fig.4.8(a) is not feasible as -18.75 kW is being passed to the fourth interval. Further, it should be remembered that the hot utility consumption for the cascade shown in Fig.4.8(a) is zero. The physical interpretation of this situation is shown in Fig.4.7 with cold composite at "(a)" position. It can be seen that some part of the shifted temperature cold composite curve is above shifted temperature hot composite curve making the heat transfer infeasible in this region. To make it feasible the shifted temperature cold composite curve has to be brought below the shifted hot composite curve (position "(b)" of cold composite curve) as shown in Fig.4.7. This will require transfer of heat from hot utility amounting to 18.75 kW from the top temperature level.

Thus, to make the heat cascade feasible one has to transfer heat from hot utility to the first interval. The smallest amount of heat that is required to be added from hot utility is the largest negative heat flow (in the present case -18.75 kW) from the cascade(Fig.4.8(a)). Note that the smallest heat from will be positive value of the largest –ve heat flow in the cascade. By doing so all the heat flows of the cascade will positive or at least zero which is the sign of feasible cascade. Thus 18.75 kW of heat is being supplied from the hot utility to the first temperature interval which changes the heat balance within each temperature interval and increases heat flow from all temperature interval by an amount 18.75 kW , making heat flow zero at an shifted interval temperature of 85°C. This gives the pinch point for the system. Further, amount of heat flowing from lowest shifted interval temperature (25°C) is 75 kW. This heat goes to the cold utility. Thus minimum cold utility demand is 75 kW. Similarly as amount of heat, in terms of hot utility, required to be supplied to highest shifted interval temperature (165°C) is 18.75 kW, the minimum hot utility requirement of the system is 18.75 kW. The pinch temperature reported above is shifted temperature and this needs to be converted to actual temperature. While converting actual temperature to shifted temperature, $\Delta T_{min}/2$ was added to cold stream temperatures and $\Delta T_{min}/2$ was deducted from hot stream temperatures. Hence, this process has to be reversed to get actual temperature from shifted temperature.

Thus, the summary results from the Fig.4.8(b) are:

Shifted pinch temperature = 85 ^{0}C
Hot Pinch Temperature = 85+10/2 = 90 ^{0}C
Cold Pinch Temperature = 85-10/2 = 80 ^{0}C
Hot Utility Required = 18.75 kW
Cold Utility Required = -75 kW

Reference

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