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MASTER

RESIDENTIAL ELECTRIC HEATING AND COOLING: TOTAL COST OF SERVICE

by

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INTRODUCTION

Until recently, the only electric technologies used for supplying heating and cooling services in the United States were electric resistance heating, vapor compression air conditioning, and, to a lesser extent, electric heat pumps. Confronted with sharply higher fuel and capital costs, electric utilities are now examining more closely other electric and electric-assisted technologies.

Several of the technologies under consideration for U.S. application are already available from European manufacturers. These include storage resistance heating systems and bivalent (dual-fuel) resistance heat and heat pump systems. In addition, electric utilities are testing and evaluating storage air conditioners and solar/resistance and solar assisted heat pump systems.

A number of these newer technologies offer substantially improved energy efficiency. However, aside from meeting requirements of reliability, maintainability, and consumer comfort, their potential for gaining acceptance among utility planners ultimately will depend upon their overall economic competitiveness relative to conventional systems.

In this paper, we report the findings of a recent study at Argonne National Laboratory to evaluate and compare the total costs of supplying space heating and cooling services with these alternative technologies. Under the study method, both the utility's cost of service and those device investment and maintenance costs borne directly by the customer were evaluated. Unlike the usual assumption of constant (time-independent) electric supply costs, the study used a detailed cost allocation model to calculate the utility capital and operating costs to meet device-specific loads.

Case studies of a number of utility service areas were performed. The two service areas for which results are presented here were selected to illustrate the important factors affecting the overall cost of service for the different heating and cooling technologies. One service area is located in the Northeast and is supplied by a winter-peaking utility; the other service area, located in the Middle Atlantic Region, is served by a summer-peaking utility.

Our analyses indicate that in the service area supplied by a winter-peaking utility the lowest cost space heating technologies are storage-augmented resistance systems and heat pump systems augmented either by storage or by an oil furnace. In the service area supplied by a summer-peaking utility, heat pumps are the most economical heating systems, while storage air conditioning is a cost effective technology for reducing the summer peak load.

HEATING AND COOLING TECHNOLOGIES

Total costs of space heating and cooling services were calculated for a number of electric and electric-assisted technologies.

Electric Storage Systems. In addition to evaluating conventional resistance heating, air-conditioning, and heat pump systems, the study examined storage-augmented versions of these systems. The basic function of the storage systems is to collect energy during off-peak hours for thermal application during peak-load hours. The economic rationale for storing off-peak electric energy is that the marginal cost of utility-supplied power is considerably lower during off-peak hours than during on-peak hours.

Although relatively new to the United States, electric storage heating has been successfully commercialized in a number of European countries. Britain and West Germany each have approximately 20 GW_e (150 GWh) of installed capacity (1); in West Germany this amounts to approximately 40% of system peak load. Both central furnace and room units are available from European manufacturers. For applications in new residential buildings, the central furnace systems are generally less expensive than the dispersed room units. Incorporating either refractory brick or cast iron as the storage medium, imported central furnace units can be installed at a cost of $8-10 per kWh over the cost of a standard electric furnace. Eventually, domestic production will reduce the costs of both dispersed and central storage systems.

Electric storage heaters can also be used with heat pumps, providing an alternative to direct resistance heaters that conventionally augment output below the heat pump balance point. Because in most climates the heat pump operates in a nearly fully resistance mode on the design-day, capacity requirements for the storage unit in such a hybrid system will be approximately the same as for the simple electric storage heating system described above.

Storage air conditioning systems are currently under development and testing by A.O. Smith Company and by Carrier Corporation. The most economical and practical systems for residential applications 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. A water-level sensor turns off the compressor before the ice rings merge, allowing water to circulate freely for efficient heat exchange during system discharge. Compressor size, due to the reduced hours of operation and lower evaporator temperature, is greater than for a conventional air conditioner. Depending upon the house size and the local climate, 150 to 300 gallons of storage capacity are required. Larger tanks can be used in commercial buildings. In residential applications, the incremental cost of storage air-conditioning ranges from $30-45 per kWh_e ($14-20 per kWh_t) of storage capacity.

