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Division of Buildings
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SAVINGS in ENERGY CONSUMPTION by RESIDENTIAL HEAT PUMPS:

The Effects of Lower Indoor Temperatures and of Night Setback

R. D. Ellison

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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Energy Research and Development Administration
Division of Buildings and Industry

and

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ABSTRACT

The energy saving potential of reduced indoor temperatures and of night setback is examined for residential heat pumps. Close scrutiny of the relationship of energy consumption to heating load is required, particularly if night setback is anticipated. The morning recovery period occurs during what is typically the coldest part of the day, calling for maximum output from the system when its coefficient of performance (COP) is lowest. This effect and the desire for rapid temperature recovery indicate increased use of auxiliary resistance heaters and might result in an increase, rather than a saving, in total energy consumption. It is found, however, that energy savings ranging from 40% in Atlanta to 20% in Minneapolis may be realized if indoor temperatures are reduced from 72° to 68°F in the daytime and 60°F at night.

The National Bureau of Standards Load Determination (NBSLD) computer program was used to calculate heating loads. It was modified to evaluate the heating capacity, energy consumption, and running time of heat pumps on an hourly basis as a function of outdoor dry bulb temperature, and to simulate the use and energy consumption of auxiliary resistance heaters. Annual heating loads, energy consumption, percentage savings, and seasonal COP's are presented for several indoor temperature regimes and a variety of climatic conditions. Hourly profiles of these quantities give some insight into the energy savings found.

INTRODUCTION

Recent studies[1,2] of the energy consumed by residential space heating systems have predicted that substantial energy savings may be achieved by reducing indoor temperatures, and that further reduction of temperature at night will produce additional savings. Experimental observations[3,4,5] confirm the trends predicted by computer simulation of warm air systems driven by constant capacity gas, oil, or electric furnaces.

Implicit in previous simulation studies is the assumption that energy consumption is proportional to the space heating load. This assumption cannot, a priori, be applied if the heating system consists of a heat pump supplemented by resistance heaters even if indoor temperatures are held constant throughout the heating season. If night setback of indoor temperatures is anticipated, much closer scrutiny of the relationship of energy consumption to load is required. The morning recovery period occurs during what is typically the coldest part of the day, calling for maximum output from the system when the heat pump's coefficient of performance (COP) is lowest. This effect and the desire for rapid temperature recovery indicate increased use of the auxiliary resistance heaters and might result in an increase, rather than a saving, in total energy consumption.

The purpose of this computer simulation study is to compare energy consumption of heat pump systems (heat pump plus resistance heaters) for several different indoor temperature regimes under varied climatic conditions, and to assess energy savings that may be realized. In order to facilitate comparisons of savings found with those reported for constant capacity systems, calculations of heating loads are made for the same model home used by Pilati[2] in his night setback study. The performance of several heat pumps was simulated. Ratings were chosen so that the cooling capacities satisfied the cooling load, as is the usual procedure when a heat pump is actually installed for residential service. Except for this consideration, cooling performance of the heat pumps was omitted from the study.

Simulations of heating load and energy consumption were run using hourly weather information from six cities. These computations indicate that if the indoor temperature is reduced from 72 to 68°F (with no night setback), the percentage reduction of energy consumption is about the same as that of load reduction, ranging from 30% in Atlanta to 13% in Minneapolis. If indoor temperatures are reduced to 68°F daytime and further reduced to 60° at night, the energy saving is, in mild climates, less than the load reduction, ranging from 40% in Atlanta to 31% in Seattle, with corresponding load reductions of 44 and 35%. For colder climates the differences between energy savings and load reduction are smaller.

METHOD

The National Bureau of Standards Load Determination (NBSLD) computer program[6] was used to calculate hourly heating loads. It was modified to calculate heat pump output under the outdoor weather conditions of the hour, the heat required from auxiliary resistance heaters, and to estimate the energy consumption of both. Extensive "bookkeeping" sections were added to provide convenient daily, monthly, and yearly summaries of load, system output, consumption, and seasonal COP. Detailed hourly information for the coldest day of each month was made available.

T. Kusuda[6] has given an excellent description of NBSLD; however, a very brief summary may be useful. NBSLD solves the set of simultaneous heat balance equations at all interior surfaces of a room using conduction transfer functions to account for heat conduction through and storage in the walls (including roof and floor), and radiation exchange factors to account for radiant exchange between interior surfaces. Input data include detailed thermal parameters for each exterior wall, window, and door; inventories of expected internal heat sources such as lights and appliances for each hour of the day; and occupancy schedules. Weather data, also hourly, are read from magnetic tapes provided by the National Climatic Center.[7]

The heat balance equations are solved for each hour and the room temperature that would result if no heat were supplied (or removed) by the space conditioning equipment is calculated. The heat required to maintain the room temperature at set point is calculated and compared to the capacity of the heating system. If the system capacity is insufficient, NBSLD calculates the room temperature that may be expected and uses it as the starting point for the next hour.

For this study NBSLD was modified so that during execution of this part of the program it calls a new subroutine that provides the capacity of the heat pump at the outdoor temperature for that hour via a table look-up and interpolation of manufacturer's performance data. If the capacity exceeds that needed to maintain set point, the fraction of the hour that the heat pump must run is calculated and stored; if the capacity is insufficient to maintain set point or the room temperature is more than 2°F below set point at the start of the hour, auxiliary heaters are "turned on." Should the capacity of both heat pump and auxiliary heaters be insufficient, the program calculates (using the methods of NBSLD) the room temperature that will result.

In order to handle realistically the case that room temperature is below set point at the start of the hour, as occurs during the morning recovery period following night setback and may occur during very cold weather, an algorithm is provided for staging auxiliary heaters out as the room temperature approaches set point. Two schemes for control of the auxiliary heaters were simulated: (1) the usual arrangement of a two-stage indoor thermostat with one or more outdoor thermostats to stage the heaters; and (2) a multi-stage indoor thermostat that would, if available, stage in auxiliary heaters depending on the difference between room temperature and set point. The second scheme, a simple generalization of the first, was used in several simulations but was found to have negligible effect on energy consumption.

