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NEW APPLICATIONS OF ENERGY STORAGE IN ELECTRIC HEATING AND COOLING SYSTEMS

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NEW APPLICATIONS OF ENERGY STORAGE IN ELECTRIC HEATING AND COOLING SYSTEMS

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INTRODUCTION

Electricity, in combination with appropriate load management techniques, is a cost-effective method of providing building heating and cooling services. Storage systems that enable the use of nighttime, off-peak, energy to meet the following day's load are among the most promising load management techniques.

For many conservationists, the use of electricity for building heating is at best an inelegant practice. One critic likened it to "cutting butter with a chain saw (1)". This viewpoint -- to wit, electricity is too high in quality and too expensive to use in building heating applications -- has gained wide acceptance. However, our studies at Argonne indicate that just the opposite is true; we find that electricity is well matched to building heating and cooling requirements -- economically and thermodynamically.

In recent studies at Argonne, we evaluated the total cost of providing space heating and cooling services with electricity and then compared these costs with oil and gas-based systems. Detailed cost allocation models were used to compute gas and electric utility costs of supply. The ANL SIMSTOR model, which uses hourly synoptic load and weather data, represents a robust methodology for estimating the long run marginal costs of supplying device-specific electric loads (2).

A number of different electric technologies were evaluated including: electric storage heating, storage air conditioning, dual-fuel heating, and solar heating with electric backup.

SPACE HEATING AND COOLING TECHNOLOGIES

Electric Storage Heating: A proven technology in Europe, electric storage heating is a method of storing off-peak electric energy in thermal form for application during peak load hours. Both central furnace and room-size storage heating systems are available from European manufacturers. The storage medium is usually refractory brick or cast iron, although water is sometimes used in central systems. The advantage of bricks is the high temperature, 750°C, to which they can be heated, resulting in a relatively compact storage volume. Commercially available central furnace units cost about $1100 more than standard direct resistance furnaces for a single family house.

In a program designed to establish the performance requirements of storage heating under U.S. operating conditions, the U.S. Department of Energy is sponsoring field tests of central and room-sized storage heating systems. In a completely separate project, American Electric Power, a large utility holding company, has evaluated central furnace systems in several of its Midwestern service areas. Still other work is being sponsored by the Electric Power Research Institute and independently by other utilities.

Dual-Fuel Heating Systems: Another type of heating system, one that also can be used in winter-peaking service areas to minimize the contribution to the utility peak load, is the dual-fuel heating system. Incorporating either an oil- or a gas-fired backup furnace, a dual-fuel system operates in an electric mode during periods of low or moderate electricity demand and switches over partially or completely to the fossil mode during periods of high demand. In addition to reducing utility capacity requirements, a dual-fuel system achieves a direct fuel savings. During periods of peak demand, the utility's "peaker in the customer's basement" operates with an energy conversion efficiency of 50% to 60% compared with about 25% for conventional utility oil-fired peaker plant.

Electric Heat Pumps: Heat pumps have an inherent thermodynamic advantage over direct resistance heating systems. Converting electrical energy into mechanical work, heat pumps use a compression-expansion cycle to transfer about two units of thermal energy from the outdoor air to the indoor house air for each unit of electrical energy consumed. The higher initial cost of the heat pump system is offset not only by its higher energy efficiency but also by its ability to provide cooling as well as heating services. Thus, the initial cost of a heat pump is only about $400 more than a conventional resistance furnace plus central air conditioner.

Although, as we show below, the heat pump is an ideal space heating technology in service areas supplied by summer-peaking utilities, it suffers a serious disadvantage in winter-peaking service areas. It is a fundamental characteristic of the heat pump that it loses heating capacity as the outdoor temperature drops. The decline in rated capacity is so severe that heat pumps designed to operate in cold climates incorporate resistance heaters as backup systems. Thus, on peak-making cold weather days, the heat pump presents the electric utility with the same peak load as a direct resistance system.

Several technologies are available to reduce the peaking requirement of the conventional heat pump. One technique is to replace the direct resistance backup with an electric storage heating furnace, so that on cold weather days the backup energy requirement can be supplied during off-peak hours. Another technique, by analogy with the dual-fuel system described above, is to substitute an oil- or gas-fired furnace for the direct resistance backup.