Bivalent Systems. An alternative to the use of storage for reducing the electric peak loads associated with space heating systems is the incorporation of a gas- or oil-fired backup unit in the central heating system. The backup unit, ideally under the direct control of the electric utility, is switched on during peak load hours, thereby reducing utility peak capacity and fuel requirements. Bivalent heat pump and bivalent resistance heating systems are available from European and domestic manufacturers (2).

In simulations of the performance of the bivalent heat pumps, the auxiliary fuel unit is operated in either of two modes. Under the first mode, the auxiliary unit is operated so as to simulate and exactly substitute for the heat pump's electric resistance backup. Under the second mode of operation, the auxiliary unit is switched on during those periods when normally either resistance backup or utility peakers would be used.

When substituting for the operation of peaker plant, the bivalent system not only reduces peak capacity requirements but also saves fuel, because the oil furnace has a higher conversion efficiency than utility peaker plant.

In our simulations of the performance of bivalent direct resistance heating systems, we assumed the backup unit was turned on during periods when utility peaking plant otherwise would have been used.

Solar Systems. Two types of solar heating systems were evaluated — direct solar heating systems with electric resistance backup and solar-assisted heat pumps. Residential space heating represents one of the most promising applications of solar energy; however, as described in an earlier paper, active solar energy systems and conventional electric utilities are a poor technological match (3). In particular, because of the high fixed costs of electric generation, transmission, and distribution facilities, these facilities cannot be economically justified as a "standby" energy system to cover periods of solar insolation outage. Nevertheless, because of widespread interest in electric-solar heating systems, we have included them in the present analysis.

For solar augmented by resistance heating, either of two operating strategies can be adopted. Under the first strategy, or operating mode, the backup furnace switches on as required to augment the heat flow from the solar collector or the storage reservoir to the load. This is the mode of operation of most conventional solar systems.

The second mode, as conceived and advanced by several solar system designers, would take advantage of low cost off-peak electricity to augment solar energy supplies. Under this strategy, which requires predictive information about the following day's insolation and heating load, auxiliary energy requirements are input to the storage unit during the previous nighttime period. In practice to prevent degradation of solar collection efficiency, this mode of operation requires either the addition of a separate storage reservoir or maintenance of perfect stratification within the existing reservoir. For purposes of our analysis, we assumed perfect stratification with no increase in storage system cost.

Parametric studies were performed to analyze the tradeoffs between utility and customer costs as a function of collector area and storage capacity. Systems sized to meet 25, 50 and 75% of the annual space heating load were evaluated. For

Mode 1, the optimum storage capacity was found to be approximately equal to the average daily output of the collector system. For Mode 2, because of the possible unavailability of solar input on the peak winter day, the storage capacity was set equal to the full design-day building load, independent of the collector size.

A number of different solar/heat pump systems were also analyzed. The results presented here refer to the solar-assisted heat pump configuration in which solar energy is input to a storage reservoir on the cold side of the heat pump before delivery to the building load. Second phase heating is provided by the heat pump drawing from ambient air; and final phase heating, by resistance heaters. The solar/heat pump system in which storage is on the hot side of the heat pump and both the heat pump and solar collector supply energy directly to the storage reservoir was also examined. Our analysis indicated that this design concept is inferior to the one incorporating a solar-supplied storage unit on the cold side of the heat pump.

The costs assumed for the solar system components represent somewhat optimistic projections of near-term installed system costs. Relative to direct resistance heating systems, solar heating systems were assumed to have an incremental cost of $1,000 for plumbing and controls, $15 per square foot of collector area, and $1.00 per gallon of storage capacity. For the solar-assisted heat pump system, where lower performance collectors are acceptable, collector costs were assumed to be $\$10/ft^2$.

STUDY METHOD

In each service area the individual heating and cooling systems were matched to the load requirements of a 1500 ft^2, well-insulated, detached single family dwelling unit. The heating load amounted to approximately 4 kWh_t/degree-day.