Figure 1 is an idealized plot of room temperature versus time during a morning recovery period for a system under control of a two-stage indoor thermostat. Time delays that may be built into the circuits that control

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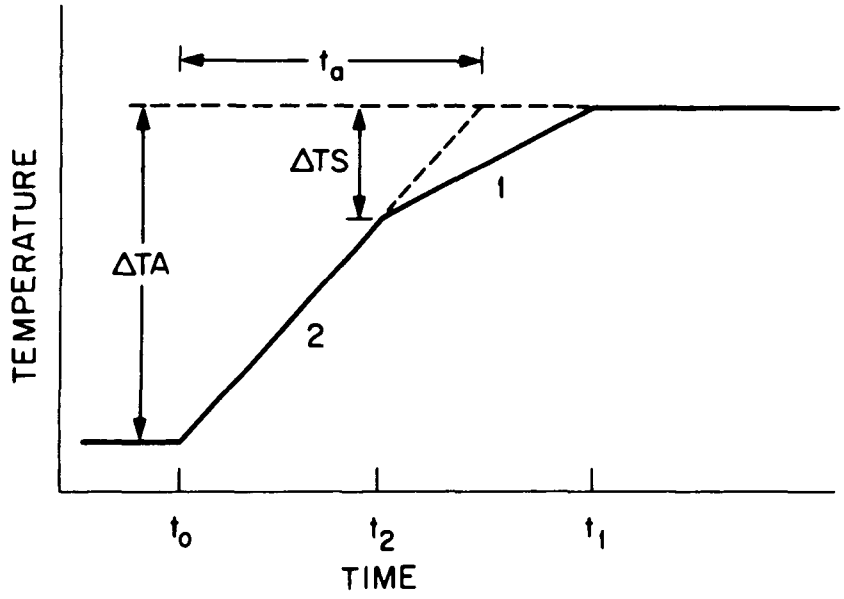

Fig. 1. Idealized plot of room temperature versus time during a morning recovery period.

resistance heaters (small, compared to recovery time) are ignored, as is the change in efficiency of the heat pump with indoor temperature. The latter omission, which is discussed below, is conservative in nature. Thus, the plot of room temperature versus time is approximated by straight line segments. Line Segment 2 in the diagram represents the rise in temperature while the heat pump as well as auxiliary heaters are turned on. Its slope is given by

$$S_2 = \Delta TA/t_a = \Delta TA/[QL/(qp + \sum_{i=1}^{n} qa_i)] ,$$

where

ΔTA = temperature rise required,

t_a = time required to achieve this rise if both heat sources remain on until set point is reached,

QL = heat required,

qp = heating rate of the heat pump alone,

qa_i = heating rate of the i-th resistance heater, and

n = number of heaters operating, a function of outdoor temperature.

The time t_2 that the resistance heaters remain on is then

$$t_2 = (\Delta TA - \Delta T_s)/S_2 \ ,$$

ΔT_s is the difference between set point and the temperature at which the second stage of the thermostat trips.

Line Segment 1 represents the rise in temperature while the heat pump alone is running. Its slope is proportional to S_2 by the ratio of the heating rates during the two time periods. Thus

$$S_1 = S_2 \ [qp/(qp + \sum_{i=1}^{n} qa_i)] \ ,$$

and the time that the heat pump runs is

$$t_1 = t_2 + (\Delta T_s/S_1) \ .$$

Since the heating load and room temperature are calculated each hour, t_1 and t_2 are constrained to the range 0 to 1.

Selection of the number of auxiliary heaters is on the basis of outdoor temperature. One heater is always available to supplement the heat pump and for use during the defrost cycle. Additional heaters, if available, are staged in at 10° and 0°F outside dry bulb temperature. At −10°F the heat pump is turned off and one resistance heater is turned on in its place. The use of an auxiliary heater during the defrost cycle is merely to prevent a flow of chilled air into the house; the heat produced during this use was not included in the summation of outputs of the system, but the energy used was added to the total consumption. Several methods are used by the different manufacturers of heat pumps to sense the need for control of frost formation on the evaporator. Rather than model the defrosting operation of a particular heat pump, it was estimated[8] that 5% of the compressor running time was spent defrosting if the outdoor dry bulb temperature was less than 45°F. Accordingly, an additional energy charge was made for that amount of time against one auxiliary heater if it was not already operating for at least half of the hour.

DATA

Manufacturer's performance data were used to provide heating capacity and energy consumption of heat pumps as a function of outdoor dry bulb temperature. These data, shown in Table 1 for a heat pump of rather high COP, were modified where necessary to account for reduction of heating capacity due to defrosting and to include heat generated and power consumed by indoor fan motors. No correction was made to performance data to account for increased capacity when pumping to indoor temperatures of less than 72°F because quantitative information was not available. The error introduced by this omission is in the range of 5 to 10% of capacity, but for a calculation of energy savings due to reduced indoor temperatures it is conservative. Calculated seasonal COP's for reduced indoor temperatures will be slightly low.

As previously mentioned, the model home used for this study is the same one as described in some detail by Pilati:[2] a single family detached house of about 1500 ft^2 floor area with three bedrooms, two baths, and a basement. Pertinent construction characteristics are given in Table 2.

Table 1. Integrated heating capacity and power input for heat pump

Outside db temperature °F	Heating capacity 1000 Btu/hr	Power input kWhr
-10	11.2	2.1
- 5	13.8	2.3
0	16.4	2.4
5	18.4	2.5
10	20.4	2.6
15	22.4	2.8
20	24.4	2.9
25	25.9	3.1
30	27.4	3.3
35	29.9	3.5
40	32.4	3.7
45	37.4	4.0
50	39.4	4.2
55	41.9	4.5
60	44.4	4.7

Table 2. Model home construction characteristics[a]

Exterior wall	1/2 in. gypsum board, 1-7/8 in. fiberglass insulation (reflective backing), 5/8 in. sheathing board, 4 in. face brick;
Ceiling	1/2 in. gypsum board, 3 in. fiberglass insulation;
Floor	3/4 in. hardwood floor, building felt, 25/32 in. subfloor;
Roof	5/8 in. wood deck, 1/4 in. asphalt shingles;
Windows (all single glazed)	(W-1) - 112 in. x 51 in. (W-2) - 37 in. x 51 in. (W-3) - 37 in. x 38 in. (W-4) - 53 in. x 51 in. (W-5) - 19 in. x 38 in.
Exterior doors	34 in. x 80 in. x 1-3/4 in. solid core;
Basement	below ground level, unheated, concrete block walls, and concrete slab floor.

[a]From Pilati, Ref. 2.

Heat, in addition to that from the heat pump system, is supplied to the house by appliances and lights according to the schedule shown in Table 3 which also shows the occupancy schedule.

RESULTS

Calculations of the heating load and the energy required to meet it were made using the thermal parameters of the model home and weather tapes from six cities chosen to span a wide range of climatic conditions. Simulations were run for the heating season only in Atlanta, Knoxville, Philadelphia, Seattle, Cheyenne, and Minneapolis. In each case, the room temperature was allowed to float if it exceeded the thermostat set point (no cooling was supplied). Calculations were made for constant thermostat settings of 72° and 68°F. Simulations to examine night setback effects are based on daytime indoor temperature of 68°F with setback to 60°F and to 55°F between the hours of 10 p.m. and 6 a.m.

Table 3. Hourly appliance and occupancy loading[a]

	Time period (hour ending)											
	1	2	3	4	5	6	7	8	9	10	11	12
Appliance and lighting load (kWhr)	0.41	0.41	0.41	0.41	0.41	0.41	0.60	0.98	1.45	0.77	0.77	1.01[b]
	1.16	0.45	0.65	0.65	0.83	1.45	0.74	0.74	0.74	0.74	0.41	0.41[c]
Occupancy (adults)[d]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	1.0	1.0	1.0	1.0[b]
	1.0	1.0	1.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0[c]

[a]The schedule is for normal weekdays. On weekends a 100% occupancy rate was assumed with no change in appliance schedule. On holidays the occupants were assumed away from 9 a.m. to 6 p.m. and the appliance loading was 0.4 kWhr during their absence. This table was taken from Pilati, Ref. 2.

