329
6/28/78 BNL 50798 Dr. 207

TIME-OF-DAY PRICING OF ELECTRICAL ENERGY: DOES IT PROMOTE THE NATIONAL INTEREST?

A.L. Berlاد, F.J. Salzano, R.J. Hoppe, and J. Batey

October 1977

DEPARTMENT OF ENERGY AND ENVIRONMENT

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

UNDER CONTRACT NO. EY-76-C-02-0016 WITH THE
UNITED STATES DEPARTMENT OF ENERGY

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TIME-OF-DAY PRICING OF ELECTRICAL ENERGY: DOES IT PROMOTE THE NATIONAL INTEREST?

A.L. Berlاد,* F.J. Salzano, R.J. Hoppe, and J. Batey

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

October 1977

*College of Engineering and Applied Science, State University of New York, Stony Brook, N.Y. 11794

DEPARTMENT OF ENERGY AND ENVIRONMENT

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy (DOE), nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$4.00; Microfiche \$3.00

March 1978

465 copies

ABSTRACT

Time-of-day pricing of electrical energy involves rate incentives designed to encourage a shift of user demand from a utility's peak periods to its off-peak periods. Low "off-peak" rates may also serve as an incentive which encourages large, new, inelastic and/or inefficient uses of electrical energy. In the Long Island, New York area, installation of air-to-air heat pumps for space heating and cooling may be stimulated by currently proposed time-of-day pricing structures. Possible consequences of a significant market penetration of the Long Island home heating market by the air-to-air heat pump are considered. In this case, serious questions are raised regarding the ability of the time-of-day rate structure to achieve its espoused aims. This case may be typical of others throughout the country.

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction.....	1
II. The Air-to-Air Heat Pump vs. Fossil-Fuel-Fired Heating for Long Island, New York. Current Costs and Efficiencies.....	3
III. The Air-to-Air Heat Pump vs. Fossil-Fuel-Fired Heating for Long Island, New York. Operating Cost and Other Changes Which May be Engendered by a Given Time-of-Day Pricing Strategy.....	5
IV. References.....	11
V. Tables	
(1) Annual Performance of a High Quality Air-to-Air Heat Pump.....	12
(2) Annual Performance of a High Quality Oil-Fired Boiler.....	13
(3) Measured Operating COP (Overall) for a High Quality Air-to-Air Heat Pump Sized to Heat a 50,000 Btuh Design Heat Load.....	14
(4) Experimental Rate Structure Employing Time-of-Day Pricing for Electrical Energy.....	14
(5) Domestic Hot Water Costs.....	15
(6) Annual Operating Costs of the Previously Considered Heat Pump Installation, Based on the (Experimental) Time-of-Day Pricing Schedule for Electrical Energy.....	16
Acknowledgments.....	17

I. Introduction

It costs an electric utility more to deliver a kW-hour of electrical energy during its "peak load" periods than it does during its "off-peak" periods. During off-peak periods, only the most efficient electric generators, i.e., base load equipment, need be utilized. During peak-load periods, inefficient, standby generators generally have to be utilized. Further, the law requires that an electric utility meet current and future peak demands. Thus, plans for the construction of new generating capacity are heavily influenced by the "peak loads" anticipated in future years. Economies and benefits accrue to both customers and the environment if an unnecessary new plant is not built. Nevertheless, adequate and wisely employed plant, equipment and personnel are required to meet current and anticipated customer needs.

Accordingly, it is generally desirable to encourage consumers to shift their discretionary demands for electric energy from peak periods to off-peak periods. Elimination of sharp peaks and deep troughs in the utility's power versus time demand curve is expected to reduce the total annualized costs of providing services to energy consumers. Economists generally consider it desirable that each energy consumer group or class be charged according to the marginal cost or "fair" cost of service. It is thereby argued, that marginal cost pricing can help promote the aim of minimal annualized system costs as well as the aim of "fair pricing" of electrical energy.