The Argonne cost allocation model, SIMSTOR, was used to calculate the utility costs of meeting the individual heating and cooling device loads. The model uses hourly synoptic load and weather data and device performance characteristics to generate load profiles over a full annual (8760 hour) cycle (4). It then calculates the incremental utility capital and fuel costs to meet changes in the utility's load. SIMSTOR incorporates a load dispatch model and observes operating constraints such as scheduled and forced outages and the cycle time of each type of generating unit. It calculates transmission and distribution costs as well as generating costs. Because SIMSTOR uses an equilibrium method to solve for optimum plant capacity and mix, the long-run marginal cost estimates pertain to planning horizons beyond the construction times of projects to which utilities are already firmly committed.

The building-load submodels used to simulate the performance of the heating and cooling devices are based on ASHRAE-recommended response factor methods and take into account such effects as solar radiation incident on exterior walls and windows, internal heat generation, and wind surface film phenomena. All the major energy inputs and outputs for the devices were simulated, except water pump and fan electrical requirements. (The latter loads are small and, because they are roughly equal for all the technologies, do not significantly affect relative costs.) Device-specific load profiles were generated on an hourly basis over the full annual cycle.

In order to value units of capital consistently on both sides of the electric meter, one set of system cost comparisons was made with heating/cooling device capital costs calculated on the basis of the utility capital recovery rate. This accounting procedure is conceptually equivalent to assuming utility ownership of the heating/cooling device. Another set of comparisons was made with the customer cost of money equal to present mortgage rates less an effective income tax credit.

The annual utility capital costs were calculated with a 17% capital recovery rate for plant of 30 year lifetime. This rate, which is representative of recent utility experience, incorporates a large (≈6%) inflation component in the cost of both bond and equity money. For consistency, fuel costs, which were assumed to have a 0% real rate of escalation, were inflated at the same 6% rate and were discounted by the same (11%) discount rate. The resulting annual fuel levelization factor was equal to 1.77. Because initial-year fuel was valued at full marginal cost, this procedure is not expected to understate fuel costs relative to capital costs.

Utility energy supply costs for space heating technologies were calculated for an incremental load corresponding to the addition of 1000 space heating customers; for air conditioning technologies, the addition of 2000 customers. These load increments represent approximately 10 MWe of diversified peak electrical demand if met with conventional heating and cooling technologies. Although utility supply costs change as the number of installations increase — for example, the marginal cost of supplying storage heating customers increases as the nighttime valleys are filled - the dependence of supply costs on market penetrations is not discussed here (4). Thus the calculated marginal costs correspond to what economists would refer to as the case of perfectly inelastic demands.

Because load curves and weather data for a specific year, 1975, were used, the estimated utility supply costs do not constitute a forecast of the costs of meeting device-specific loads. Rather, the calculated costs may be interpreted as representative for utilities expecting to face load curves having shapes similar to the ones used here. Moreover, because of the heterogeneous nature of the electricity market, the estimates of the relative costs of the heating and cooling technologies are not regarded as constituting a universal ranking of the technologies. Before encouraging installation of a particular technology, a utility will want to evaluate the technology under conditions specific to its own service area.

STUDY FINDINGS

The estimated cost of the different heating and cooling technologies are presented in Tables 1 and 2 for the winter and summer peaking service areas, respectively. As indicated in Table 1, the storage and bivalent systems are the most efficient heating systems in terms of overall cost. 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 ripple-controlled bivalent heat pump is especially attractive. 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 shown in Table 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 only solar system offering supply costs comparable to those for the storage and bivalent heating systems is the solar resistance system operating in the second mode. By the very nature of the design of this system — essentially a storage resistance system <u>plus</u> a solar collector — the customer costs for this system are always greater than for a simple storage resistance heating system. As this system comparison makes clear and as pointed out in an earlier paper (3), the addition of a solar collector can be justified only in terms of the value of the off-peak utility supplied energy that it displaces. For Service Area A, the total cost of the solar storage technology becomes comparable to the cost of electric storage heating at a collector cost of about $4.50/ft^2, if it is assumed that the collector is financed at the utility cost of money. If lower cost home mortgage money is used to finance the solar system (as well as the competing, storage heating system), the collector breakeven cost is $7.00/ft^2.

