Load Characteristics of Southeastern Iowa Farms Using Electric Ranges

by Landy B. Altman, Jr. and Emil H. Jebe
Department of Agricultural Engineering
Statistical Laboratory

Farm Electrification Section
Agricultural Research Service
United States Department of Agriculture
cooperating

AGRICULTURAL EXPERIMENT STATION, IOWA STATE COLLEGE

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Most farms now have electric energy supplied from central stations. As the number of farms using electricity increased and as the application of the electrical energy to agricultural production expanded, it became evident that the electric load characteristics of farms were different from those of residential consumers. The farm is a business establishment as well as a residence. Electricity is used in brooding, water pumping, machinery repair, feed handling and processing, milking, refrigeration and many other productive operations. These uses of electricity often occur at the same time as similar uses on adjacent farms and at a time when electrical household equipment is in operation.

Load research is a detailed examination of small numbers of consumers assumed to be representative of a large group to determine load characteristics. Many such studies have been made by the larger utilities. The information obtained is used in system design, rate analyses, long-range planning and sales promotion programs. Since most farms are served by smaller electric distribution companies and cooperatives which have been unable to undertake this type of research, the United States Department of Agriculture in cooperation with the Iowa Agricultural Experiment Station and several Iowa power suppliers is making a series of studies of farm load characteristics.

The first of these studies (1) was a load survey on a case-study basis conducted in 1950-51. Although considerable information was obtained, only 16 farms from a small area were metered. The farms used were chosen on basis of ownership of major appliances without any attempt at random selection. The following study of farm load characteristics was designed to overcome some of the limitations in the previous one.

LOCATION OF STUDY AREA

The Eastern Livestock Area of Iowa was chosen for this study as a matter of convenience and because farming practices and enterprises in this area are similar to those followed in much of the Corn Belt. An additional reason was the desire to associate this study with an economic survey of the use of electricity in this area (2).

* This study was conducted by the Agricultural Research Service, United States Department of Agriculture, in cooperation with the Iowa Agricultural Experiment Station (Project 1081) and seven Iowa electric distribution companies and cooperatives.

The areas in which metering was done are shown in fig. 1. There were four sets of meters used in Marshall County, two sets with their use divided between townships in Muscatine and in Cedar counties, and two sets in each of the other counties. Power suppliers in these counties installed and moved as instructed the metering equipment used in this study.

SELECTION OF THE SAMPLE

Since the sample size in this survey was restricted by the number of meters available, 14, it was decided to limit the sampling to a homogeneous group. The range was selected as the determining characteristic in choosing farms for this study. It is well known that the range has an important effect on the electrical load characteristics of households, and it was believed that this effect would appear on the farm load as a whole.

Seven power suppliers agreed to install the 14 sets of meters. The universe from which the sample was drawn was restricted to the four townships most convenient to each power supplier's office. One township was selected at random at each location. The names of all the farms in the selected township that owned ranges were listed. Six names were randomly drawn from each list.

The order of metering was randomized each month. At each location two of the six farms were metered for one week, and the two sets of meters were rotated among the six farms in accordance with the randomization schedule. In cases where suitable records were not obtained, the farm was remetered the fourth week of the month. Even so, six of the weekly demand records could not be obtained because of faulty meter opreation or inaccessible roads during winter months. Farms were metered in the months of May, July, September and November 1952 and January and March 1953.

DESCRIPTION OF SAMPLE FARMS

An information schedule showing the ownership of various electrical appliances, size of farm, electrical energy used in 1951, the year electrified, livestock enterprises, size of house, number of people on the farm

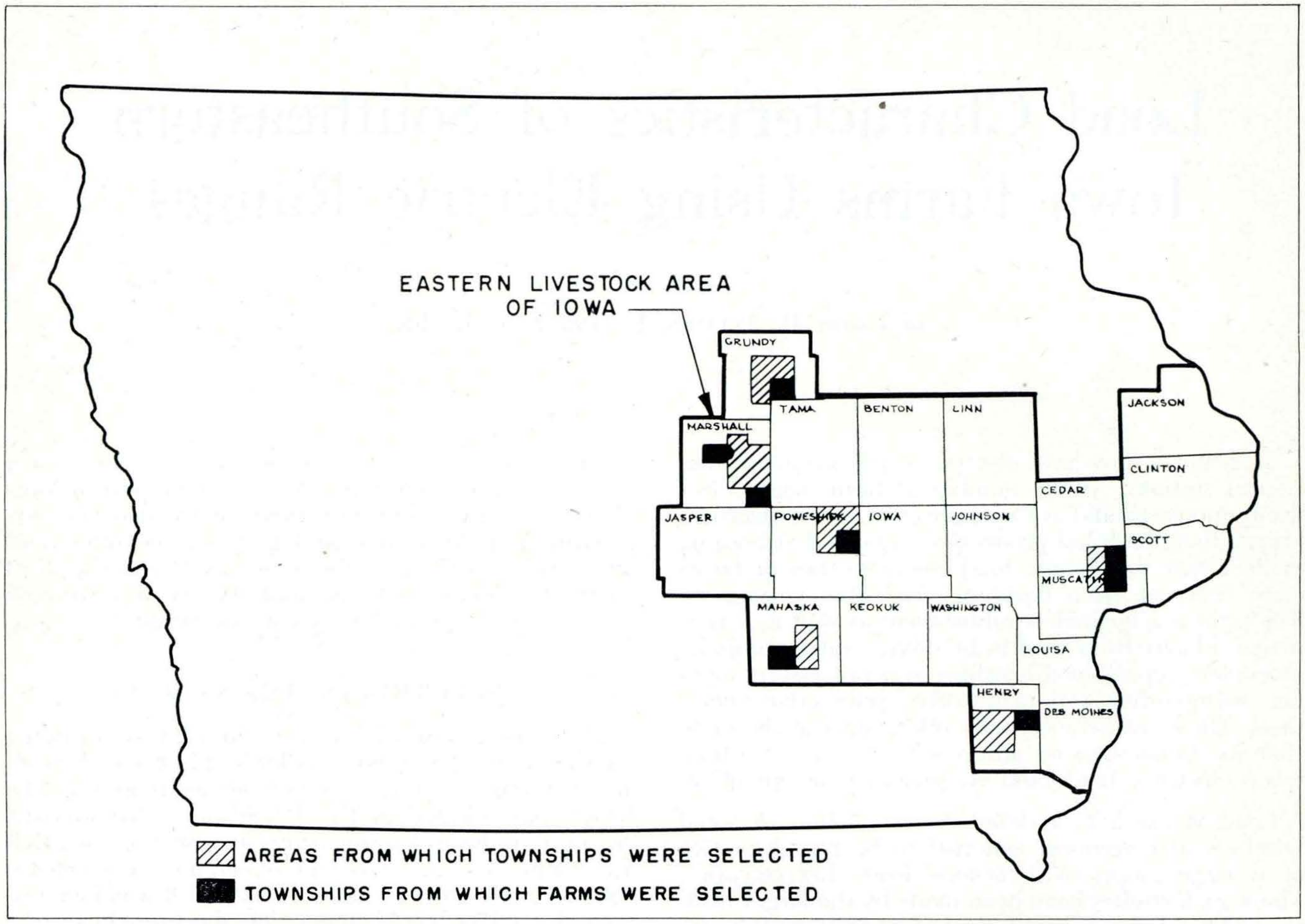

Fig. 1. Location of study area. Electric demand study, 1952-53.

and transformer size was filled out on each farm. A group of bar graphs showing the distributions of some of these factors is shown in fig. 2. Four of the farms had two families served from a single meter. Such farms were not excluded from the study. Two of these had two ranges, two had two water heaters, and one had two television sets.