[b]A.M.

[c]P.M.

[d]Children count as one-half an adult.

Summaries of the loads, energy consumption, and seasonal COP's are given in Table 4. Variations of these quantities with change of climatic conditions show the expected trends, as do the variations of load and consumption with change of indoor temperature. COP's, however, may show the reverse of the expected variation with indoor temperature partly because of the data inadequacies mentioned earlier, and partly because the energy consumed by auxiliary heaters to prevent flow of chilled air into the house.

Table 4. Yearly heating loads and energy consumption for six cities

THERMOSTAT SETTINGS DAY/NIGHT	HEATING LOAD MBTU	TOTAL INPUT KWH	COMPRESSOR INPUT KWH	COMPRESSOR HOURS	COMPRESSOR COP	AUXILIARY HEATERS HEATING KWH	AUXILIARY HEATERS DEFROST KWH	AUXILIARY HEATERS DEFROST HRS	SYSTEM SEASON COP[a]
ATLANTA									
72/72	31.2	3838.	3478.	945.	2.39	54.	305.	34.	2.37
68/68	21.7	2723.	2449.	683.	2.34	26.	248.	28.	2.32
68/60	17.5	2321.	1904.	533.	2.33	225.	192.	21.	2.20
68/55	16.7	2228.	1786.	497.	2.35	269.	174.	19.	2.19
KNOXVILLE									
72/72	43.2	5520.	4889.	1382.	2.32	125.	506.	56.	2.29
68/68	32.9	4255.	3765.	1086.	2.28	66.	424.	47.	2.26
68/60	27.8	3790.	3053.	883.	2.28	394.	343.	38.	2.15
68/55	26.3	3639.	2827.	812.	2.29	504.	309.	34.	2.11
PHILADELPHIA									
72/72	73.5	9436.	8150.	2316.	2.31	477.	859.	95.	2.24
68/68	59.2	7688.	6678.	1928.	2.28	258.	751.	83.	2.24
68/60	51.4	6980.	5601.	1620.	2.28	747.	632.	70.	2.14
68/55	48.4	6683.	5158.	1484.	2.29	957.	567.	63.	2.11
SEATTLE									
72/72	73.0	8748.	7999.	2124.	2.42	90.	660.	73.	2.41
68/68	56.6	6860.	6264.	1681.	2.40	43.	553.	61.	2.39
68/60	47.5	6014.	5109.	1371.	2.40	459.	446.	50.	2.29
68/55	44.9	5729.	4766.	1274.	2.41	563.	399.	44.	2.28
CHEYENNE									
72/72	113.8	16403.	11749.	3570.	2.23	3223.	1431.	159.	1.99
68/68	96.0	13773.	10214.	3152.	2.20	2254.	1304.	145.	2.01
68/60	85.3	12470.	8929.	2762.	2.20	2412.	1129.	125.	1.97
68/55	80.3	11898.	8240.	2539.	2.22	2652.	1005.	112.	1.95
MINNEAPOLIS									
72/72	126.0	20992.	11741.	3808.	2.19	7987.	1264.	140.	1.73
68/68	109.6	18154.	10593.	3498.	2.15	6320.	1240.	138.	1.75
68/60	100.0	16840.	9584.	3195.	2.13	6091.	1165.	129.	1.72
68/55	95.3	16289.	8969.	2995.	2.13	6253.	1067.	119.	1.70

[a]The system seasonal COP shown here is the ratio of system output to input. The system output (not included in this table) ignores humidification requirements and may be as much as 2-1/2% smaller than heating load, which does include humidification. COP's calculated as the ratio of heating load to system input would be very slightly (but misleadingly) higher.

during the defrost cycle is charged to the compressor, further lowering its calculated COP. The results shown in Table 4 for Atlanta, Cheyenne, Philadelphia, and Seattle are averages for the 5 year period starting with January 1955; those for Minneapolis are averaged from the 5 year period starting with January 1949; and those for Knoxville are for the calendar year 1955 — a year that had within 1% the same number of heating degree days as the 5 year average for that city.

The annual energy savings found, expressed as percentages of the energy consumed if the room temperature is held at 72°F, are shown in Table 5 along with the corresponding percentage load reductions. The savings that may be achieved by reduction of temperature to 68° day and 55° night range from 42% in Atlanta to 22% in Minneapolis with heating load reductions of 47 and 24% respectively. Energy savings and load reductions to be expected with night setback from 68°F daytime temperatures are shown in Table 6. It should be noted that the heating load reductions shown in these two tables are equal to the energy savings for a fixed capacity

Table 5. Percent reduction of heating load and energy consumption due to reduction of indoor temperatures from constant setting of 72°F (temperatures are shown as day/night)

	68/68		68/60		68/55	
CITY	LOAD	ENERGY	LOAD	ENERGY	LOAD	ENERGY
ATLANTA	30.6	29.0	43.8	39.5	46.5	41.9
KNOXVILLE	23.8	22.9	35.6	31.3	39.1	34.1
PHILADELPHIA	19.4	19.0	30.0	26.4	34.2	29.6
SEATTLE	22.5	21.6	34.9	31.3	38.5	34.5
CHEYENNE	15.6	16.0	25.1	24.0	29.4	27.5
MINNEAPOLIS	13.0	13.5	20.6	19.8	24.4	22.4

Table 6. Percent reduction of heating load and energy consumption due to reduction of indoor temperatures from constant setting of 68°F (temperatures are shown as day/night)

	68/60		68/55	
CITY	LOAD	ENERGY	LOAD	ENERGY
ATLANTA	19.1	14.8	23.0	18.2
KNOXVILLE	15.5	10.9	20.1	14.5
PHILADELPHIA	13.2	9.2	18.4	13.1
SEATTLE	16.0	12.3	20.6	16.5
CHEYENNE	11.2	9.5	16.3	13.6
MINNEAPOLIS	8.7	7.2	13.0	10.3

heating system, since for such systems the energy consumption is proportional to load.

Estimates of the savings that may be realized at locations other than the six cities shown in the tables may best be estimated from a plot of savings versus some quantity that conveniently expresses the severity of the winter. The usual choice for this quantity is heating degree days, and indeed, the choice is usually a good one for annual heating loads. As may be seen from Figs. 2 and 3, the choice is less satisfactory for energy savings when a heat pump is used. Since the COP of the heat pump is highly dependent on the outdoor temperature, length of the heating season (which increases the number of heating degree days) may be less important than the average temperature. There is little correlation between the two for different locations. For example, Strock and Koral[9] report that Seattle has an average winter temperature of 49.6°F, close to Atlanta's 50.5. But because of Seattle's very long 309 day heating season, it has almost twice as many heating degree days (5,443 to 2,857 for the 5 years used in this study). Percent savings versus average temperature, shown in Figs. 4 and 5, may be a more useful diagram for estimating savings for other cities.