Although the total cost of supplying space heating services with the solar-assisted heat pump is less than the total costs for the solar/resistance heating systems, the breakeven cost of the collector component is lower for the solar-assisted heat pump than for the solar/resistance heating systems in Service Area A. If the storage heat pump is chosen as the reference technology and if utility financing is assumed, the breakeven cost of the collector component of the solar-assisted heat pump is $1.40/ft^2. If home mortgage financing is assumed, the annual device costs of both the solar and the reference technology are reduced. The breakeven cost of the solar collector then falls below $1/ft^2, a difficult cost target indeed.

For the service area supplied by a summer-peaking utility, the entire heating season is off-peak so that the benefits of storage and bivalent heating systems are greatly reduced. The conventional heat pump is the most economical heating technology. Storage and bivalent technologies are 10-20% more expensive in terms of overall cost and suffer the disadvantage of being more complicated technologies. Solar/storage-resistance heating becomes cost competitive with storage resistance heating at collector costs of $2.75/ft^2 (utility financing) and $6.00/ft^2 (customer financing). Under either utility or customer financing, the breakeven cost of the collector component of the solar-assisted heat pump is less than $1.00/ft^2.

Figures 1 and 2 display annualized energy supply costs (utility capital and fuel and bivalent fuel costs) and device (customer) capital costs for each of the heating technologies. The dashed lines represent constant total cost curves. As shown in the figures, storage and bivalent systems are the most efficient technologies in the winter-peaking service area, while the conventional heat pump is the lowest cost technology in the service area supplied by a summer-peaking utility.

DISCUSSION AND CONCLUSIONS

Subject to the caveats required of any analysis based on a case studies approach, a number of important conclusions can be drawn.

In winter peaking service areas, several storage and bivalent technologies offer substantial savings relative to conventional heat pump and direct resistance heating systems. Largely neglected in the United States, these technologies merit the attention of utilities attempting to reduce the overall cost of electric heating services.

In the summer peaking service area, the conventional heat pump is the most cost-effective means of supplying heating services. This result, combined with the finding that storage air conditioning is a low cost method of providing summer space conditioning, indicates that a heat pump, using diurnal ice storage during the summer months, is an efficient technology for year round space conditioning.

The low breakeven cost values established for solar collectors are symptomatic of the problem of interfacing solar energy systems and electric utilities. The electric utility, because of the high fixed costs of generation, transmission, and distribution capacity is an inefficient source of "standby" energy for the solar energy system. In particular, it is virtually impossible to justify the solar-assisted heat pump when this technology is forced to compete with the storage heat pump.

The economic instrument that encourages the attachment of inefficient technologies to the electric supply grid and discourages the installation of efficient technologies is the present day electric rate schedule. Because the benefits of storage and bivalent technologies stem mainly from improved load factors rather than from direct kilowatt-hour savings, the only efficient and effective method of encouraging their installation is the introduction of some form of peak-load pricing. Following the British example, redesigned price offers may take the form of time-of-use rates or, following the German experience, the form of load management contract rates. If offered on an optional basis, the load management rate must be set sufficiently low relative to the standard rate to provide the customer with the required payback on his additional investment outlay.

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Table 1. Cost of Supply, Service Area A

System	System Characteristics	Contribution to Utility Peak (kW/Customer)	Average Utility Cost (¢/kWh)	Costs ($/Yr/Customer): Energy Supply: Utility: Generating[a]	T&D	Total	Energy Supply: Supplemental Fuel[b]	Device[c]: Util. Rate	Mort. Rate	Total: Util. Rate	Mort. Rate
Space Heating											
Resistance											
Direct	Central Electric Furnace	16.6	9.0	1125	820	1945	--	240	140	2185	2085
Storage	8 hour Central Storage	0.0	1.7	365	0	365	--	535	320	900	685
Bivalent	Ripple Controlled Oil Furnace Backup	0.0	2.9	580	0	580	45	610	380	1235	1005
Heat Pump											
Conventional	2.5 ton (SPF = 2.06)	15.0	11.8	730	740	1470	--	325	200	1795	1670
Storage	8 hour Resistance Storage	0.0	2.9	305	0	305	--	575	350	880	655
Bivalent (Mode 1)	Oil Furnace Backup	3.3	6.4	360	165	525	65	430	280	1020	870
Bivalent (Mode 2)	Ripple Controlled Oil Furnace	0.0	3.0	230	0	230	100	460	300	790	630
Solar											
Resistance	330 ft^2 (50% solar)	10.8	9.6	395	530	925	--	1300	760	2225	1685
Storage Resistance	330 ft^2 (50% solar)	0.0	1.6	155	0	155	--	1360	800	1515	955
Heat Pump	270 ft^2 (SPF = 2.3)	9.1	9.0	365	450	230	--	1110	650	1340	880
Air Conditioning											
Conventional	2.5 ton Heat Pump	0.0	4.3	95	0	95	--	255	175	350	270
Storage	8 hour Ice Storage	0.0	1.6	35	0	35	--	475	310	510	345