In order to encourage desirable patterns of electric energy demand, time-of-day pricing has been suggested. Under such a pricing plan, peak period demand for electric energy would be more costly to the consumer, reflecting the higher costs as well as providing an incentive for the user to "shift" his demand to

an "off-peak" period. Lower rates for electric energy are to be charged during off-peak periods. Although time-of-day pricing would necessitate some changes in consumer habits, it is argued that consumer demand has the necessary elasticity to be responsive to the objectives of time-of-day pricing.

The idea of time-of-day pricing appears to have won substantial endorsements from consumers, environmentalists, and utility managers. Recent endorsements by various Public Service Commissions and related governmental institutions have been strongly supportive of the idea.

However, for a given electric utility service area, the use of the above noted arguments to justify a given time-of-day pricing structure may be quite hazardous. Such hazards may derive from untimely and/or undesirable new and expanded uses of electrical energy which are encouraged by low off-peak rates. If this is the case, the utility's rate structure would be promotional. We consider the specific case of the Long Island, New York area. Although consideration is limited to this specific case, conclusions reached may very well be representative of the situations in other areas of the country.

II. The Air-to-Air Heat Pump vs. Fossil-Fuel-Fired Heating for Long Island, New York Current Costs and Efficiencies

Heat pumps are generally powered by electric energy and during a winter heating season may consume a large fraction of the electrical energy generated. Fossil-fuel-fired systems have electrically powered peripherals, e.g. pumps, fans, igniters, which are found to consume less than five percent of the anticipated electrical energy required by a high quality, 5 ton air-to-air heat pump operating in the Long Island area.⁽¹⁾

At present, a negligibly small fraction of the home heating market on Long Island is captured by the air-to-air heat pump. Nevertheless, this class of device is one of the choices to be considered by builders and homeowners, when selecting new or refit heating systems. Anticipated near-term and long-term operating costs (heat pump vs. oil or gas) are clearly primary considerations to the consumer. We have calculated⁽¹⁾ the anticipated seasonal heating costs for a high quality air-to-air heat pump for the Long Island, New York area. Based on 1976-77 electric rate structures of 3.5 cents per kW-hr, these heating costs (for a 50,000 BTUH design heating load structure) for the heat pump are shown in Table (1). We have also calculated the anticipated seasonal heating costs for a high quality oil-fired boiler for the Long Island, New York area. These results are shown in Table (2). In both calculations, it has been assumed that the equipment has been wisely and properly installed and serviced. In the case of the heat pump, domestic hot water is assumed to be supplied by electric resistance heat. These detailed calculations take account of the typical hour-to-hour weather patterns in the Long Island area,⁽²⁾ as well as the various operating figures of merit measured for both heat pumps and oil burners. The operating heat pump coefficients of performance shown in Table (3) are taken from

Reference (3). The steady state and cycle efficiencies of oil burners were determined at Brookhaven National Laboratory.⁽¹⁾

It is clear from the results derived to date that for the Long Island Area:

- (a) the seasonal efficiency to be expected from a high quality oil-fired boiler (including domestic hot water for 12 months) is some 1.5 times that which is to be expected from a high quality air-to-air heat pump.
- (b) based on the regional costs of oil and electrical energy during the 1976-77 winter heating season, the corresponding costs bear a similar, but inverse, ratio. That is, for the typical case (space heating plus 80 gallons of domestic hot water per day) the seasonal energy costs expected for the air-to-air heat pump is some 1.5 times that which is to be expected for the oil-fired boiler.

Although the cost ratios cited for the two systems are not to be taken as life cycle cost ratios, current initial hardware and non-energy operating costs suggest that life cycle cost ratios are not less than the 1.5 calculated (above).