The use of an electric range does not indicate that the farms are among the more prosperous in the area. It was found in 1948 that 20.7 percent of the low-income farms electrified before 1943 used ranges (2). The general appearance of several of the farms and farm homes in this study indicated that they were in the low-income group.

DESCRIPTION OF METERS

General Electric Type G-9 recording demand meters were used to obtain records of the demands of the farms. These meters are used in combination with watt-hour meters having contact devices in them. The meter records the demand of the circuit on a circular chart. The values thus recorded represent the demand, integrated and averaged, for each 15-minute period.

The metering equipment was assembled into adaptor units to provide easy installation and transportability between farms. In most instances, the adaptor could be plugged into the meter socket of the farm.

Graphic, recording, clock-driven, AC ammeters were used to obtain records of the current use of ranges, water heaters and clothes dryers during selected periods.

LOAD CHARACTERISTICS OF INDIVIDUAL FARMS

The data obtained in this study are presented in three sections, namely; load characteristics of individual farms, coincident or diversified demands of farms and demand and diversity characteristics of appliances.

MAXIMUM 15-MINUTE DEMANDS

The mean, high and low maximum 15-minute integrated demands by months of groups of farms in this study are shown in table 1. The farms were divided into broad appliance-ownership groups. It may be noted that the individual farm demands for January are only slightly greater than for other months.

MAXIMUM 2-HOUR DEMANDS

The maximum 2-hour demands of each farm are of use in studies of transformer loading. The mean, high

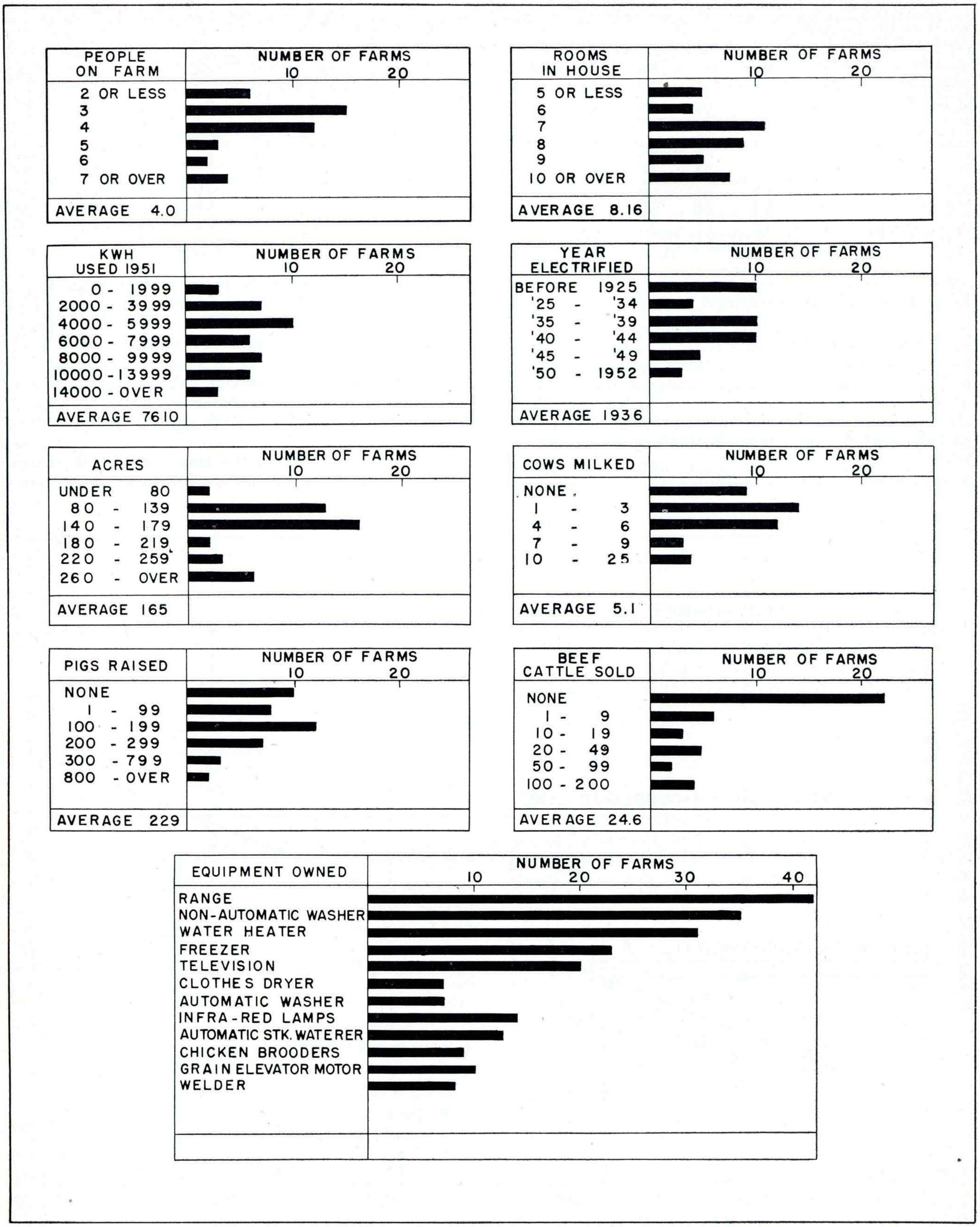

Fig. 2. Distribution of factors which may affect electrical load characteristics of farms in demand study, southeastern Iowa, 1952.

TABLE 1. MAXIMUM 15-MINUTE DEMANDS OF SAMPLE FARMS BY APPLIANCE-OWNERSHIP GROUPS AND MONTHS, SOUTH-EASTERN IOWA, 1952-53.

	Maximum 15-minute demand in kilowatts					
Appliance group	May	July	Sept.	Nov.	Jan.	March
Ranges only (10 farms in group)						
Mean	3.5	3.6	3.7	3.5	4.3	3.6
High	5.8	4.6	5.2	5.8	6.2	4.7
Low	2.4	2.4	2.3	2.6	2.4	2.3
Range and water heater (25 farms in group)						
Mean	4.8	4.8	4.7	4.8	4.8	4.5
High	7.2	7.0	9.0	7.8	7.8	7.3
Low	1.7	2.0	2.4	2.6	2.4	0.9
*Range, clothes dryer and water heater** (7 farms in group)						
Mean	6.3	6.2	6.1	7.0	7.0	6.6
High	8.7	10.3	9.2	10.6	12.2	11.8
Low	3.7	4.1	4.3	4.3	5.2	5.0
Overall average	4.8	4.7	4.7	4.9	5.1	4.6

* One farm did not use electric water heater.

TABLE 2. MAXIMUM 2-HOUR DEMANDS OF SAMPLE FARMS BY APPLIANCE-OWNERSHIP GROUPS AND MONTHS, SOUTHEAST-ERN IOWA, 1952-53.