Storage Air Conditioning: Storage air conditioning systems are currently under development and testing. The most economical and practical systems incorporate ice storage tanks which are connected to the central air conditioning system. As water in the tanks is chilled, it forms ice on evaporator coils. Compressor size, due to the reduced hours of operation and lower suction temperature, is greater than for a conventional air conditioner. Depending upon house size and location, from 150 to 300 gallons of storage capacity are required. In residential applications, the incremental cost of storage air conditioning ranges from $30 to $45 per kWhe ($14 to $20 per kWht) of storage capacity. Cool storage can also be used with heat pumps.

Solar Energy Systems: Next to residential water heating, residential solar space heating is the most promising thermal application of solar energy. The basic development problem confronting this, like most forms of solar energy, is the achievement of low cost solar collection systems.

The conventional solar heating system with electrical backup can be conceived as an electric storage heating system plus solar collector. In principle, the inclusion of storage in solar heating systems makes it possible to provide auxiliary energy without recourse to on-peak electric power. All that is required is predictive information about the following day's weather so that insolation outages can be covered by off-peak nighttime energy. Although this mode of operation reduces the overall cost of solar heating, once recognized, it has the effect of reducing the benefits that can be claimed for the collector component of the solar heating system. Because the storage reservoir can be charged with electricity every night, the benefit of the collector component of the solar system is reduced to the value of the displaced off-peak electricity.

Solar collectors arranged either in tandem or in parallel with heat pumps represent another set of systems that use solar and electrical inputs to supply space heating services. In the tandem design, the better of the two configurations, the output of the solar collector is used to warm a storage tank that serves as an input reservoir for the heat pump. As with the solar-resistance heating system, the basic problem with the solar-assisted heat pump is the difficulty in justifying the solar collector component of the system once the benefits of the other components have been identified and counted. As we have already seen, the standard heat pump uses about one-half as much electrical energy as direct resistance heating. Solar warming of the input reservoir can improve performance by another factor of two; however, the addition of the solar collector must now be justified in terms of a savings equal to only one-fourth the energy used by a conventional direct resistance system. The savings from the collector are further reduced by the presence of storage, which means that the displaced energy is mostly off-peak energy.

TOTAL COST OF SERVICE

If electrical energy were priced at true marginal cost, it would be easy to construct an index of the total cost of service for each of the above-described technologies. The simplest index would be the sum of two components: (i) the customer's annual electric bill, plus (ii) the customer's annual mortgage payment on the space heating equipment. (For purposes of calculation, we could assume that no down payment was necessary.) However, in the absence of correct pricing (cost) signals from the electric utility, a method must be devised to calculate the cost of electricity.

In a case studies approach to this problem, we applied the Argonne cost allocation model SIMSTOR to estimate utility supply costs in service areas in different parts of the country. The SIMSTOR computer model uses device performance characteristics and hourly weather data to calculate space heating loads over a full annual (8760 hour) cycle. It then calculates the utility capacity expansion and fuel costs to meet these load profiles. SIMSTOR incorporates a load dispatch submodel to simulate generating plant performance and observes operating constraints such as scheduled and forced outages and the cycle of time of each type of generating unit. It takes into account the effects of load diversity and calculates transmission and distribution costs as well as generating costs. Although its data requirements are rather demanding, SIMSTOR can be applied to any electric supply system.

Figures 1 and 2 show the results of the analyses of the different heating and cooling technologies for two service areas. One of the service areas is located in the Northeast and is supplied by a winter-peaking electric utility; the other, located in the Middle Atlantic Region, is served by a summer-peaking utility. The energy costs in the figures correspond to the combined costs of heating and cooling. The energy supply cost (vertical axis) includes utility (gas or electric) and/or fuel oil costs. Expressed in annualized values, the supply cost can be conceived as the utility's annual fuel bill plus its annual mortgage payment on the plant and equipment needed to meet the heating and cooling device load. The device cost (horizontal axis) represents the annualized capital cost of the on-site residential heating and cooling equipment plus the annual cost of a service contract covering repairs and maintenance. The dashed lines in the figures represent points of constant total cost. The total cost, representing the sum of before- and after-the-meter costs, thus represents the best available index for comparing the overall economic efficiencies of the different systems.