[a] Includes generation capital, fuel, cycling, and maintenance costs.

[b] Cost of fossil fuel for bivalent system.

[c] All heat pump device costs are net an air conditioner capital cost credit of $1050.

Table 2. Cost of Supply, Service Area B

System	System Characteristics	Contribution to Utility Peak (kW/Customer)	Average Utility Cost (c/kWh)	Costs ($/Yr/Customer): Energy Supply: Utility: Generating[a]	T&D	Total	Supplemental Fuel[b]	Device[c]: Util. Rate	Mort. Rate	Total: Util. Rate	Mort. Rate
Space Heating											
Resistance											
Direct	Central Electric Furnace	0.0	4.2	805	0	805	--	235	140	1040	945
Storage	8 hour Central Storage	0.0	1.9	370	0	370	--	415	245	785	615
Bivalent	Ripple Controlled Oil Furnace Backup	0.0	2.9	450	0	450	20	605	380	1075	850
Heat Pump											
Conventional	2.5 ton (SFP = 2.0)	0.0	2.7	260	0	260	--	325	200	585	460
Storage	8 hour Resistance Storage	0.0	2.3	220	0	220	--	440	270	660	490
Bivalent (Mode 1)	Oil Furnace Backup	0.0	2.5	185	0	185	60	430	280	675	525
Bivalent (Mode 2)	Ripple Controlled Oil Furnace	0.0	2.3	165	0	165	90	460	300	715	555
Solar											
Resistance	300 ft^2 (50% solar)	0.0	2.0	180	0	180	--	1200	710	1380	890
Storage Resistance	300 ft^2 (50% solar)	0.0	1.5	135	0	135	--	1280	750	1415	885
Heat Pump	270 ft^2 (SPF = 2.4)	0.0	2.4	200	0	200	--	940	550	1140	750
Air Conditioning											
Conventional	2.5 ton Heat Pump	5.5	23.3	415	265	680	--	255	175	935	855
Storage	8 hour Ice Storage	0.0	2.1	60	0	60	--	475	310	535	370

[a]Includes generation capital, fuel, cycling, and maintenance costs.

