SECTION XII

Evaluating the effectiveness of energy utilization

The concept of evaluating the effectiveness of energy utilization in conversion apparatus is not new. It was this challenge which commanded much of the attention of the nineteenth century thermodynamicists. The results of these activities are the well-known statements of the Carnot principle that no heat engine cycle can be more "efficient" than a reversible cycle and that no refrigeration cycle can have a coefficient of performance greater than a reversible cycle.

In these definitions, the terms efficiency and coefficient of performance are exactly defined, and using these exact definitions and a bit of elementry thermodynamic relationships, the maximum attainable efficiency and coefficient of performance, respectively, are determined and are found to be a function of the temperature limits of the cycle. In theory, then, these relationships have had two very fundamental uses in the development of thermodynamics and the machines based upon this development.

1) Since the maximum attainable effectiveness is based upon the temperature limits (high and low), a continual effort has been made over the years to develop machinery to operate at the most favorable attainable temperatures. This effort is one of the germane reasons for the economy of scale or size in electric power plants.

2) With given temperature ranges, the major efforts in cycle design have been to develop cycles that come as close as possible to a reversible cycle. This activity has produced the approximations to the Carnot cycle that account for the most commonly used power and refrigeration cycles today, the Rankine cycle and the vapor compression cycle.

In addition to pointing the way to "most favored" cycles, the concept of Carnot efficiency can be used for the basis of comparing the success of any given design. Such a comparison is made in some detail in the chapter, "Thermal Effectiveness of a Vapor Compression Cycle," where the results show that the commercial system analyzed used approximately five times as much energy as the Carnot coefficient of performance would require. Thus, the real cycle could be considered 20 percent effective compared to the ideal.

As is discussed in the chapters of this section, it is essential that in the continued development of power and refrigeration cycles, as well as in pure thermal cycles, the concept of evaluation of effectiveness of energy use be expanded well beyond the simple thermal efficiency and refrigeration coefficient of performance as defined in the days of Carnot. That is not to say that the Carnot concepts should be discarded; quite the contrary, they should be expanded. As used in their classical manner, thermal efficiency and refrigeration coefficient of performance have been *power*, not energy evaluation functions.

As real machines are developed, there emerges the need to supplement the pure cycle with auxiliary devices of various kinds. These auxiliary devices include such system components as control actuators, pumps, fans, etc., all of which consume energy. Thus, at design loading, the true value of thermal efficiency or refrigeration coefficient of performance should consider the burden of the auxiliary devices.

Even more significant is the time-integrated concept which transforms the evaluation functions from power to energy functions. For example, a steam Rankine cycle power plant may have a design capacity thermal efficiency (work out/heat in) of 38 percent but when integrated over a long cyclical time span such as a year, the efficiency may well drop to near 20 percent. A consciousness of the time-integrated nature of energy-use effectiveness will significantly change the approach to system designs. This concept is discussed in the chapter, "Thermodynamic versus System Efficiency."

A bit more subtle is the problem of evaluating the effectiveness of energy conversion when several different useful forms are produced from the same cycle. As, for example, when the heat rejected from a heat engine can be put to beneficial use in such a way that it replaces heat which would otherwise be provided by the consumption of energy resources (otherwise high-level energy).

By the "zeroth law" concept, considering a "scale" of energy, if the reject heat is at a useful temperature it must be above the temperature of an ultimate sink such as the atmosphere. Since the electric energy will also ultimately flow into the ambient sink, the electricity and useful thermal energy can be considered additive. The addition process could be thought of as adding apples and oranges with the sum being so many pieces of fruit.

The problem becomes infinitely more complex when a third product is produced by the cycle in the form of "cooling." So-called cooling energy falls on the "zeroth law" scale below ambient temperatures, such that it will not degrade as did the useful heat and electricity. This concept is the essence of the discussions on energy effectiveness factor.

Attention is also called to some of the chapters of Sections III and VII. In Section III, the chapter, "Proposed Format for Organizing the Study of Building Energy Economics" is included as an effort to provide a method of measuring the effectiveness of energy use in all the elements of a building system, and extending the segregated analysis to the integrated system.

Evaluations of energy-use effectiveness often lead to not only the most desirable or beneficial system from an energy consumption standpoint but also to those which are the most cost beneficial. This is not, however, always the case. Thus, to perform one analysis without the other can and has led to serious errors in judgment on the part of designers.