If for the cities that have very long heating seasons, calculations are performed ignoring the days in June and August that may call for some heating, the decrease in percent savings is accompanied by a drop in average temperature. For Seattle the average temperature becomes 46.8°F and for Cheyenne it is 38.9. Figures 6 and 7, showing percent savings versus average temperature for these truncated heating seasons, may be more useful to those who have access to detailed temperature information for cities of interest not shown on the plots.

Hourly energy consumption of the heat pump and auxiliary heaters (including the use of heaters during the defrost cycle) is shown in Fig. 8 for four indoor temperature regimes for a day in Minneapolis when the average outdoor temperature was 9°F. The differences in consumption for 72 and 68°F indoor temperatures represent reduced use of auxiliary heaters at 68°; the consumption by the compressor is the same for both cases. During the hours of night setback there is reduced consumption by both the compressor and the heaters, and for 55°F night-time temperature the compressor alone met the load requirements. The increased (compared

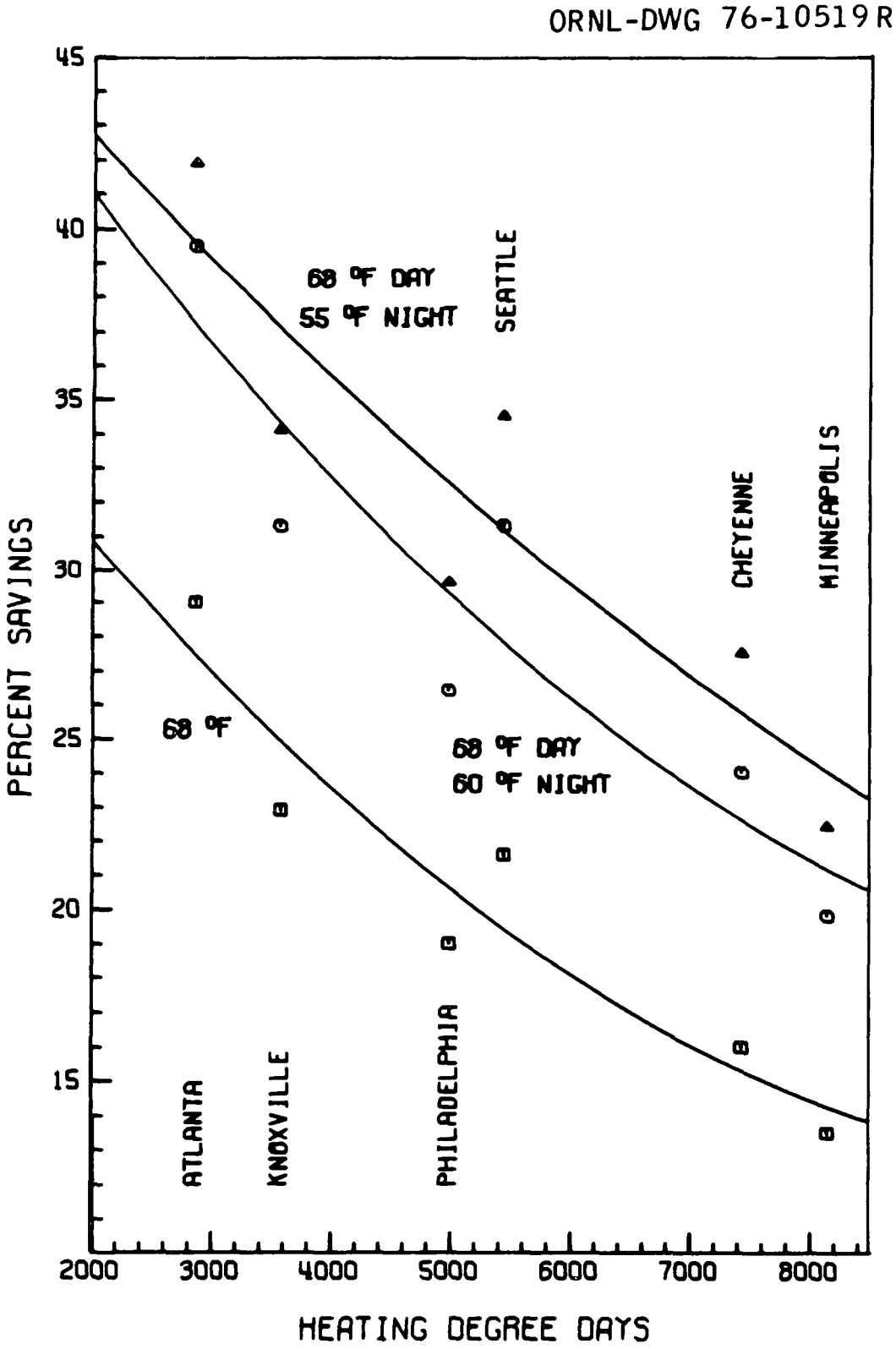

Fig. 2. Percent energy savings (compared to consumption at constant indoor temperature of 72°F) as a function of heating degree days.

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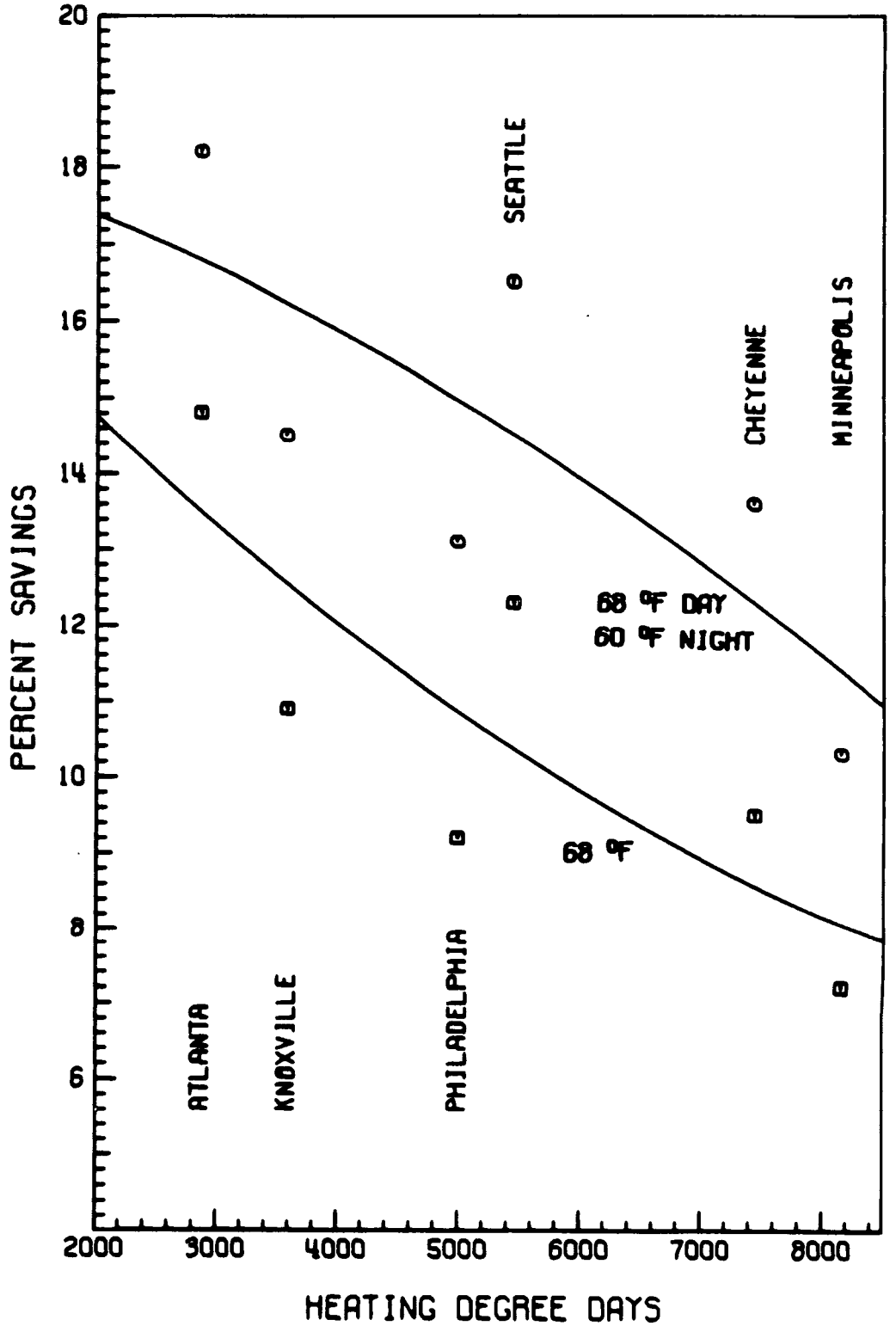

