A Tale of Two kWhs

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Many a time complaints can be due to lack of information or understanding as the one that was received by us from an HVAC contractor. He was worried about the thermal energy (BTU) meter not functioning properly at his site. Our engineer went to the site and, after being convinced that the meter was not faulty, asked for the reason for the dissatisfaction. He realized that the HVAC contractor, builder and the end-user were all unhappy because the energy reading in kWh being shown by the BTU meter installed by us on an AC plant was different (and much higher!) than the kWh reading shown by the energy (kWh) meter installed on the electric supply feeding the same AC plant.

For a non-technical person to be confused by this anomaly is but natural. After all, why should different energy meters installed on the same line show different readings? As such, the customer (who is finally footing the bill for both the kWhs) was confused. What they failed to understand was that though the reading of both meters was in the same unit – kWh, one was reading out the thermal kWh or the cooling load consumed and the other was reading out the electric kWh or power consumed.

As per the laws of thermodynamics – energy can neither be created nor destroyed and whenever some form of energy is converted to another some losses are bound to occur. In other words, output cannot be more than input or no system can have an energy efficiency of more than 100%. The laws hold good in each and every case, but there is a catch – the refrigeration plant does not convert electrical energy to thermal energy, it simply transfers the heat energy from one area to another area and the energy consumed is to facilitate this transfer only.

During heating, the heat is extracted from the cold ambient condition and transferred to the indoors. Similarly, during cooling, heat is extracted from indoors and transferred to the ambient. It is unlike either a boiler where fuel is burnt to heat water or an electric heater where electric energy is converted to heat energy.

In technical terms, refrigeration cycles transfer thermal energy from a region of low temperature to one of higher temperature. Usually the higher temperature heat sink is the ambient air or cooling water.

Performance of a refrigeration cycle is described by a coefficient of performance (COP), defined as the amount of heat removed divided by the energy required to operate the cycle.

$$COP = \frac{\text{Useful refrigerating effect}}{\text{Net energy supplied from external resources}}$$

For mechanical vapor compression based refrigeration system, the net energy supplied is usually in the form of electrical energy consumed by compressor, pumps or cooling tower fans.

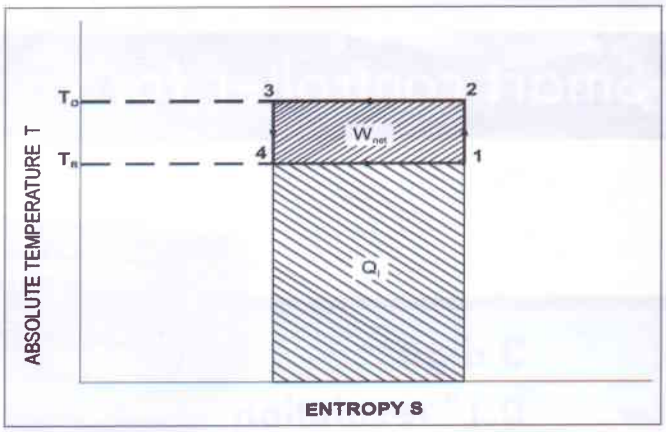

Figure 1: Temperature-Entropy (T-S) representation of Carnot Cycle

A compression refrigeration cycle working between two fixed temperatures can be compared to a reversed Carnot Cycle. *Figure 1* shows the cycle on temperature-entropy coordinates. Heat is withdrawn at constant temperature T_R from the area to be refrigerated and is rejected at constant ambient temperature T_o. The energy transfers are given by

$$Q_0 = T_0 (S_2 - S_3)$$
$$Q_i = T_R (S_1 - S_4) = T_R (S_2 - S_3)$$
$$W_{net} = Q_0 - Q_i$$
$$COP = \frac{Q_i}{Q_0 - Q_i} = \frac{T_R}{T_0 - T_R} \quad (T_0 \text{ \& } T_R \text{ being absolute temp.})$$

For the Carnot cycle working between 5°C (278K) and 35°C (308K)

$$COP = \frac{278}{308 - 278} = 9.26$$

Due to practical limitations, it is not possible to make a perfect refrigerating machine working on the reversed Carnot cycle, therefore, the actual COP achieved is much less, but is usually more than 1.

This means that in refrigeration systems the heat output is usually more than the work put in and that explains the reason for the reading in thermal energy meter being more than that in the electrical energy meter.

Cost of Thermal Energy

The other problem often faced is about calculating the cost of thermal energy, and for sure, it is a difficult one, because it is difficult to calculate the COP of the complete plant that includes chillers, pumps, fans etc

Here are 5 easy steps to help you do this:

- Install a dedicated electrical energy (kWh) meter for the refrigeration plant.
- Install a thermal energy (BTU) meter in the main header.
- Note down the initial reading of both the energy meters.
- Run the plant for few hours and again note the reading of both the meters and calculate the difference.
- Then,

Unit cost of Thermal Energy =

$$\frac{\text{Electrical energy consumed}}{\text{Thermal energy used}} \times \text{Unit cost of electrical energy}$$

Wherever it is not possible to install a thermal energy meter in the main header, the thermal energy rate has to be approximated. The plant may be operated at a known capacity, say 50% or 100%, for some time and electrical consumption noted, to work out the cost per unit of thermal energy.

Units of energy

kWh, TR-hr, BTU, kcal are all units of energy, however, it is common to measure electrical energy in kWh and Thermal energy in TR-hr, BTU or kcal. Conversion ratios are as under.

1 TR	=	12000 BTU/hr
1 TR-hr	=	12000 BTU
1 kcal.	=	3.968 BTU
1 kWh	=	3412 BTU
1 kWh	=	859.9 kcal