	Maximum 2-hour demand in kilowatts					
Appliance group	May	July	Sept.	Nov.	Jan.	March
Ranges only (10 farms in group)						
Mean	2.0	1.8	2.1	1.9	2.2	1.9
High	4.7	3.5	3.5	3.8	4.5	2.7
Low	0.8	1.0	1.4	1.0	1.1	1.4
Range and water heater (25 farms in group)						
Mean	2.7	2.8	2.7	2.9	3.0	3.0
High	4.3	5.8	5.4	5.4	5.9	5.8
Low	1.0	1.3	0.6	1.5	0.9	0.8
*Range, clothes dryer and water heater** (7 farms in group)						
Mean	4.7	4.0	4.2	5.4	4.7	5.0
High	7.2	6.7	6.3	8.5	8.5	9.8
Low	2.7	1.8	3.1	2.9	3.2	3.3
Overall average	2.9	2.8	2.9	3.1	3.1	3.1

* One farm did not use electric water heater.

and low maximum 2-hour demands of the groups of farms by months are presented in table 2.[1]

Distribution transformers may be loaded without loss of life expectancy to 1.37 times the rated load for a 2-hour period with average ambient temperatures of 86°F. and with further increases in loading allowable for lower ambient temperatures (3). It was observed from the data that the load on 17 of the 33 transformers serving single farms exceeded the transformer rating and that 10 of these farms reached this load in more than 1 month. Seven of the 17 transformers served loads more than 1.37 times the rated load. The overload on several of these farms occurred during months when ambient temperatures are low. The transformers at only three of the farms were excessively loaded from transformer life expectancy considerations.

Figure 3 which shows the regression of maximum 2-hour demand on maximum monthly energy con-

[1] The size of transformer and the maximum monthly energy consumptions of individual farms may be found in fig. 3.

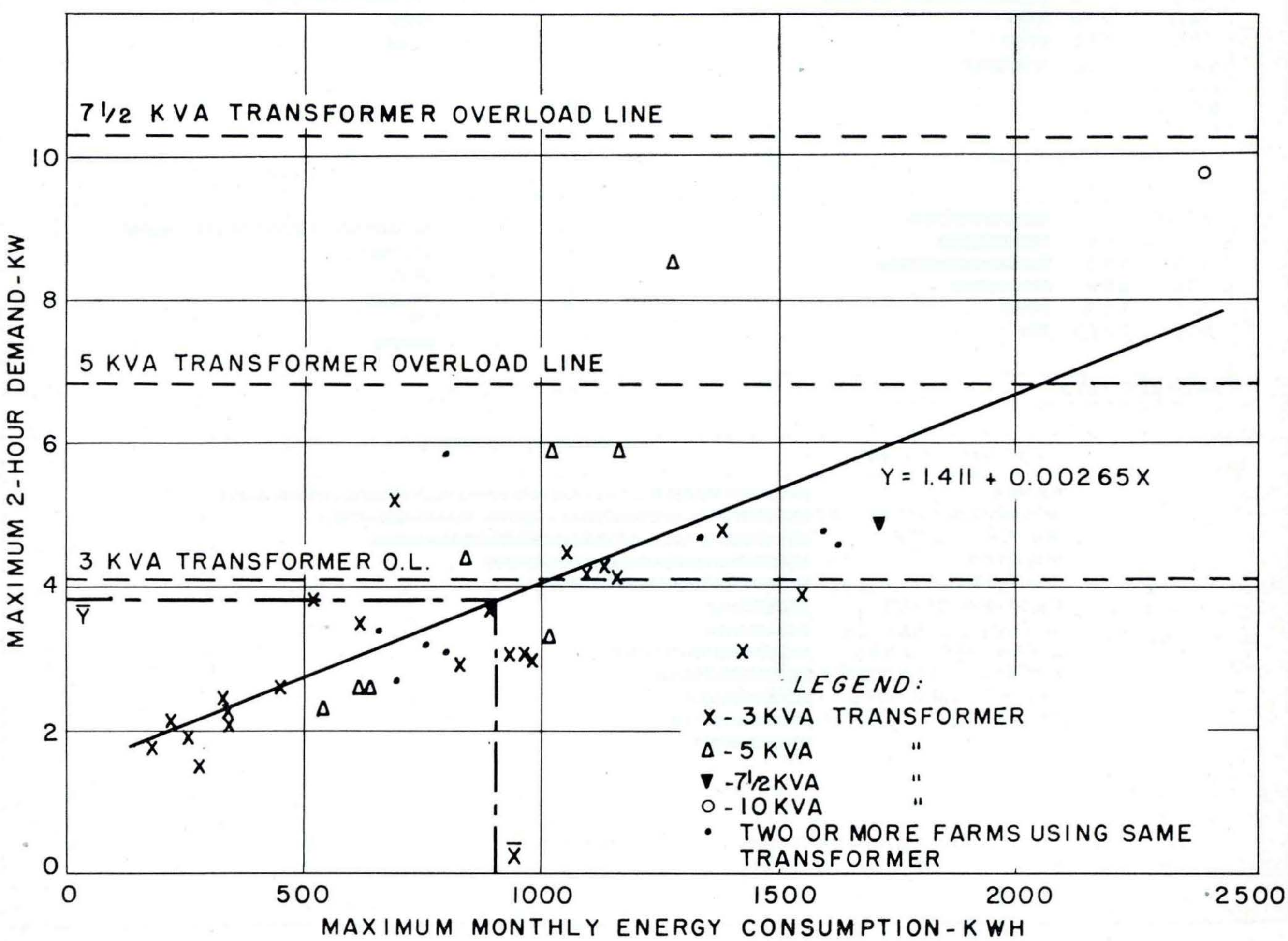

Fig. 3. Regression of maximum 2-hour demand on maximum monthly energy consumption of farms with ranges in southeastern Iowa, 1953.

sumption also may be of value in studying transformer loading. The sizes of the transformers used are shown by symbols. The horizontal dashed lines in this figure indicate the maximum 2-hour demands to which the different sized transformers can be subjected at 86°F. without overloading. From the regression line fitted, it may be deduced that approximately one-half of the 3 kva transformers serving farms with a maximum monthly energy consumption of 1,000 kwh would be overloaded at the stated ambient air temperature. The corresponding kwh point for the 5 kva unit is 2,050.

The minimum size transformer used on farms with ranges was 3 kva. Five of the 10 transformers larger than 3 kva and serving a single farm had loads which probably could have been served adequately by a smaller transformer.

From transformer life expectancy considerations and the data available, it may be concluded that relatively few of the distribution transformers are overloaded and that many of the larger distribution transformers could handle larger peak loads. In some instances the large transformer may have been necessary to provide a satisfactory voltage to the farm.

AVERAGE LOADS

The average loads of the farms in this study are shown by months in table 3. The values in this table were obtained by dividing the number of kilowatt hours used by the number of hours in the metered period, about 168.

LOAD FACTORS OF FARMS

The mean, high and low load factors—the ratio of average load to peak load—of the sample farms by groups are shown in table 4. An examination of the data from which this table was obtained showed that eight of the sample farms reached load factors of 0.30 or higher during that part of the month in which the farm was metered. Six of these were in the group with range and water heater, one was in the range only group, and the other in the range, clothes dryer and water heater group. The latter two farms were the ones which had two families and two ranges served from the same meter. It appears that farms with two families living on them may have improved load factors, although both have ranges. The fact that the range and water heater group had the highest load factors may be noted. That the water heater contributes to increasing the load factors is evident.

The peak demands used in determining the load factors shown in the last line of table 4 were the monthly maximum coincident demands of the sample farms taken as a group. These load factors approximate those of several REA-financed cooperatives in this area which serve several thousand farms.

DEMAND FACTORS

The mean, high and low demand factors—the ratio of maximum demand to connected load—of the sample farms by groups are shown by months in table 5. The stability of the monthly average demand factors, varying only from 0.17 to 0.19, may be noted. An examination of the data from which table 5 was prepared showed that the average of the highest demand factors for all farms over the six periods was 0.22, with values ranging from 0.13 to 0.34. The lower demand factors occurred most frequently on farms with high connected loads.