Fig. 3. Percent energy savings (compared to consumption at constant indoor temperature of 68°F) as a function of heating degree days.

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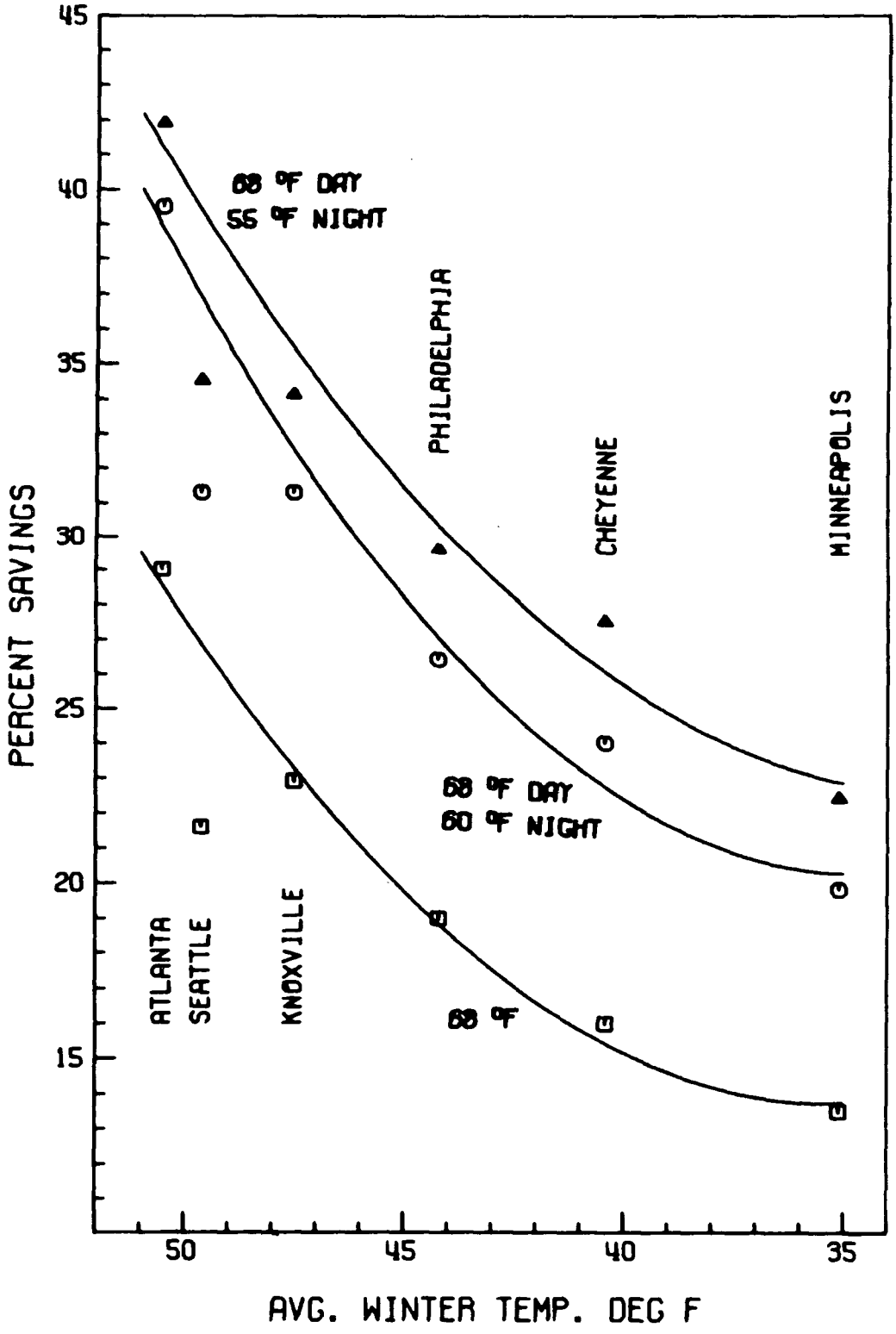

Fig. 4. Percent energy savings (compared to consumption at 72°F) as a function of average temperature during the heating season.

