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The relationships between system balance and energy use

In the study of energy economics relating to energy conversion systems, the first step is to identify the two fundamental components of the analysis, product energy and process energy.

The product energy in building systems is that energy which is required to directly satisfy space environmental needs, in the form needed. Some examples of product energy are the heat introduced into the room at a rate identically equal to the rate at which heat leaves the room to the surroundings and heat extracted from the room at a rate exactly equal to the rate at which it enters the room from the surroundings or relevant internal sources such as the occupants, lighting devices, and appliances.

The process energy is the energy which is consumed by the "system" to satisfy the product need. Examples of process energy are such energy-consuming subsystems as pump energy, fan energy, psychrometric control energy, energy to condition excess ventilation air, and all forms of energy losses.

Product energy and process energy

The total energy required, say annually, by the building is then the sum of the product energy and the process energy.

Experience in analyzing numerous actual buildings and building systems has revealed that the process energy components far exceed the product component in by far the majority of cases—especially if product energy for refrigeration is based on ideal Carnot relationships.

This chapter is directed at the need for careful initial and ongoing adjustments of the various subsystems and components to achieve minimization of process energy. It must be remembered that all process energy is considered energy loss.

Systems technology advances

The field of building systems technology has undergone significant technological advances throughout the past 30 years. The pressures motivating these advances were such that the primary design parameter (and evaluation of success of the design) was the system performance, that is, did it satisfy the product energy requirement.

As a result, very little attention was directed to process energy requirements, and the systems designed were most forgiving of improper adjustments. Some examples of these phenomena are:

1) Oversized primary conversion capacity negated the need for fine tuning the apparatus. Even in a state of poor adjustment, the oversized equipment or subsystem produced the output needed.

2) Low design temperature ranges in fluid transportation or conveying systems enabled most heat transfer elements of the system to perform with flow rates far short of the intended design. An example of this is the flow rate versus capacity curve in the ASHRAE Systems Volume which illustrates that for a 20 F temperature drop coil, 50 percent design flow provides 90 percent design heat transfer.

3) Multiple zoning of high-velocity dual duct air systems, when designed for the sum of the peak flow rates were capable of maintaining space conditions regardless of system imbalance—a control which resulted from the correct proportionate mixture of high- and low-temperature air streams.

Improved design yields results

In the past decade (1965–1975), however, two significant changes occurred. The realization of the limited supply of energy in the form needed for building systems and increased costs of investment monies. These, simultaneous with advances in computer technology (both hardware and software), have resulted in the realization of other design parameters that have been recognized as an equal to that of ultimate performance. This recognition has resulted in the following:

1) Extremely exacting analysis of the product requirement in the form of building design loads, daily time-integrated loads to carefully identify not only peak individual space or room loads but maximum coincident system loads and annual load energy requirements.

2) The selection and design of equipment and subsystems to match the calculated diversified loads.

3) A reduction in the dependency of simultaneous heating and cooling in an effort to minimize psychrometric control process burdens (otherwise known as "runaround" energy).

4) Maximizing temperature ranges in fluid transportation systems for the purpose of both reducing pipe sizes and reducing pumping energy.

5) Variable flow fluid systems (both transport fluid and conditioned air) to reduce annual energy burden.

The systems thus designed are much less forgiving of poor adjustment or balance. As a result, the performance has not been as successful in cases wherein the adjustments were not achieved.

Also, in the earlier systems, in virtually all of the maladjustments which went unnoticed because of the ability of the system to adjust, such inherent system maladjustments were at the expense of increased process energy consumption.

Two basic requirements

There are two fundamental requirements in the concern of system adjustment and balancing:

1) Initial adjustments. These are the adjustment requirements which must be performed prior to putting a new system into operation. In the case of existing systems which are either being modified or subjected to a newly established energy management program, the initial adjustments must be completed before the management program commences.

2) Ongoing monitoring. These are tests and adjustments which must be made as a part of the continued ownership responsibility in carrying out the preventive or planned maintenance program.

Design guidelines suggested

Providing for the initial adjustments should be the responsibility of the system designer. Unless the system designer recognizes these requirements at each and every phase of both design development and construction monitoring, there is little possibility of successful accomplishment. Suggested guidelines for the designer to follow in addressing this responsibility are:

1) Develop flow diagrams. In each phase of design development, for all thermal fluid subsystems such as air, water, steam, and refrigerants, flow diagrams should be developed prior to the actual layout and modified and updated as the layout proceeds. The flow diagram is the only tool that presents a visual indication of the overall system. Subsequently, all balancing, testing, and adjustment points and devices should be identified on the flow diagrams and they should be included in the construction documents.