As seen in Fig. 1, both storage resistance heating with conventional air conditioning and storage heat pumps are very efficient technologies in terms of overall system cost in the winter-peaking service area. Presenting the utility with electric loads only during the off-peak hours, these systems do not contribute to the utility's coincident peak demand.

The dual-fuel heat pump is a serious competitor with the storage heating systems in terms of overall cost. Entailing a small customer capital cost penalty -- approximately $500 over the cost of a heat pump with electric resistance backup, the heat pump with oil furnace backup achieves substantial savings through the virtual elimination of the on-peak electrical load.*

As indicated in Fig. 1, the costs of energy supply to the solar resistance and the solar-assisted heat pump systems are lower than for direct resistance heating; however, the solar systems are not competitive with respect to overall cost with the storage and dual-fuel heating systems. In the winter-peaking service area, the total cost of the solar-resistance heating system becomes comparable to the cost of electric storage heating at a collector cost of about $5.00 per square foot.

For the service area supplied by a summer-peaking utility, the entire heating season is off-peak so that the benefits of storage and dual-fuel heating systems are greatly reduced. The conventional heat pump is the most economical heating technology. Storage and dual-fuel technologies are 10-20% more expensive in terms of overall cost and suffer the disadvantage of being more complicated technologies.

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*The dual-fuel systems use an oil furance, not a gas furnace, backup.

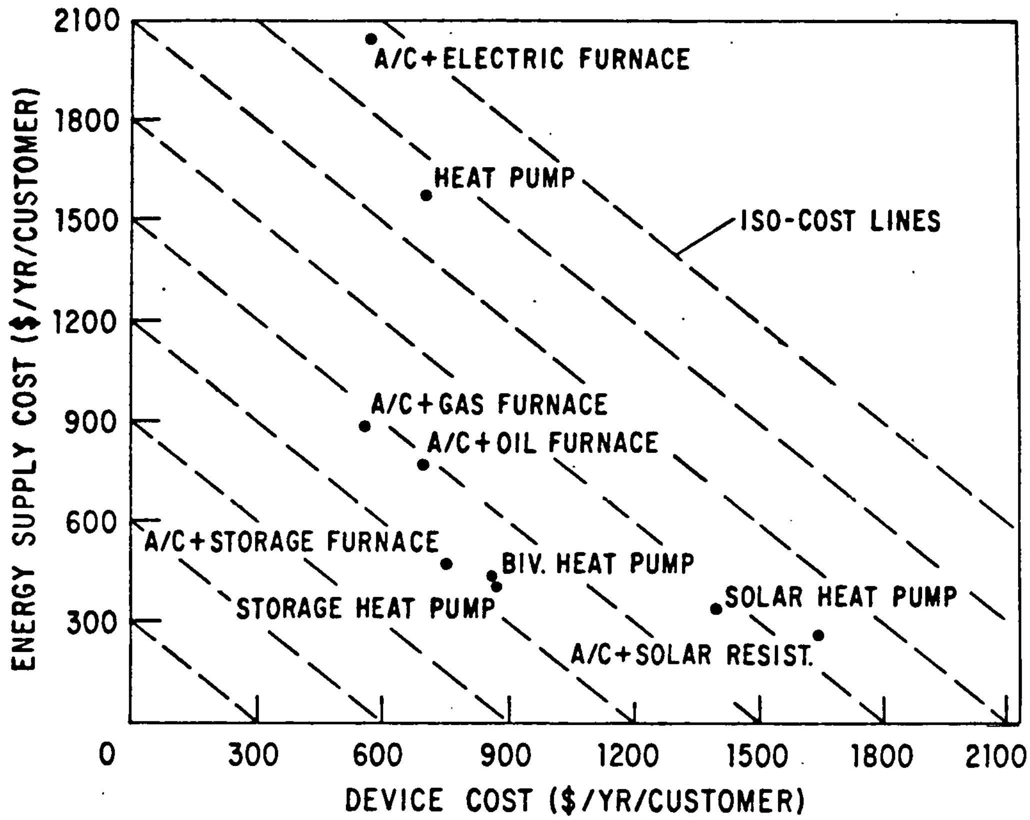

Fig. 1. Annualized Costs for Different Heating and Cooling Technologies, Winter-Peaking Service Area, Utility Cost of Money on Both Sides of Meter. "A/C" denotes a conventional central electric air conditioning system.