III. The Air-to-Air Heat Pump vs. Fossil-Fuel-Fired Heating for Long Island, New York. Operating Cost and Other Changes Which May Be Engendered by a Given Time-Of-Day Pricing Strategy

It is generally found that prospective buyers of new or refit heating equipment are substantially influenced by considerations of anticipated operating costs as well as initial equipment costs. Consider then, the changes that may occur in anticipated operating costs for the above heat pump installation if the time-of-day rate schedule of Table (4) is substituted for the 1976-77 fixed (winter) rate of \$0.035 per kWh (a special rate for "all-electric" homes). A rate structure such as that shown in Table (4) is being tested on a small scale test basis for implementation in the Long Island area.

We have modified the formulation of Reference (1) to account for time-of-day pricing strategies and have recalculated, accordingly, the seasonal operating costs to be expected for the previously considered high quality heat pump. Table (5) gives the integrated costs of generating domestic hot water (80 gallons per day) according to several alternate schedules. Assuming that prudent usage of domestic hot water implies a half day/half night schedule, we derive the total cost figures shown in Table (6).

Based on the proposed trial time-of-day pricing structure considered, the estimated heating and domestic hot water costs for the previously considered all-electric home on Long Island, using the air-to-air heat pump under discussion, are only 1.15 times those incurred during 1976-77 by the very high quality oil-fired boiler. Of course, time-of-day pricing has not changed the ratio of seasonal efficiencies of the two systems under consideration. However, it has made anticipated operating energy costs quite similar.

Accordingly, we may ask the following questions:

- (a) To what extent may we consider the proposed (trial) time-of-day pricing structure to be promotional--an incentive which encourages installation of low efficiency, but cost competitive space conditioning and other electrically operated equipment?
- (b) To what extent does the trial rate structure encourage owners of resistance heated homes to not convert to more efficient systems?
- (c) To what extent may we consider the proposed rate schedule of assistance to a public utility's penetration of a relatively new and large (heating) market for electrical energy?
- (d) To what extent will air-conditioning (summer) loads be increased by expanded use of air-to-air heat pumps into the market?
- (e) Should a significant, albeit minor, fraction of the Long Island home heating market be captured by the air-to-air heat pump, what effect will this have on anticipated electrical energy demand (load) patterns that result?
- (f) What fraction of the Long Island home heating market need be captured by the electric powered heat pump before the local public utility becomes a winter-peaking utility? (It is presently a summer-peaking utility).
- (g) What trends and major revisions in time-of-day rate structures will be engendered when a utility shifts from summer-peaking to winter-peaking?
- (h) Would time-of-day pricing then survive the punitive costs to be sustained by the air-to-air heat pump users--members of a newly captured market, heating their homes during peak usage periods?

- (i) What revisions would be engendered in terms of accelerated generating plant construction needed to service the Long Island area?
- (j) To what extent will the installation of future, more efficient heat pump systems be preempted by premature promotion of current day air-to-air heat pumps for the heating market?
- (k) To what extent will valuable energy storage facilities, in the form of customers' oil storage tanks, be replaced by homes having neither chemical nor thermal storage^(4,5) facilities.

We now employ the aforementioned data, together with demographic and energy data⁽⁶⁾ for the Nassau-Suffolk region of Long Island to examine some of the above questions.

Consider the expected changes in the winter peak electric power requirements for the Nassau-Suffolk area which would result if a significant fraction of the home oil-heat market were captured by a high quality air-to-air heat pump. The Dubin-Mindell-Bloome study of Energy Usage on Long Island⁽⁶⁾ takes the public utility's 1975 Winter Peak Load to be 2324 megawatts. The 1975 Summer Peak Load is 2892 megawatts. Thus, the ratio of 1975 winter peak to summer peak load is 0.80. The Oil Heat Institute of Long Island notes⁽⁷⁾ that some 650,000 residences in the Nassau-Suffolk area are oil heated. Studies⁽⁸⁾ of the in situ design heat load for single family residences in this area indicate a mean value of greater than 40,000 Btu per hour. Such a residence, heated by the high quality heat pump characterized in Table 3, would, under design conditions, i.e., conditions of lowest outside temperature and expected peak demand, have a COP of 1.05 and require 11.16 kW to meet its peak heating requirements. Accordingly, if only 10 percent of the (1975) oil-heated home heating market were "captured" by such air-to-air heat pumps, the electric utility's

winter peak demand would have been increased by

$$(65 \times 10^3) (11.16 \times 10^3) \text{ watts} = 725.4 \text{ megawatts.}$$