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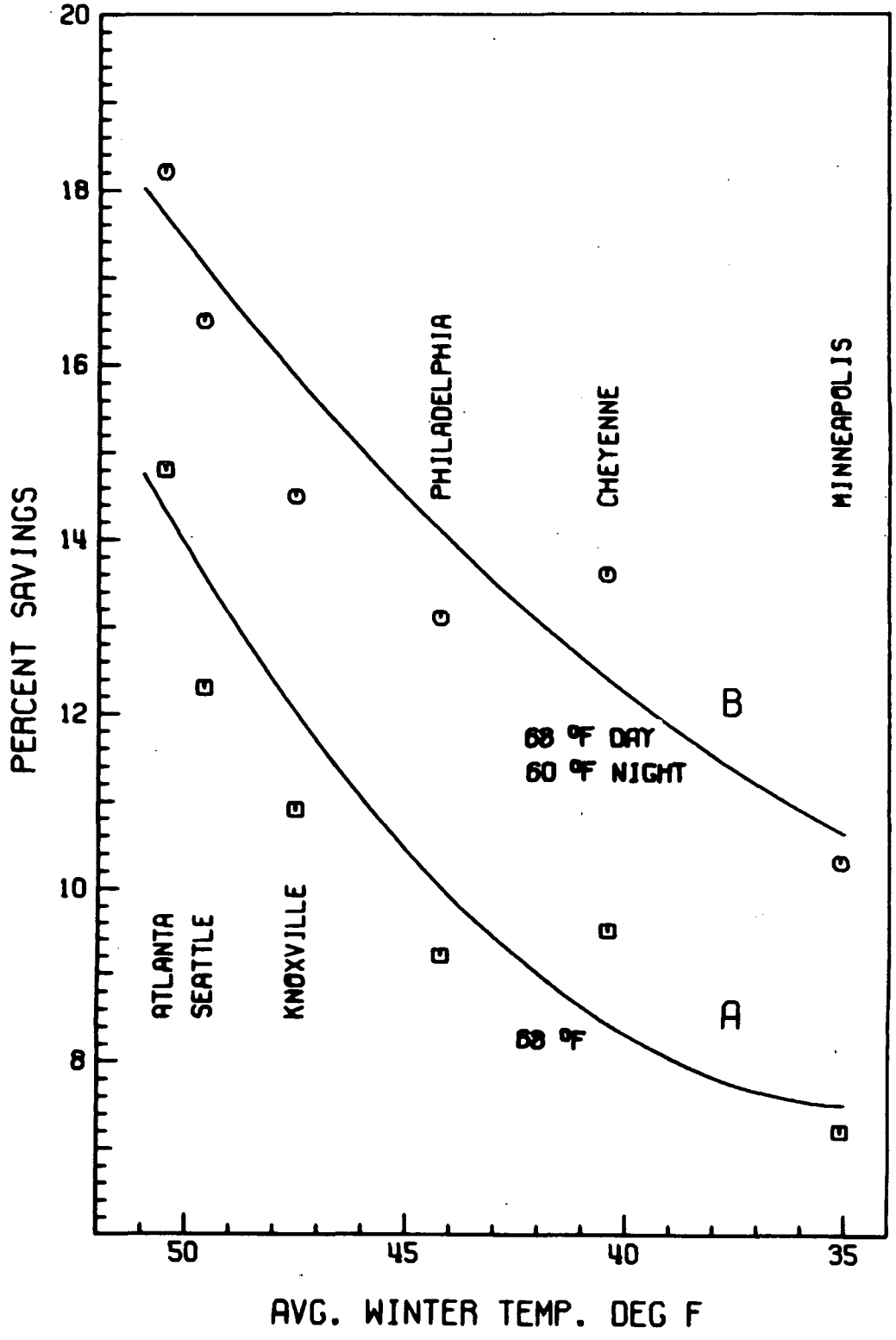

Fig. 5. Percent energy savings (compared to consumption at 68°F) as a function of average temperature during the heating season.

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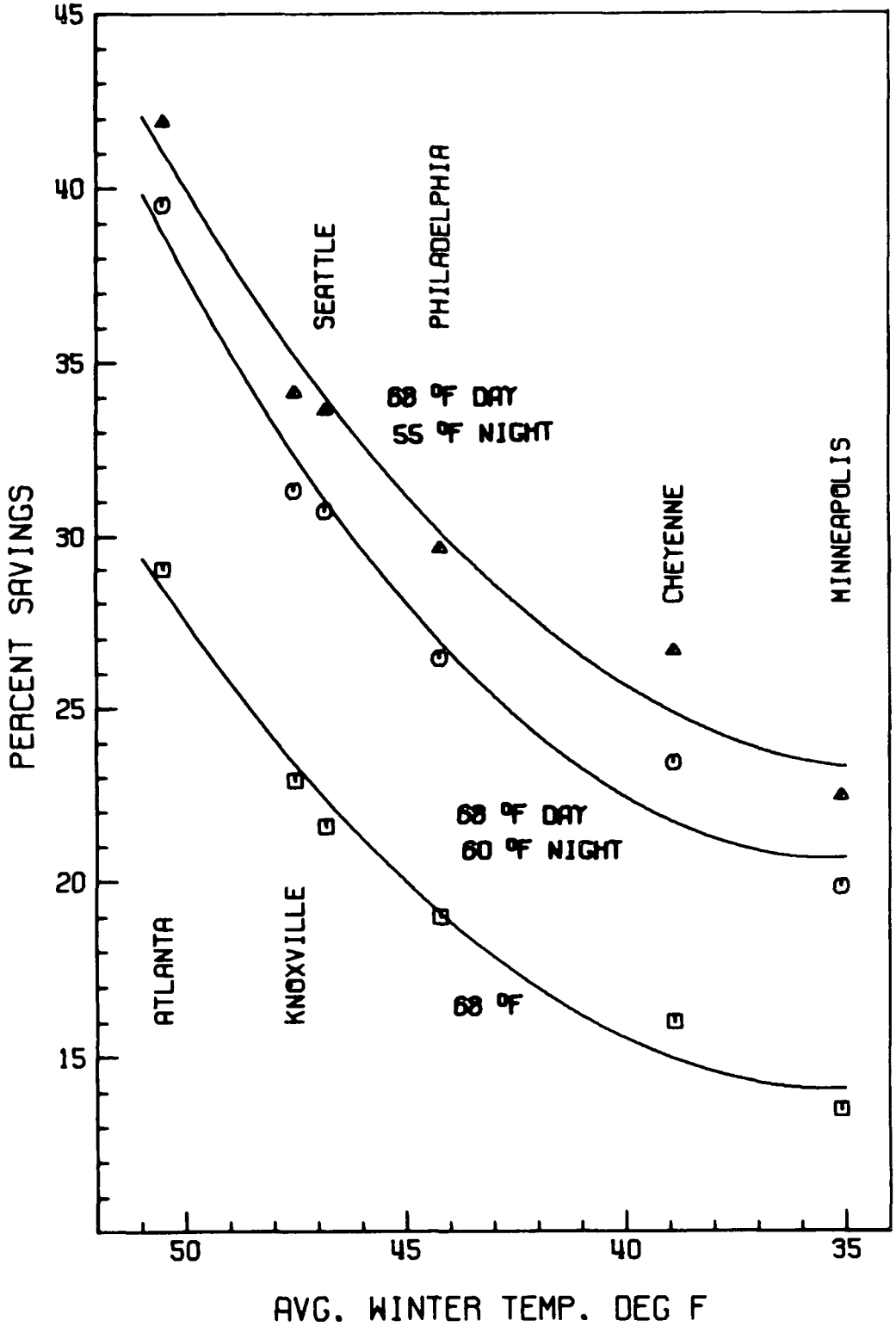

Fig. 6. Percent savings (compared to consumption at 72°F) as a function of average temperature for heating seasons limited to September through May.