2) Develop system schematics for psychrometric and other energy conversion subsystems. These are analogous to the flow dia-

grams for the fluid systems and should be developed for such subsystems as air-handling units, chillers, and converters. The schematic should include such devices as control dampers, control valves, and temperature-control devices. These, like the flow diagrams, should include heat transfer data, flow data, points of measurement for adjustment, and adjustment devices, and should be included in the construction documents.

3) Design a "balanceable" system. With the help of the diagrams the hydraulic and thermal dynamic interrelationships of the system components upon one another at both full load and reduced-load conditions should be identified. It is at this phase of design that "designed-in" problems are minimized. Such potential problems as unanticipated series pumping phenomena, reverse flow paths, fluid overdraw, etc., become evident when the dynamic interrelationships are carefully considered.

4) Assure adequate metering characteristics at measuring points. At all points where velocities are to be used to measure volumetric flow rates, for instance, adequate velocities must be assured and designed into the system. Likewise, for pressure differential measurements, adequate drops must be provided.

5) Construction plans and details should be carefully coordinated with the flow diagrams to assure compatibility and to assure adequate access to measurement and adjusting points.

6) A logistics mechanism for effecting the testing and adjustment program must be achieved. This mechanism is dependent upon the availability of technical expertise in the locale of the building. The technical expertise may be in the form of independent testing and balancing firms, construction contractor, in-house capabilities, or, in some cases this service may have to be performed by the design engineer himself.

Use complete specifications

Following recognition of the available technical expertise, the logistics mechanism must include recognition of the extent of the work to be done when establishing the construction budget, a clear definition of the work and identification of the acceptable technical expertise in the construction specifications, a mechanism for achieving coordination between the design engineer, the installing contractor, and the testing and adjusting team, and a method for verifying that the work has been successfully accomplished.

Much education is needed

The ongoing monitoring of the system adjustments is, needless to say, the responsibility of the building owner. It must be recognized, however, that the need for this phase of preventative or planned maintenance is a totally new concept to most building owners, if not to many practitioners in the building systems design profession itself. Thus, a good deal of education remains to be done.

This education must proceed as a dissemination of information among the engineering community through our engineering society's technical publications, and seminars along with other available sources. Simultaneously, the informed design professionals should initiate the task of informing their clients, the building owners and managers, initiating at the embryo stages of project description and economic analysis.

The flow diagrams and subsystems diagrams discussed above will prove to be a useful tool in the continued monitoring and adjustments of the system. Design firms with the capability should consider the possibility of providing the services of maintenance management consultation to building owners, and construction contractors with the capabilities should consider the possibility of providing contracted system maintenance which should include the ongoing testing and adjusting.

Identify energy use areas

The preceding discussion was directed toward procedures relevant to new building projects. However, existing building systems which have been constructed without the benefit of this planning should be addressed. These buildings very likely consume more process energy by inherent design than the future buildings will. As a result, there is an ever-increasing demand for energy analysis and resulting steps at reducing the summary energy consumed by their systems. The first step in such an analysis is to develop a mathematical model of the building energy systems which will accurately identify the sources of energy consumption, both product and process. This initial step, the results of which can be verified by historical energy consumption records requires, in most cases, precise testing of the present operating adjustments and maladjustments. Once the operations modes have been verified by field testing, the mathematical modeling currently available through computer programs is acceptably accurate; to a degree that deviations from acceptable norms of accuracy lead to additional field testing which ultimately reveals the area or cause of the deviation.

When this iterative process of calculation and testing achieves compatibility with the operations records, many of the areas of excess energy use will have already been identified quantitatively.

Decide on energy-saving steps

The next step in the retrofit process is to use the mathematical model (the accuracy of which has now been confirmed) to determine the effects of changes to the product requirement (such as alternative fenestration systems), process requirement (such as reductions in total air flow or variable water circulation, and adjustments) on the annual energy consumption. After an acceptable program for modifications in both apparatus and operations techniques has been established, the fundamental requirements of "initial adjustment" and "ongoing monitoring" discussed above should be effected.

Needless to say, any program which does not continually monitor the results to confirm the success of the initial or ongoing adjustment will not have confirmed either the benefits of the effort itself or the degree of success of the responsible agent.