This is the space heating electrical peak power increase that would result from such a market penetration. It is also reasonable to assume that resistance heat is used for domestic hot water generation in a heat pump heated home---whereas an oil heated home generally employs oil heat for the generation of domestic hot water. To the winter peak load increase of 725.4 megawatts one should add the estimated⁽⁶⁾ peak power demands for domestic hot water, 0.9 kWt per household. Thus, an additional 58.5 megawatts is assumed to be required, at peak winter load periods, for domestic hot water for the 65,000 homes considered.

Accordingly, the revised 1975 Winter Peak Load would have been 3108 megawatts. That is, the net effect of a hypothetical 10% market penetration of the home oil-heat market in 1975 by a high quality air-to-air heat pump would have caused a normally summer-peaking utility to be transformed into a winter-peaking utility.

Reexamining the undesirable promotional aspects of the experimental time-of-day pricing strategies summarized in Table (4), leads us to the conclusions

- (1) The rate structure would provide a powerful price incentive to the preservation of current inefficient, resistance electric heat installations in homes.
- (2) The rate structure would provide a strong price incentive for the installation of relatively inefficient air-to-air heat pump installations and resistance heated domestic hot water installations.
- (3) Peak summer electric power demand would increase substantially due to expanded and/or new air conditioning and electric hot water installations.

- (4) Peak winter electric power demand would increase dramatically, causing a summer-peaking utility to be transformed into a winter peaking utility.
- (5) As consumers respond to the promotional pricing of off-peak electric energy, the new and evolving marginal costs may be dramatically higher than those anticipated by the consumer at the time when he invested in an air-to-air heat pump.
- (6) Where a greater than 10 percent home heating market by the air-to-air heat pump occurs, correspondingly greater base load capacity would generally be required.
- (7) Home heating is an absolute necessity on Long Island. Home cooling generally is not. Accordingly, the considered scenario introduces fairly inelastic demand in creating the winter peak under discussion.

One cannot help but view with apprehension the anticipated seasonal operating costs to be incurred by air-to-air heat pump homeowners if the "time-of-day" ("FAIR") pricing approach were to be continued, once a summer-peaking utility has become a winter-peaking utility. Under the proposed (trial) time-of-day rate, electrical energy users will be asked to pay twenty-six cents per kilowatt-hr during the (currently anticipated) summer-peak periods Table (4). Such a rate may indeed discourage (peak) summer uses where demand is elastic. But what if we consider such punitive energy prices for the winter-peak of the considered scenario? Could the (captive home heating) users of electrical energy be asked to pay twenty-six cents per kilowatt-hr when the outside air temperature is, say, less than 10° F?

One may also inquire about the validity of current cost analyses for all electrical systems for which time-of-day operational strategies are central. The implications are profound, for example, to analyses of operating costs for electric automobiles.⁽⁹⁾

It is generally thought that the batteries in these electric vehicles will be recharged with low cost electricity during off-peak periods and that these off-peak periods will generally occur during nighttime hours. This need not be the case. Analyses for electric resistance back-up systems for solar thermal space heating are similarly affected.

To what extent, then, may currently proposed time-of-day pricing fail to promote its espoused purposes of Energy Conservation and Consumer Equity?

Finally, we note that the issue of a national shift to decreased dependence on foreign oil impinges on the issues raised in this paper. We have not addressed any possible contribution to national goals which may derive from a shift to coal or nuclear-derived electrical energy. Nevertheless, if time-of-day pricing strategies are to play a role in promoting such a policy, detailed impact of time-of-day pricing requires greater delineation. An analysis of national impacts alone appears insufficient. Load and regional impacts of such pricing strategies may be substantial--and not necessarily in the public interest.