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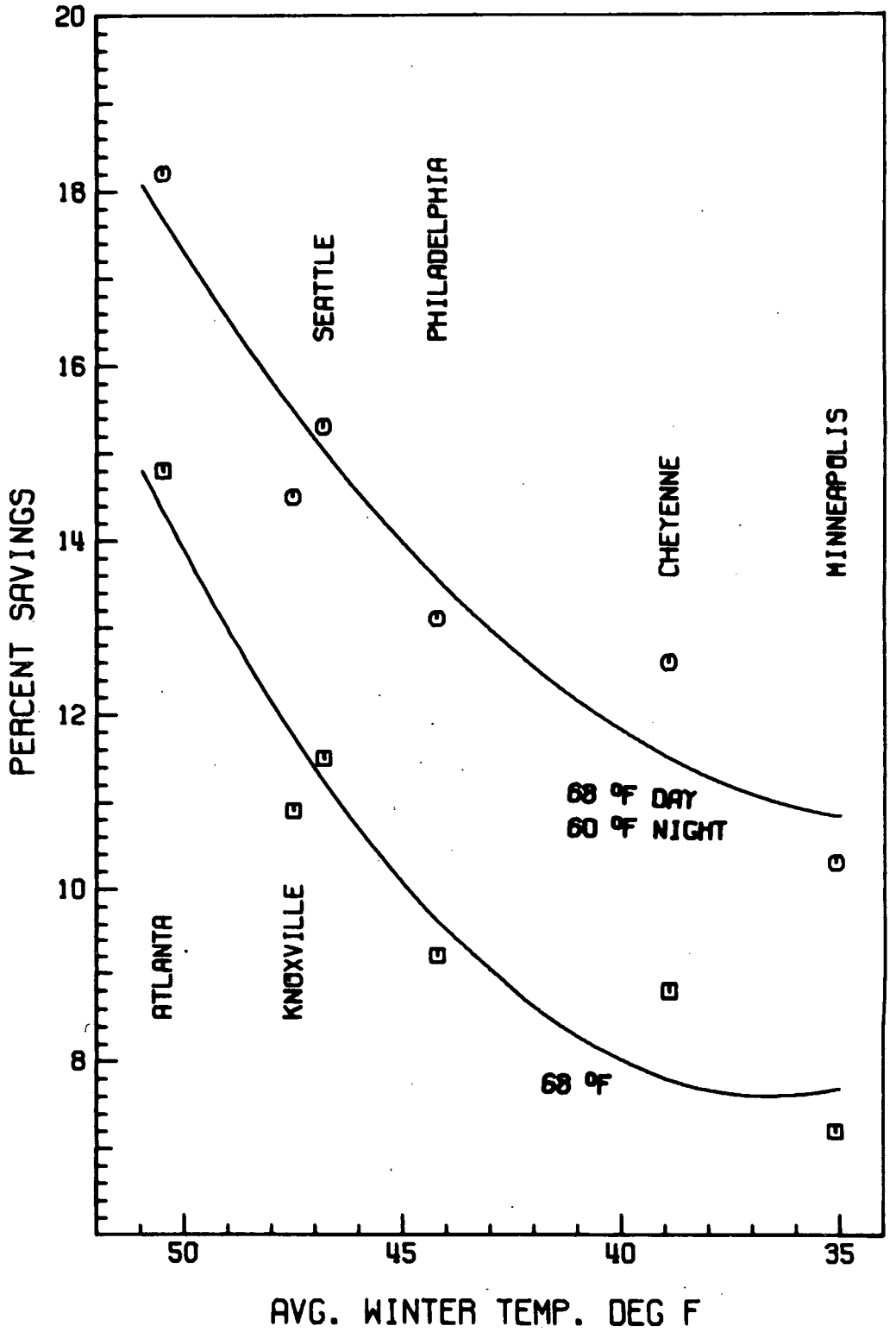

Fig. 7. Percent energy savings (compared to consumption at 68°F) as a function of average temperature for heating season limited to September through May.

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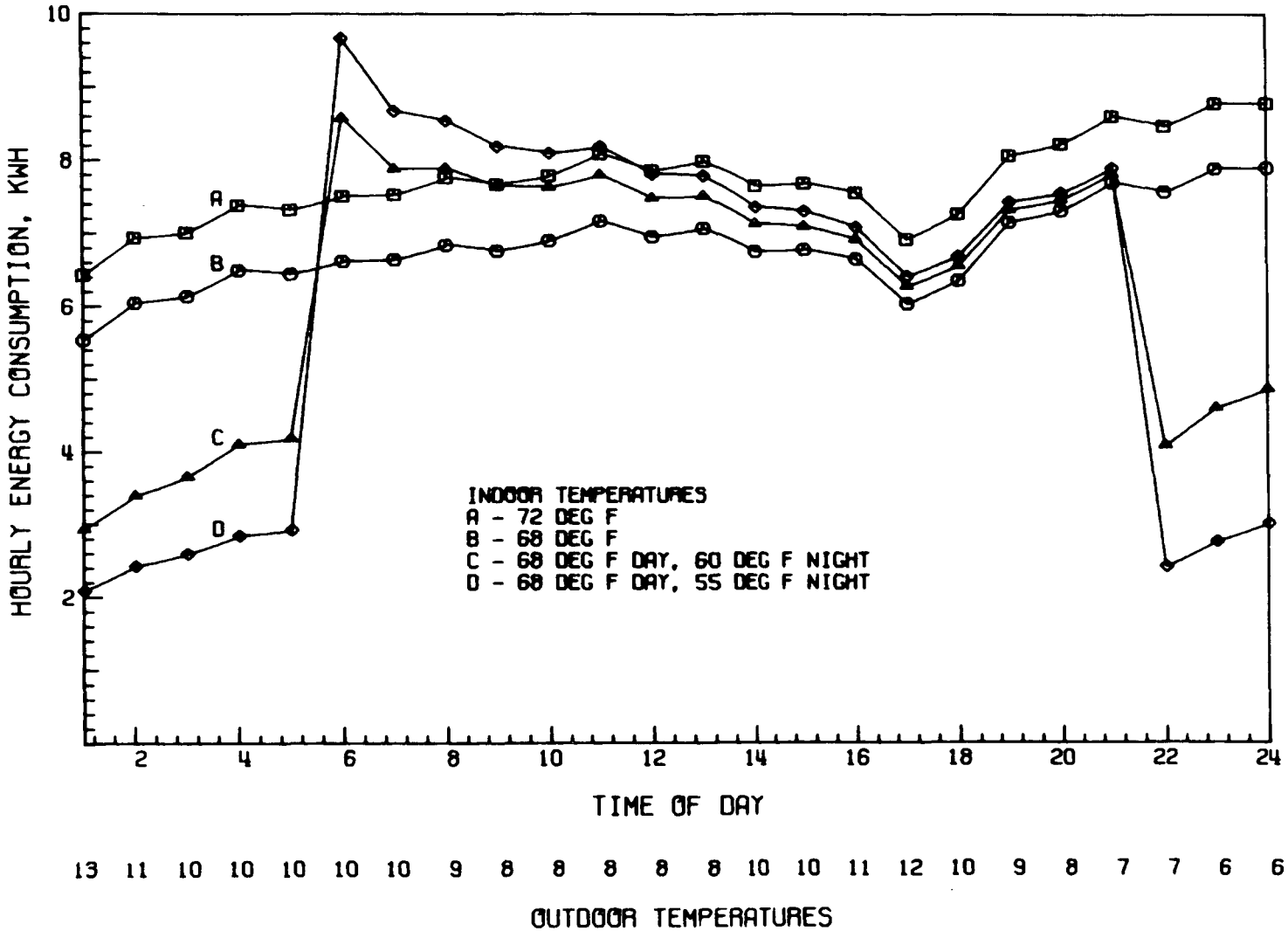

Fig. 8. Hourly energy consumption by a heat pump system during one day for four thermostat regimes. Each point represents the consumption for the hour starting at the time shown on the abscissa.

to 72°) consumption during the morning recovery period is due to increased use of auxiliary heaters. Total energy consumption for the day was 185.1 kWhr at an indoor temperature of 72°F, 163.5 kWhr at 68°, 150.7 kWhr for 68° day with 60° night, and 145.6 kWhr for 68° day with 55°F night-time temperature.