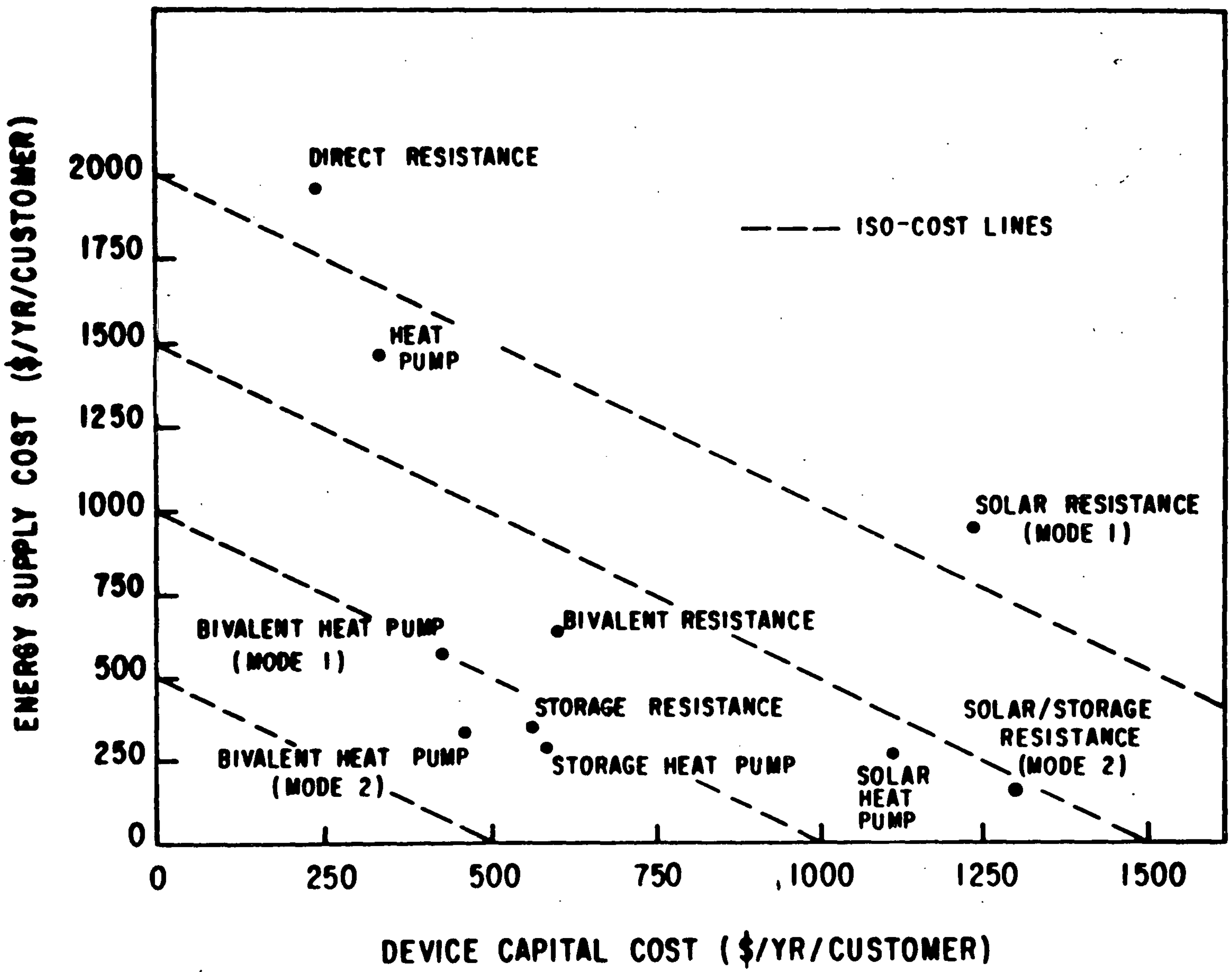
[b]Cost of fossil fuel for bivalent system.

[c]All heat pump device costs are net an air conditioner capital cost credit of $1050.

Figure Captions

Fig. 1. Annualized Costs for Different Electric Heating Technologies, Winter Peaking Service Area, Utility Cost of Money on Both Sides of Meter.

Fig. 2. Annualized Costs for Different Electric Heating Technologies, Summer Peaking Service Area, Utility Cost of Money on Both Sides of Meter.



DIRECT RESISTANCE
ISO-COST LINES
HEAT PUMP
SOLAR RESISTANCE (MODE 1)
BIVALENT HEAT PUMP (MODE 1)
BIVALENT RESISTANCE
STORAGE RESISTANCE
SOLAR/STORAGE RESISTANCE (MODE 2)
BIVALENT HEAT PUMP (MODE 2)
STORAGE HEAT PUMP
SOLAR HEAT PUMP
ENERGY SUPPLY COST ($/YR/CUSTOMER)
2000
1750
1500
1250
1000
750
500
250
0
250
500
750
1000
1250
1500
DEVICE CAPITAL COST ($/YR/CUSTOMER)