IV. References

- (1) A. L. Berlad, H. C. Lin, J. Batey, F. J. Salzano, W. S. Yu, R. J. Hoppe, and T. Allen. Seasonal Performance and Energy Costs of Oil or Gas-Fired Boilers and Furnaces. Brookhaven National Laboratory Report. BNL 50647 (March 1977).
- (2) Anon: E CUBE Weather Data, Pub: American Gas Association, Arlington, Va. (1975).
- (3) G. E. Kelley and J. Bean. Dynamic Performance of a Residential Air-to-Air Heat Pump. National Bureau of Standards Report BSS-93 (1976).
- (4) A. L. Berlad, F. J. Salzano, and J. Batey "On Enthalpy Management In Small Buildings". ENERGY 1, 429 (1976). Also BNL reports 20572 and 21577.
- (5) A. L. Berlad, H. C. Lin, F. J. Salzano, and J. Batey "Comfort Range Thermal Storage." ENERGY 2, 161 (1977).
- (6) Dubin-Mindell-Bloome Associates: "A Study of Existing Energy Usage on Long Island and the Impact of Energy Conservation, Solar Energy, Total Energy and Wind Systems on Future Requirements." Report to Department of Environmental Control, County of Suffolk, New York (Oct. 31, 1975).
- (7) Personal Communication. The Oil Heat Institute of Long Island.
- (8) A. L. Berlad, A Field Method For Determination of the Performance Parameters of an Operating Structure and its Heating System. Brookhaven National Laboratory Report, BNL 50684 (June 1977). Also, unpublished field surveys.
- (9) Anon. Electric Vehicle Demonstration Program. Phase I Performance Report. Long Island Lighting Company Report (November 1977).

Table (1)

Annual Performance of a High Quality Air-to-Air Heat Pump*

H ₂ O	0	40 gal/day	80 gal/day	120 gal/day
Annual Kwt-hrs used (Electrical)	20,400	24,005	27,609	31,214
Annual Costs of Electrical Energy (Heat Plus Domes- tic h.w)	\$714	\$840	\$966	\$1092
Overall (Seasonal) COP	1.72	1.61	1.53	1.47
Seasonal Effi- ciency (0.29)xCOP	0.50	0.47	0.44	0.43

*The operating COP is taken from Table 3. A 50,000 BTU hr design heat load is assumed in the N. Y. Metropolitan area and is based on 10 year average hourly weather data. It includes heat plus domestic hot water and the cost of electricity is assumed to be \$0.035 per kw-hr thermal.

Table (2)

Annual Performance of a High Quality Oil-Fired Boiler*

H _o	0 gal/day	40 gal/day	80 gal/day	120 gal/day	
Gallons of Oil Used Annually	1021	1214	1292	1380	
Annual kwt-hrs Used	677	713	723	734	
Annual Costs	\$480 30 \$510	\$571 32 \$603	\$607 33 \$640	\$649 33 \$682	Oil Elec. Total
Seasonal Performance Factor	.7845 -----	.7302 .2372	.7522 .4406	.7663 .5749	12 Months Summer Only

*The design heat load is assumed to be 50,000 BTU hr in the N. Y. Metropolitan area and is based on 10 year average hourly weather data. Heat plus domestic hot water are included. The assumed rates are \$0.045 per kWh electric and \$0.47 per gallon of No. 2 fuel oil. H_o corresponds to domestic hot water usage.

Table (3)

Measured Overall Operating COP for a High Quality
Air-to-Air Heat Pump Sized to Heat a 50,000 Btuh
Design Load.*

Measured (COP)	Outdoor Temp.
1.05	2°F
1.22	12°F
1.42	22°F
1.60	32°F
2.12	42°F
2.17	52°F
2.18	62°F

*NBS data from Reference 3. Return air is at 66°F, the fan is rated at 1680 CFM and is used only for heating.