Clearly the increased consumption during the morning recovery period will add to the morning peak load experienced by the electric utility company. During the winter this peak typically occurs between 8:00 and 10:00 a.m. The maximum consumption by a heat pump system that has been set back at night occurs during the first hour of recovery and may take 3 to 4 hours to fall to the value expected if the temperature had been maintained at 72°F. It should be expected that night setback to 55°F with the recovery period starting at 6:00 a.m. will cause about a 10% increase in consumption by the heat pump during the 8:00 to 10:00 a.m. utility peak load.

All of the results presented above are based on performance data for a modern heat pump chosen for its rather high COP. Results of calculations for other heat pumps with lower COP are shown in the Appendix.

SUMMARY AND CONCLUSIONS

The user of a residential heat pump can, by reducing indoor temperatures, decrease energy consumption for space heating by about the same percentage as the user of a fixed capacity heating system. Further reduction of temperature at night will produce additional savings, with a heat pump, but not by as great a percentage as may be achieved with a constant capacity system. The concern that increased use of auxiliary resistance heaters during the morning recovery period following night setback might result in increased energy consumption, rather than a saving, is seen to be unfounded.

Selection of a heat pump for residential application is usually based on its cooling capacity rather than its heating capacity. Compensation for inadequate heating capacity can be provided by auxiliary resistance heaters, at some reduction of seasonal system COP; no compensation is available for inadequate cooling capacity. Excess heating capacity results in a short operating cycle accompanied by some reduction

in efficiency.[10] Excess cooling capacity results not only in reduced efficiency, but loss of humidity control as well. A "properly sized" heat pump will, then, have a cooling capacity approximately equal to the maximum hourly cooling load expected. Because the peak cooling loads for comparable houses in different parts of the country are remarkably similar, the heat pump will have excess heating capacity where winters are mild, and insufficient heating capacity where winters are severe.

This excess of heating capacity in mild climates means that the auxiliary resistance heaters will be used more during the defrost cycle (to prevent a flow of chilled air into the house) than for augmenting the heat pump if indoor temperature is held constant. If, following night setback of temperature, rapid recovery is demanded, there will indeed be increased energy consumption by the resistance heaters. This increase is, however, smaller than the decrease in consumption by the compressor, so that there is a substantial net saving of energy.

Where winters are as severe as these experienced by Minneapolis, the heating capacity of the heat pump is expected to be insufficient. The principal use, then, of the auxiliary heaters is to augment the heating capacity of the heat pump, rather than to counter the unpleasant effects of the defrost cycle, whether indoor temperature is held constant or reduced at night. One may then expect reduced consumption by both the compressor and the auxiliary resistance heaters if night setback of indoor temperature is anticipated, and of course, a net reduction of energy consumption for space heating.

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APPENDIX

Energy requirements of three heat pumps meeting the same load requirements are shown in Table 7. Two of the heat pumps are relatively new models, the third an older model. Calculations are based on manufacturers' performance data, modified to account for reduction of heating capacity due to defrosting and for the heat generated and power consumed by indoor fan motors. As stated before, no correction was made to account for increased capacity when pumping to reduced indoor temperatures. Seasonal COP's are thus under-estimated if indoor temperatures are less than 72°F.

The energy consumed by auxiliary heaters when they are used to prevent flow of chilled air into the house during the defrost cycle is charged to the compressor, further lowering its calculated seasonal COP. The results shown in Table 7 are based on calculations for the calendar year 1955 in Knoxville. The load reductions and energy savings, expressed as a percentage of the loads and energy consumption at constant 72°F, are shown in Table 8. Those compared to the same quantities at 68°F are shown in Table 9.

Heating load reductions reported here are not significantly different from those given by Pilati[2] for the same house under similar conditions. Percentage energy savings are somewhat smaller than corresponding per-

Table 7. Yearly heating loads and energy consumption: comparison of three heat pumps

THERMOSTAT SETTINGS DAY/NIGHT	HEATING LOAD MBTU	TOTAL INPUT KWH	COMPRESSOR INPUT KWH	COMPRESSOR HOURS	COMPRESSOR COP	AUXILIARY HEATERS HEATING KWH	AUXILIARY HEATERS DEFROST KWH	AUXILIARY HEATERS DEFROST HRS	SYSTEM SEASON COP
HIGH COP									
72/72	43.2	5520.	4889.	1382.	2.32	125.	506.	56.	2.29
68/68	32.9	4255.	3765.	1086.	2.28	66.	424.	47.	2.26
68/60	27.8	3790.	3053.	883.	2.28	394.	343.	38.	2.15
68/55	26.3	3639.	2827.	812.	2.29	504.	309.	34.	2.11
MED. COP									
72/72	43.2	6399.	5710.	1705.	2.03	374.	315.	67.	1.97
68/68	32.9	4951.	4481.	1355.	1.99	200.	270.	57.	1.95
68/60	27.8	4341.	3649.	1106.	1.98	473.	219.	47.	1.88
68/55	26.3	4155.	3343.	1009.	2.00	618.	193.	41.	1.85
LOW COP									
72/72	43.2	7795.	7288.	1431.	1.64	221.	285.	57.	1.62
68/68	32.9	6064.	5692.	1130.	1.60	131.	241.	48.	1.59
68/60	27.8	5247.	4656.	927.	1.60	393.	198.	40.	1.55
68/55	26.3	4976.	4290.	851.	1.61	510.	176.	35.	1.55

centage load reduction particularly when night setback is involved. As expected these differences are largest with a heat pump of high COP, and, of course should drop to zero as the COP of a system approaches unity.

Table 8. Percent reduction of heating load and energy consumption due to reduction of indoor temperatures from constant setting of 72°F for heat pumps with different COP's (Temperatures are shown as day/night)

HEAT PUMP	68/68 LOAD	68/68 ENERGY	68/60 LOAD	68/60 ENERGY	68/55 LOAD	68/55 ENERGY
HIGH COP	23.8	22.9	35.6	31.3	39.1	34.1
MED. COP	23.8	22.6	35.6	32.2	39.1	35.1
LOW COP	23.8	22.2	35.6	32.7	39.1	36.2

Table 9. Percent reduction of heating load and energy consumption due to reduction of indoor temperatures from constant setting of 68°F for heat pumps with different COP's (Temperatures are shown as day/night)

HEAT PUMP	68/60 LOAD	68/60 ENERGY	68/55 LOAD	68/55 ENERGY
HIGH COP	15.5	10.9	20.1	14.5
MED. COP	15.5	12.3	20.1	16.1
LOW COP	15.5	13.5	20.1	17.9

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