The highest demand factor of the 42 farms taken as a group was 0.08. Thus, only about one-twelfth of the available load was in operation at any one time.

MAXIMUM DEMANDS BY DAYS OF THE WEEK

The magnitude of the daily maximum demand of each farm was tabulated by days of the week and by locations for the 6 months of the study. Analyses of these data showed that there is no significant effect of day of the week on the magnitude of the maximum individual farm demands.[2] These analyses also showed that there are real differences between locations and between farms within locations in the amount of the maximum demands.

The distribution of the maximum demands for the week by days was examined to determine if more demand peaks occur on some days than others. Table 6 shows these data in contingency-table form. It may be noted that Monday in each month had a high number of individual demand peaks. When Monday was tested against the remainder of the week for each month separately, it was found that only in May was the number of peak demands significantly greater. When the data from the 6 months are pooled, the per-

[2] Analysis of variance procedures were used in analyzing these data. Sources of variation were locations, farms within locations, days of the week, days × locations interaction and days × farms within location interaction.

TABLE 3. AVERAGE LOADS OF SAMPLE FARMS BY APPLIANCE-OWNERSHIP GROUPS AND MONTHS, SOUTHEASTERN IOWA, 1952-53.

	Average load in kilowatts					
Appliance group	May	July	Sept.	Nov.	Jan.	March
Ranges only (10 farms in group)						
Mean	0.49	0.37	0.38	0.37	0.63	0.59
High	1.79	0.57	0.62	0.59	1.91	0.92
Low	0.11	0.19	0.24	0.11	0.23	0.19
Range and water heater (25 farms in group)						
Mean	1.00	0.92	0.83	0.95	1.10	1.04
High	2.08	2.14	2.05	2.24	2.31	2.01
Low	0.19	0.26	0.19	0.34	0.21	0.04
*Range, clothes dryer and water heater** (7 farms in group)						
Mean	1.19	1.13	1.13	1.35	1.53	1.34
High	2.00	2.22	2.05	3.28	3.23	3.12
Low	0.61	0.50	0.68	0.59	0.77	0.61
Overall average	0.94	0.82	0.77	0.88	1.07	1.00

* One farm did not use electric water heater.

TABLE 4. LOAD FACTORS OF SAMPLE FARMS WITH RANGES BY APPLIANCE-OWNERSHIP GROUPS AND MONTHS, SOUTHEASTERN IOWA, 1952-53.

	Load factor					
Appliance group	May	July	Sept.	Nov.	Jan.	March
Ranges only (10 farms in group)						
Mean	0.12	0.11	0.10	0.11	0.14	0.16
High	0.31	0.14	0.15	0.23	0.31	0.30
Low	0.04	0.07	0.06	0.03	0.04	0.07
Range and water heater (25 farms in group)						
Mean	0.22	0.20	0.18	0.19	0.23	0.23
High	0.43	0.36	0.35	0.40	0.37	0.42
Low	0.08	0.06	0.08	0.11	0.06	0.05
*Range, clothes dryer and water heater** (7 farms in group)						
Mean	0.19	0.18	0.18	0.18	0.21	0.19
High	0.27	0.25	0.27	0.31	0.26	0.26
Low	0.10	0.12	0.14	0.10	0.15	0.12
Overall average	0.20	0.19	0.16	0.17	0.20	0.21
Diversified load factor	0.54	0.47	0.51	0.46	0.52	0.52

* One farm did not use electric water heater.

TABLE 5. DEMAND FACTORS OF SAMPLE FARMS WITH RANGES BY APPLIANCE-OWNERSHIP GROUPS AND MONTHS, SOUTHEASTERN IOWA, 1952-53.

Appliance group	Demand factor					
	May	July	Sept.	Nov.	Jan.	March
Ranges only (10 farms in group)						
Mean	0.18	0.18	0.19	0.18	0.22	0.18
High	0.31	0.25	0.27	0.25	0.32	0.23
Low	0.12	0.13	0.12	0.12	0.12	0.12
Range and water heater (25 farms in group)						
Mean	0.17	0.17	0.18	0.17	0.18	0.16
High	0.26	0.28	0.32	0.28	0.25	0.30
Low	0.08	0.10	0.10	0.10	0.12	0.05
*Range, clothes dryer and water heater** (7 farms in group)						
Mean	0.18	0.17	0.18	0.19	0.20	0.18
High	0.28	0.26	0.32	0.34	0.24	0.25
Low	0.08	0.12	0.11	0.13	0.13	0.12
Overall average	0.18	0.17	0.18	0.18	0.19	0.18

* One farm did not use electric water heater.

sistent high number of peaks occurring on Monday shows this day to have significantly more demand peaks than would be expected from a uniform daily distribution.

MAXIMUM DEMANDS BY PERIODS OF THE DAY

The maximum daily demand of a farm with a range may be expected while a meal is being prepared. To study the time of the maximum daily demands the day was divided into periods: midnight to 10 a.m., 10 a.m. to 3 p.m. and 3 p.m. to midnight. The occurrence of each daily peak was tabulated in the appropriate period. Table 7 shows the counts obtained by months. It may be observed from this table that the individual farm peak demand occurred most frequently between 3 p.m. and midnight. Lighting, ranges and electrical equipment used in chore operations usually cause rural distribution lines to have their peak loads during this period. In July the peak demand occurred most often between 10 a.m. and 3 p.m. Heavy range use and lower evening peaks resulting from natural light for doing chores probably caused the high number of peaks during this period. The days of the week were not particularly different except for Sunday with respect to the time of occurrence of the daily demand peak. On Sunday the daily peak demand was most likely to occur before 10 a.m.

RELATIONSHIP OF MAXIMUM DEMAND TO CONNECTED LOAD

The method of estimating the maximum demand recommended by the *National Electrical Code* (4) for dwellings did not give close estimates of the expected maximum demands of the farms in this study. Farms do not fit exactly into the dwelling category or any other classification given in the code. In table 1 it was shown that none of the 10 farms with "ranges only"

TABLE 6. DISTRIBUTION BY DAYS OF THE WEEKLY MAXIMUM DEMANDS OF SAMPLE FARMS FOR SIX MONTHLY PERIODS, SOUTHEASTERN IOWA, 1952-53.

Month 1952-53	Number of farm maximum demands falling on*						
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
May	11.0	4.0	4.0	1.5	5.5	5.5	4.5
July	9.0	4.0	7.0	2.5	1.5	9.0	4.0
Sept.	8.5	4.0	7.0	3.0	4.5	4.5	6.5
Nov.	8.0	5.0	4.0	4.0	5.0	6.0	6.0
Jan.	6.8	3.0	7.0	5.8	4.8	6.5	4.0
March	5.0	4.8	5.5	6.0	2.0	9.8	2.8
Total	48.3	24.8	34.5	27.8	23.3	44.3	27.8

* If a tie in the amount of the maximum demand of the week occurred between 2 or more days, an appropriate fraction was tabulated under each of the days.

TABLE 7. DISTRIBUTION OF DAILY MAXIMUM DEMANDS OF SAMPLE FARMS BY PERIODS OF THE DAY AND BY MONTHS, SOUTHEASTERN IOWA, 1952-53.