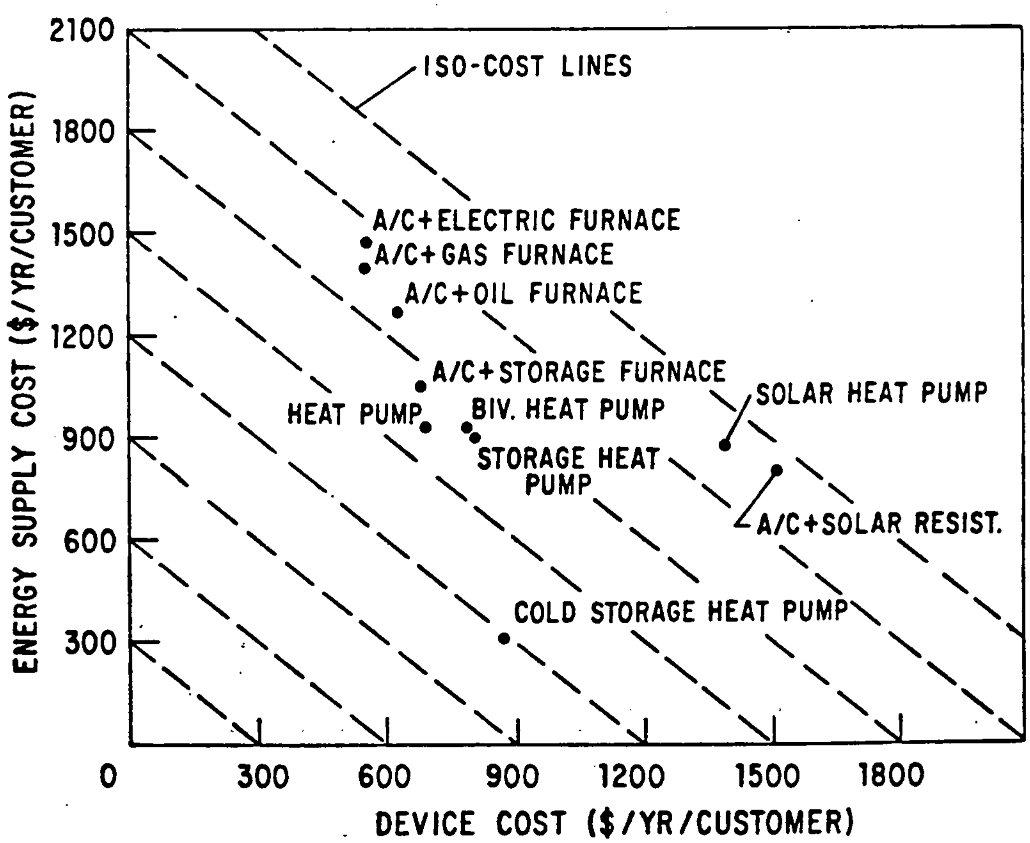

Fig. 2. Annualized Costs for Different Heating and Cooling Technologies, Summer-Peaking Service Area.

SUMMARY

An important finding, immediately evident in both figures, is that several electric-based heating technologies are cost-competitive with oil and natural gas heating. Among the electric-based technologies, the lowest cost systems in the winter-peaking service area are the storage resistance furnace combined with a conventional air conditioner and the heat pump augmented either by storage or by an oil furnace. In the summer-peaking service area, the heat pump with diurnal cool storage is the lowest cost system.

Although the foregoing results are strictly applicable only to the two service areas under study here, our analyses of other service areas indicate that load-managed electric heating is cost-competitive with oil and natural gas heating over most of the United States. For a nation wanting to reduce its dependence on foreign oil and attempting to conserve its domestic oil and gas reserves, the implications are obvious.

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