Table (4)

Experimental Rate Structure Employing
Time-of-Day Pricing for Electrical Energy

(Long Island, New York)

Time Period (or Temperature Condition)	Cost per kwt-hr of electrical energy
Oct. 1 - May 31 10:00 p.m.-10:00 a.m. Daily, and Sunday	\$0.021
Oct. 1 - May 31 10:00 a.m.-10:00 p.m. Daily, Except Sunday	\$0.033
Temperature above 83°F	\$0.26

Table (2)

Annual Performance of a High Quality Oil-Fired Boiler*

H _o	0 gal/day	40 gal/day	80 gal/day	120 gal/day	
Gallons of Oil Used Annually	1021	1214	1292	1380	
Annual kwt-hrs Used	677	713	723	734	
Annual Costs	\$480 30 \$510	\$571 32 \$603	\$607 33 \$640	\$649 33 \$682	Oil Elec. Total
Seasonal Performance Factor	.7845 -----	.7302 .2372	.7522 .4406	.7663 .5749	12 Months Summer Only

*The design heat load is assumed to be 50,000 BTU/hr in the N. Y. Metropolitan area and is based on 10 year average hourly weather data. Heat plus domestic hot water are included. The assumed rates are \$0.045 per kWh electric and \$0.47 per gallon of No. 2 fuel oil. H_o corresponds to domestic hot water usage.

Table (3)

Measured Overall Operating COP for a High Quality
Air-to-Air Heat Pump Sized to Heat a 50,000 Btuh
Design Load.*

Measured (COP)	Outdoor Temp.
1.05	2°F
1.22	12°F
1.42	22°F
1.60	32°F
2.12	42°F
2.17	52°F
2.18	62°F

*NBS data from Reference 3. Return air is at 66°F, the fan is rated at 1680 CFM and is used only for heating.

Table (4)

Experimental Rate Structure Employing
Time-of-Day Pricing for Electrical Energy

(Long Island, New York)

Time Period (or Temperature Condition)	Cost per kw-t-hr of electrical energy
Oct. 1 - May 31 10:00 p.m.-10:00 a.m. Daily, and Sunday	\$0.021
Oct. 1 - May 31 10:00 a.m.-10:00 p.m. Daily, Except Sunday	\$0.033
Temperature above 83°F	\$0.26

Table (5)

Domestic Hot Water Costs*

Usage Pattern Season	Daytime Exclu- sively	Night- time Exclu- sively	Half Day/ Half Night
"Winter" (Oct. 1- May 31)	\$156	\$100	\$128
"Summer" (June 1- Sept. 30)	\$106	\$ 60	\$ 82
Seasonal Total	\$262	\$160	\$210

*Resistance-heated domestic hot water is assumed to be used in conjunction with an air-to-air heat pump system, operating on the time-of-day pricing schedule shown in Table (4). Assumed usage is 80 gals. per day.

Table (6)

Annual Operating Costs of the Previously Considered Heat Pump Installation, Based on the Experimental Time-of-Day Pricing Schedule for Electrical Energy Shown in Table (4).

Time Period	Cost per Kwt-hr. of Electrical Energy	Operating Costs for Period	Device Employed
Oct. 1- May 31 10 pm - 10 am daily & Sunday	\$0.021	\$249	Heat Pump Only
Oct. 1- May 31 10 am - 10 pm daily ex- cept Sun.	\$0.033	\$277	Heat Pump Only
12 month period (Domes- tic Hot Water Only)	As per schedule	\$210	Domestic Hot Water Only
12 month period Heat & Domestic H.W. (total seasonal costs)	-----	\$736	Heat Pump Plus Domestic Hot Water

Acknowledgments

It is a pleasure to cite several helpful discussions with Dr. William Marcuse and Dr. Phillip Palmedo, of Brookhaven National Laboratory.