Month and interval of day	Number of farms with daily demand peak falling on*							
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	Total
May								
12 a.m.–10 a.m.	16	10	15	13	14	8	16	92
10 a.m.–3 p.m.	8	15	15	16	11	18	11	94
3 p.m.–12 a. m.	15	16	10	11	15	14	13	94
July								
12 a.m.–10 a.m.	9	12	8	11	12	20	21	93
10 a.m.–3 p.m.	15	15	24	21	14	15	13	117
3 p.m.–12 a.m.	16	15	10	10	16	7	7	81
Sept.								
12 a.m.–10 a.m.	9	11	14	11	13	11	17	86
10 a.m.–3 p.m.	20	13	12	9	15	12	12	93
3 p.m.–12 a.m.	11	17	15	21	13	18	12	107
Nov.								
12 a.m.–10 a.m.	14	12	10	8	10	14	14	82
10 a.m.–3 p.m.	7	14	8	9	15	4	14	71
3 p.m.–12 a.m.	16	11	19	16	12	19	9	102
Jan.								
12 a.m.–10 a.m.	11	10	13	9	7	6	13	69
10 a.m.–3 p.m.	10	8	6	15	9	14	11	73
3 p.m.–12 a.m.	17	20	19	14	22	18	14	124
March								
12 a.m.–10 a.m.	6	12	12	7	13	10	13	73
10 a.m.–3 p.m.	10	7	11	9	10	14	11	72
3 p.m.–12 a.m.	20	17	13	20	13	12	12	107
Total								
12 a.m.–10 a.m.	65	67	72	59	69	69	94	495
10 a.m.–3 p.m.	70	72	76	79	74	77	72	520
3 p.m.–12 a.m.	95	96	86	92	91	88	67	615

* Due to missing or incomplete records, these totals by days within a month may not add to 42 farms.

had a maximum 15-minute demand as high as the 8 kw that could occur from the full use of the range alone. The addition of the expected demands for lighting, small appliances, motors and special appliances would give very high estimates of maximum demands.

The great multiplicity of electrical appliances and the high within farm diversity in their use make farms a special class for maximum demand estimation. A common method of estimation of the maximum demand is to determine the connected load and multiply it by an appropriate demand factor. Unless this load is broken into blocks, as is done in the *National Electrical Code* for dwellings, and a high demand factor used with the first block, the maximum expected demand of the farms with small connected loads will be underestimated, those with large loads overestimated.

The relationship between the maximum demand and connected load may be better described by a linear regression of the form $\hat{Y} = a + bX$ rather than as a fixed demand factor.[3] Figure 4 shows the regression line of the maximum 15-minute demands of the farms for the year on the connected loads and the plotted points for these variates. When Y equals the maximum demand and X equals the connected load in kilowatts, a better estimate of the maximum demand of farms using ranges in this area can be obtained through the use of the equation

$$Y = 2.098 + 0.137\,X$$

than by use of the average demand factor.

The above regression is an average line. If it is desired to use this line for estimating the probable 15-minute maximum demand of a farm with a range and

[3] It should be noted that use of the fixed demand factor calculated as $\Sigma \frac{R_i}{n}$ where $R_i = \frac{Y_i}{X_i}$ for each metered customer assumes a regression. Y_i is taken to be the observed maximum load and X_i to be the connected load. The regression considered is one of the form $\hat{Y} = bX$ with the variance of Y proportional to X^2. From fig. 4 it may be observed that such a variance law is inappropriate for the data at hand and that the linear regression, $\hat{Y} = a + bX$, is a more adequate representation.

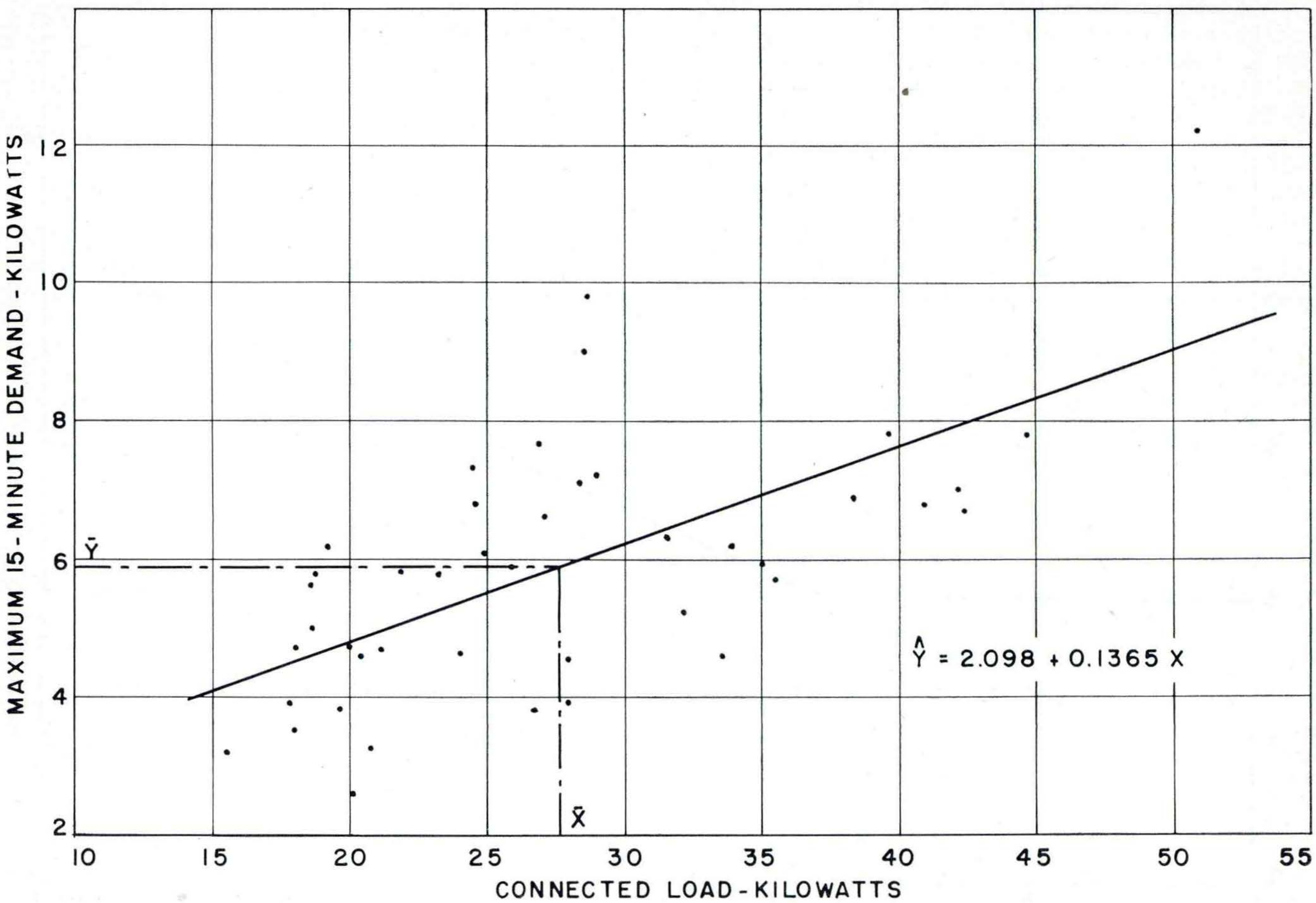

Fig. 4. Regression of maximum 15-minute demand on connected load of farms with ranges in southeastern Iowa, 1953.

not underestimate about half of the time, an additional demand of about 2 kw should be added. A further addition to the expected maximum demand should be made if a clothes dryer is used.[4]

RELATIONSHIP OF MAXIMUM DEMAND AND ENERGY CONSUMPTION

Figures 3 and 5 show respectively the regression of the individual maximum 2-hour demands and maximum 15-minute demands on the maximum monthly energy consumption. The maximum demands and monthly energy consumptions are the highest which occurred during any of the six 1-week periods in which the farms were metered. Maximum monthly energy consumption rather than average load was used as the independent variable because of its availability to power suppliers. In this study these values were obtained by multiplying the average load for the period metered by 720, the number of hours in a 30-day month.

