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Thermodynamic versus system efficiency

Thermal efficiency and *coefficient of performance* (as it relates to refrigeration systems) are exactly defined terms in classical thermodynamics and as such are well understood by mechanical engineering practitioners. Perhaps it is in the misapplication of these concepts that they have worked to the detriment of effective energy utilization.

A scan of virtually any elementary thermodynamics text reveals two interesting facts:

1) The application of *thermal efficiency* or *coefficient of performance* in examples or problems addresses power rather than energy in the equations (the terms are Btuh, ft-lb per min, horsepower, etc.). Although the definitions and development of the equations are based on energy, a time span must be included in applying the equations—thus, the substitution of power for energy.

2) The "work in" considered is generally always primary motivation power. That is, for a refrigerating machine, it is the work into the compressor. Other work requirements for the cycles are generally ignored. Similarly, for the power cycle, the "work out" is generally considered as that off the turbine (or engine) shaft, neglecting any "parasitic" work input requirements necessary to make the cycle function.

To apply these concepts properly, one should keep the limitations in the use of these terms in perspective. The designer of a refrigerating machine works at trying to set the end temperatures as favorably as possible to achieve the highest possible Carnot coefficient of performance. The next challenge is to construct a machine that will (at full load) approach the Carnot value as closely as possible. For this reason (and others), it would not be prudent to tamper with our age-old definitions.

Apply new definitions?

Perhaps we should define some new evaluation function and in the process of this definition recognize the limitations of the present definitions. It is suggested that the new terms be *system thermal efficiency* and *system coefficient of performance*, with the *original* terms then being preceeded by *thermodynamic* (i.e., thermodynamic thermal efficiency and thermodynamic coefficient of performance).

The system thermal efficiency would then be defined to include all manner and form of energy inputs to the system over a long time span such as an operating season or a year. The basic difference is that the long time span would make the evaluation more truly one of energy rather than power, and the inclusion of the secondary or auxiliary inputs would provide a true measure of the *energy* efficiency. Relating this concept to thermal systems provides a striking example of the value of carefully applying the "system efficiency" concept. In case history studies of active solar heating (and heating-cooling) systems, it has been found that when the system efficiency concept is applied, some of the solar systems are considerably less efficient in the consumption of fossil fuel energy than some so-called conventional systems. The reason is that the shaft energy requirements of the auxiliary devices required to collect, store, utilize, and control the relatively low-grade energy, integrated over, say, 8760 hr per year, are vastly more extensive than those required for some more conventional systems.

Similarly, for refrigerating systems, the definition of the *system coefficient of performance* would include *all* energy inputs integrated over a long time span. Examples of some of these inputs, in addition to primary (compressor) energy, are the energy requirements to drive condenser water pumps, condenser fans, cooling tower fans, and chilled water pumps. These are all part of the energy requirement to remove the heat from the space. A study of numerous existing installations has revealed that in many large chilled water plants, the energy required annually by the auxiliary devices surpassed the energy consumed by the compressor drive(s).

Failure to make a proper distinction between the classical thermodynamic terms and the proposed system terms has led many practitioners in both the private and public sectors to pursue unsuccessful concepts relating to more effective energy utilization. In pursuing these courses, the proponents stopped at the thermodynamic function and concluded that the problem had been solved. It was only after the expenditure of excessive funds that the concept was proven to be a failure, and even then many did not recognize the reason!

Time integration is important

The time-integration feature of this concept is probably more meaningful in the building systems sciences than in any other field of energy systems. The reason, of course, is the combination of the continually varying climatic conditions and uses of the space. Few persons would leave their automobile for the day and leave the engine running; however, it is *most common* that when we leave our building, we leave the mechanical building systems running. In the applications of active solar energy systems, there is little coincidence between the availability of the solar energy and the need. Also, there are many hours (the vast majority in most climates) during which the need for energy (heating or cooling) is but a small fraction of the design value, yet the parasitic machinery is operated at *its* full-rated energy consumption.

Another area where the time integration is of the essence in a basic understanding of the potential cycle effectiveness is in the concept of cogeneration. The thermodynamic efficiency tends to reveal a potential combined cycle efficiency of, say, 80 percent. This assumes, however, a need for shaft (electrical) energy coincident with a need for thermal energy—a coincidence that seldom exists. Thus, before the "concept" is validated, the coincidence must be understood; and then, considering the energy requirements for storage, utilization, etc., the system efficiency can be determined.

In summary, in addressing the energy effectiveness of building systems, the consumption rates must be integrated over a long (repeatable) time span such as a year or a system season, and *no* energy-consuming devices relating to the systems can be ignored. When these factors are considered in thermal, shaft energy, or refrigerating systems, we propose, the evaluation functions of thermal efficiency and coefficient of performance should be clearly identified as different from those in classical thermodynamics by use of the prefix word *system* with the former and *thermodynamic* with the latter.