Fig 1

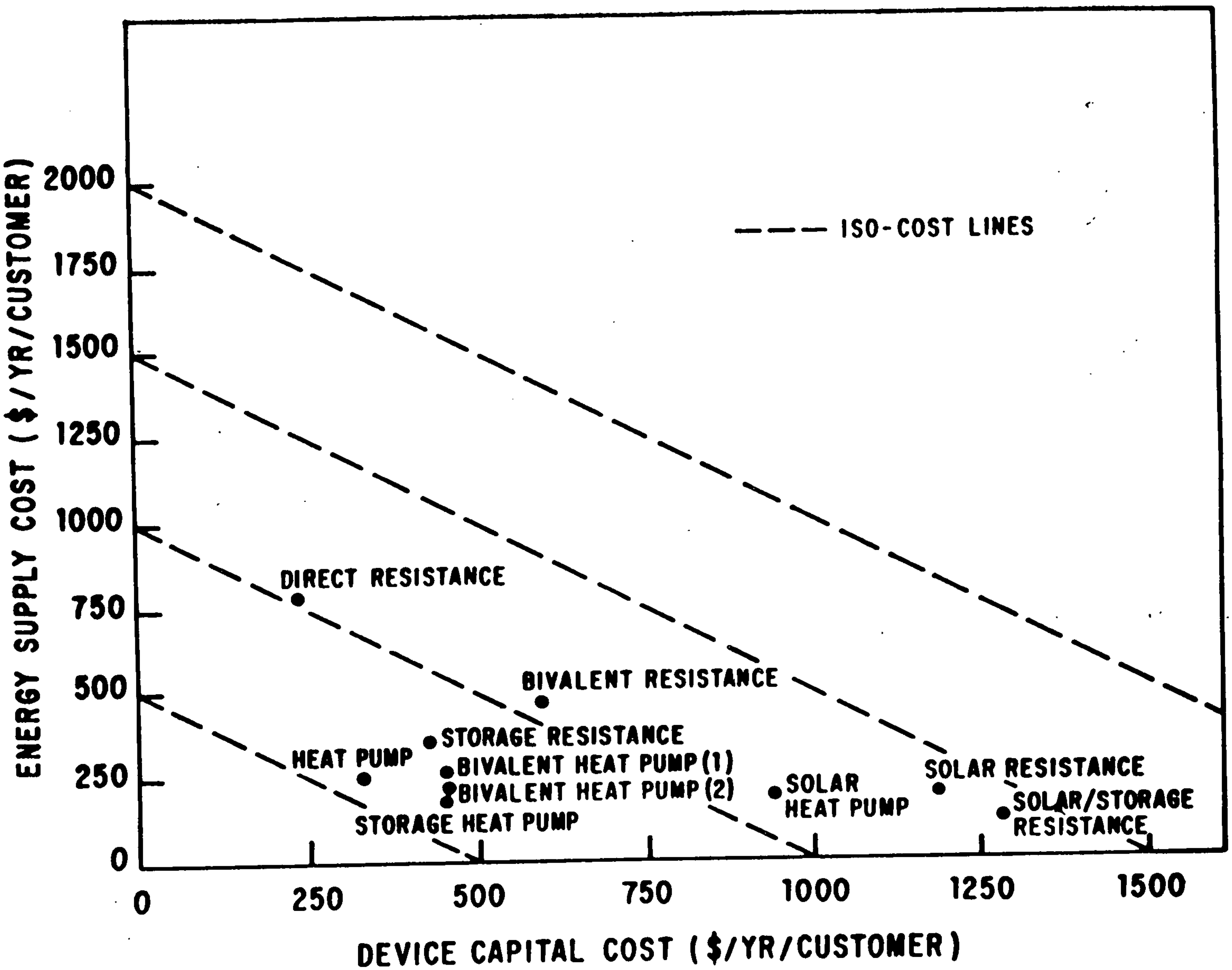

ISO-COST LINES
ENERGY SUPPLY COST ($/YR/CUSTOMER)
2000
1750
1500
1250
1000
750
500
250
0
DIRECT RESISTANCE
BIVALENT RESISTANCE
STORAGE RESISTANCE
HEAT PUMP
BIVALENT HEAT PUMP (1)
BIVALENT HEAT PUMP (2)
STORAGE HEAT PUMP
SOLAR HEAT PUMP
SOLAR RESISTANCE
SOLAR/STORAGE RESISTANCE
0
250
500
750
1000
1250
1500
DEVICE CAPITAL COST ($/YR/CUSTOMER)

Fig 2

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