The linear regression of maximum 15-minute or 2-hour demands on maximum monthly energy consumptions gave better estimates of the maximum demands of the farms in this study than did the regression of maximum 15-minute demand on connected load. In the data at hand, approximately 54 percent of the variation in maximum demands may be explained by its regression on maximum monthly energy consumption as compared with 41 percent when connected load is used as the predictor. A multiple regression of maximum 15-minute demand on connected load and maximum monthly energy consumption resulted in a trivial increase in percentage of the variation explained by the two predictors as compared with the 54 percent obtained by use of maximum monthly energy consumption alone. This can be explained in part by the fact that connected load and maximum monthly energy consumption are highly correlated. In these data this correlation was 0.704.

As may be observed in figs. 3, 4 and 5, the variation in maximum demand among farms with approximately the same maximum monthly energy consumption or same connected load is high. For use in estimating the probable maximum demand, the regression line gives only average values. The nature of the appliances owned also must be considered. For example, on farms using clothes dryers, the maximum demands are likely to be higher than for the average of a group of farms with similar connected loads or maximum monthly energy consumptions not using clothes dryers.

[4] The regression model could be extended to take account of some appliances that make major contributions to the maximum load by explicitly introducing the presence or absence of various key appliances, e.g., clothes dryer, into the estimating equation. For such variables, the regression coefficient would indicate directly the average contribution of the appliance to the demand.

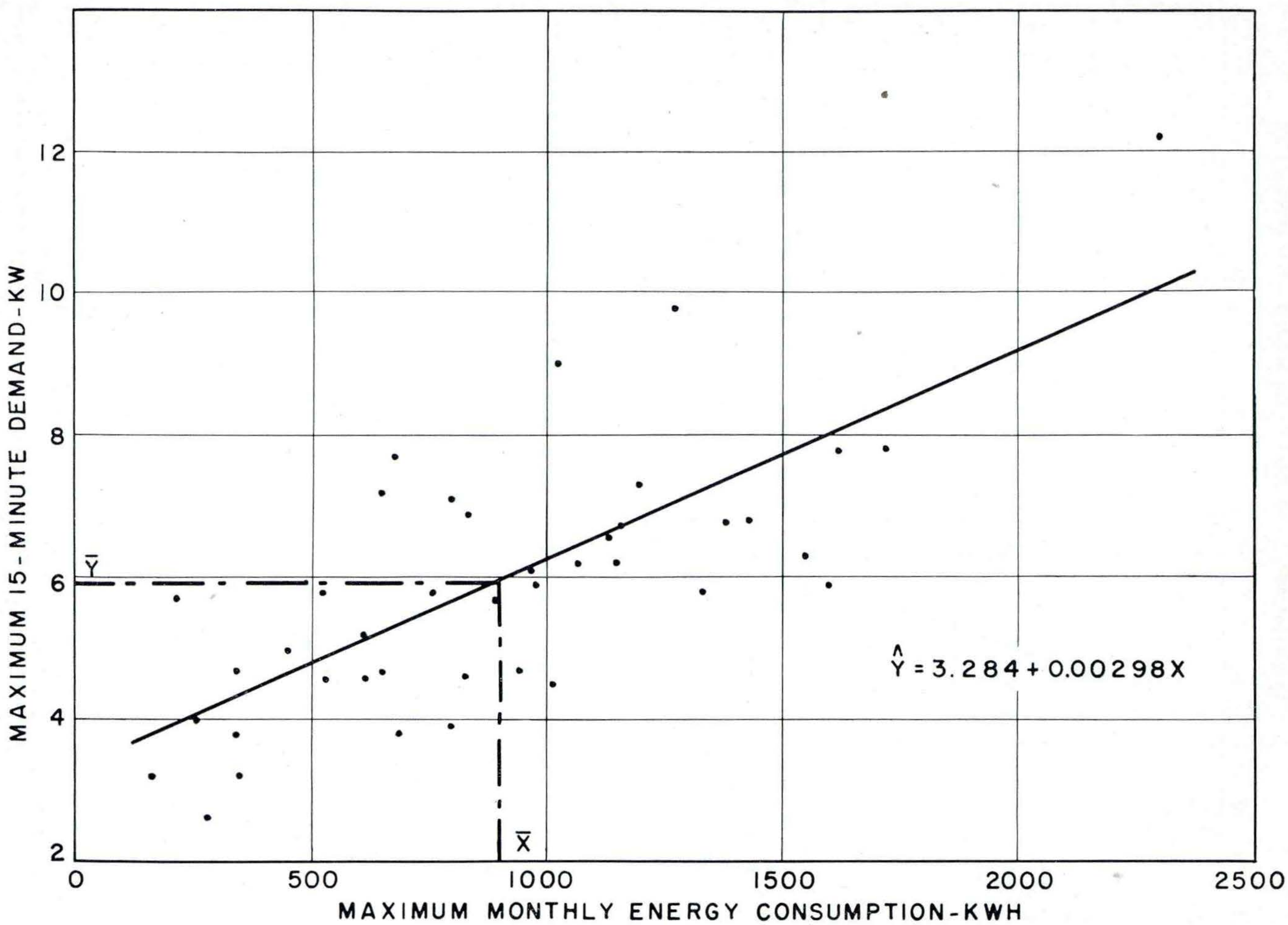

Fig. 5. Regression of maximum 15-minute demand on maximum monthly energy consumption of farms with ranges in southeastern Iowa, 1953.

COINCIDENT OR DIVERSIFIED DEMANDS OF FARMS

One of the characteristics of farm electrical loads is the similarity in time of use of particular appliances. Most farmers get up in the morning, do the chores and have their meals at the same time as their neighbors. Heat lamps are used for pigs, baby chicks are brooded and the heated livestock waterers operate at the same season on each farm. Each homemaker does the laundry, bakes, cooks meals or does the dishes at about the same time as others.

This lack of diversity or coincidence in use of electricity among farms makes it necessary for power suppliers to have generation and line capacity considerably in excess of average loads. The degree of diversity in use of electricity among the farms in this study will be shown as a diversity factor, by average daily load curves and by curves showing average maximum coincident demands per farm for various group sizes.

DIVERSITY FACTOR

The ratio of the sum of the individual farm maximum demands occurring at various times to the simultaneous maximum demand of all the farms is defined as the diversity factor (5). The maximum demand observed for this study was 82.0 kw for 38 farms. This demand occurred from 5:30 to 5:45 p.m. on Tuesdays in January. The sum of the individual 15-minute maximum demands for the 38 farms was 225.3 kw. The diversity factor obtained from these values is 2.75.

The coincidence factor—the reciprocal of the diversity factor—of the farms in this study was 0.36.

Some additional diversity is introduced by considering the weeks in the month alike with respect to use of electricity. The actual diversity factor for the farms in this study is probably slightly lower than the figure given. The magnitude of the error thus introduced will be discussed in a later section.

DAILY LOAD CURVES

Figure 6 shows average daily load curves for the farms in this study for the 6 months considered. The 15-minute demands of the days of the week were added together by periods making approximately 294 observations in each point. These are not independent since each farm appears about seven times. The shift in the time of the peak demand of the farms by seasons may be noted. The parts of the curve drawn with the dashed line are for periods of the day when data were not tabulated since loads are generally light at these times. Data were tabulated for the periods 4 to 4:15 a.m., 6 a.m. to 1:30 p.m., 3 to 3:15 p.m., 4:30 to 10:15 p.m., and 11 to 11:15 p.m. except in May and July when the evening period was tabulated from 4:30 to 8:30 p.m.

AVERAGE MAXIMUM COINCIDENT DEMAND

The diversity in individual demands among farms—the fact that the maximum demands of every consumer do not fall at the same time—may be analyzed in several ways. Two methods have already been described briefly: diversity factors, the ratio of the sum of the individual maximum demands to the maximum demand of the whole system or the part under consideration (5); and coincidence factors, the reciprocal of the diversity factors. Curves of average coincident maximum demand per farm for various group sizes are also used (6). The latter was chosen for more detailed consideration here so that the magnitude of the coincident maximum demand for various group sizes could be presented as well as information for approximating the above factors.

Curves showing the variation with group size of the average coincident maximum demand per farm were prepared by two methods. The small circles plotted on the curve for May 1952 shown in fig. 7 were obtained by randomly selecting 15 groups of each size for which there is a circle shown, totaling the demands for each group by 15-minute periods of the week, finding the maximum coincident demand for each group and averaging these values (7). A smooth curve could then be drawn through these eight points shown in the figure for May 1952. This method of handling data is very laborious.

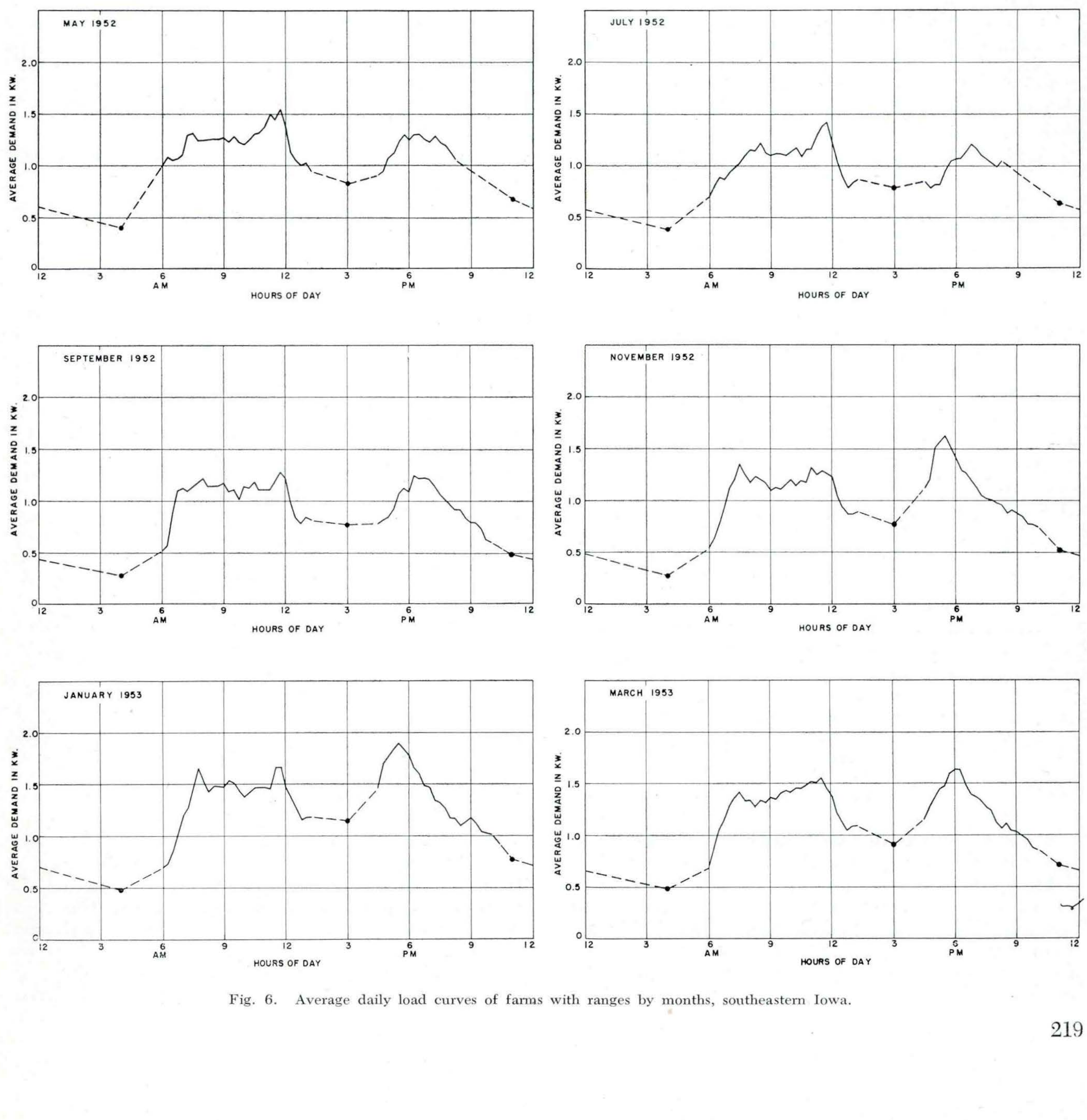

Fig. 6. Average daily load curves of farms with ranges by months, southeastern Iowa.

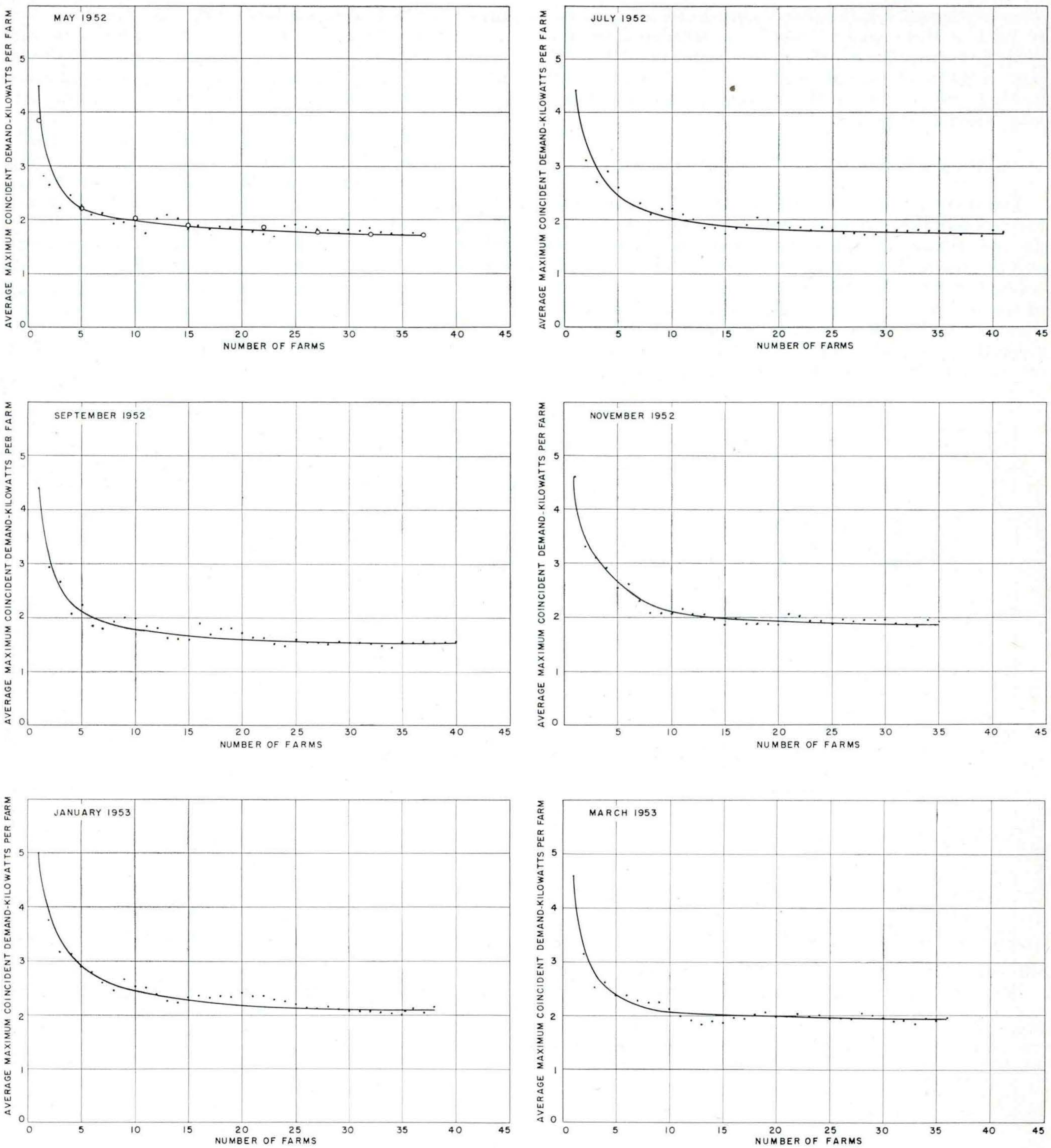

Fig. 7. Variation of average maximum coincident demand per farm with number of farms, southeastern Iowa.

A short-cut was devised which gives values that approximate those prepared by the above method. Values for average maximum coincident demand curves were obtained as follows: The farms were arrayed by the size of their maximum demand. The first point (for number of farms = 1) is the maximum demand of the median farm. The second point is the average maximum coincident demand of the median farm in the array and the farm above it. This value was obtained by adding the individual demands of the two farms by periods of the week, selecting the highest total and dividing by two. Note that this value was found by returning to the data. The third point is the average maximum coincident demand of the median and adjacent farms. Again this value was found by returning to the data. This process was continued. Farms above and below the median farm in the array were added alternately until all farms were included. A smooth curve was then drawn through the points. The curves shown in fig. 7 were drawn by this method. They do not include data from all the farms in each point; however, it may be noted that most points lie close to the line and that the end point (number of farms = 37) is the same regardless of method of plotting.[5]

As an approximate check on increased diversity introduced by considering the weeks of the month alike, values read from the curves in fig. 7 were tabulated along with the average maximum coincident demand per farm when 13 farms were actually metered the same week. A group size of 13 was selected because illegible records often reduced the maximum number which could appear at one time, 14, to a smaller number. These values are shown in table 8. It may be noted that the average maximum coincident demand per farm is always slightly higher when the farms were actually metered at the same time. It appears that there may be a decrease of about 10 percent in maximum coincident demand when weeks of the month are considered alike. From this point of view, curves in fig. 7 should have dropped off less rapidly and leveled out at slightly higher values.

THEORETICAL APPROACH TO MAXIMUM COINCIDENT DEMAND

The empirical methods of obtaining information on diversity in the use of electricity between farms have several weaknesses. It is usually possible to collect data from only a relatively small sample of the total population, and the error in sampling may be quite large. The empirical methods do not allow the calculation of confidence limits. Further, the methods that have been described in the literature have not taken account of this sampling variation; hence, only estimates of the expected average coincident demand have been secured. It would be desirable to obtain some measure of dispersion to associate with this average curve for varying numbers of consumers. Some investigations have been considered that are aimed at obtaining a fundamental understanding of the phenomena under observation.[6] It is the hope that such studies will lead to a better understanding of the problem of coincident loads and, ultimately, lead to improved predictions of maximum demands for larger numbers of consumers. The ideas embodied in these new investigations are based on the statistical theory of extreme values. This theory has been finding increasing application in many areas. As a beginning approach some of the techniques described by Gumbel (9) were employed.

Part of the data were grouped so that 57 (n) maximum coincident values for the 13 (k) farms being summed in each such value were obtained. Figure 8 shows the sample cumulative step function for these 57 observations. The solid line which follows the sample step function closely is based upon asymptotic theory (m large which may be reasonable since 672 observations per week are recorded although they are not independent) and the estimation of the relevant parameters by the method of moments. The agreement between the sample and theory shown in fig. 8 is rather remarkable.[7] Although these results are interesting they do not lead to the direct determination of the expected maximum coincident demand plotted against k, the number of consumers. The close agreement does suggest that procedures derived from extreme value theory may be useful.

[5] Further comparisons of the two methods of maximum coincident demand curve preparation have not been made up until now because of the labor involved and because it is hoped that better methods may be developed.

TABLE 8. AVERAGE MAXIMUM COINCIDENT DEMAND PER FARM FOR GROUP SIZE 13: (1) WITH VALUES OBTAINED BY CONSIDERING THE WEEKS OF A MONTH ALIKE IN RESPECT TO COINCIDENT DEMAND, READ FROM FIG. 7; (2) VALUES OBTAINED BY AVERAGING THE MAXIMUM COINCIDENT DEMAND OF THREE GROUPS OF 13 FARMS ACTUALLY METERED THE SAME WEEK, SOUTHEASTERN IOWA, 1952-53.

Month	Average maximum coincident demand per farm for group size 13 in kw when	
	3 weeks considered alike (fig. 7)	Farms metered at same time
May	1.90	1.92
July	1.92	2.17
Sept.	1.70	1.86
Nov.	2.05	2.17
Jan.	2.35	2.41
March	2.05	2.50

DEMAND AND DIVERSITY CHARACTERISTICS OF APPLIANCES

RANGES

A subsample of 10 was selected from the 42 farms. The ranges on these farms were metered with recording ammeters for 3-week periods in May 1952 and January 1953. The average range use for each 15-minute period from 5 a.m. to 8:30 p.m. was tabulated. All 21 days of the metered period were averaged by periods of the day. These data were converted into watts and are plotted in fig. 9 along with daily load curves of other appliances. The shift in peak range use from before noon in May, when field work is in progress, to late afternoon in January may be noted.

WATER HEATERS

Recording ammeters were used to obtain records of the current used by 10 of the water heaters in this study for a 3-week period in November 1952. Figure 9 shows the average daily load curve for these water heaters. Average amperes were converted to watts by multiplying by 230 volts.

None of the water heaters in this study was on an off-peak control. It may be seen that approximately 400 watts per heater could have been removed from the system peak demand through the use of some type of off-peak control.

The top elements on the water heaters were infre-

[6] Unpublished research undertaken by the authors and Prof. J. Gurland, Statistical Laboratory, Iowa State College. The work of R. F. Hamilton in this area is also extremely interesting, e.g. refer (8).

[7] The dotted lines indicate tolerance limits for acceptance of the theoretical distribution fitted to the sample. Refer Massey, F. J., Jour. Amer. Stat. Assn. 46:68. 1951.

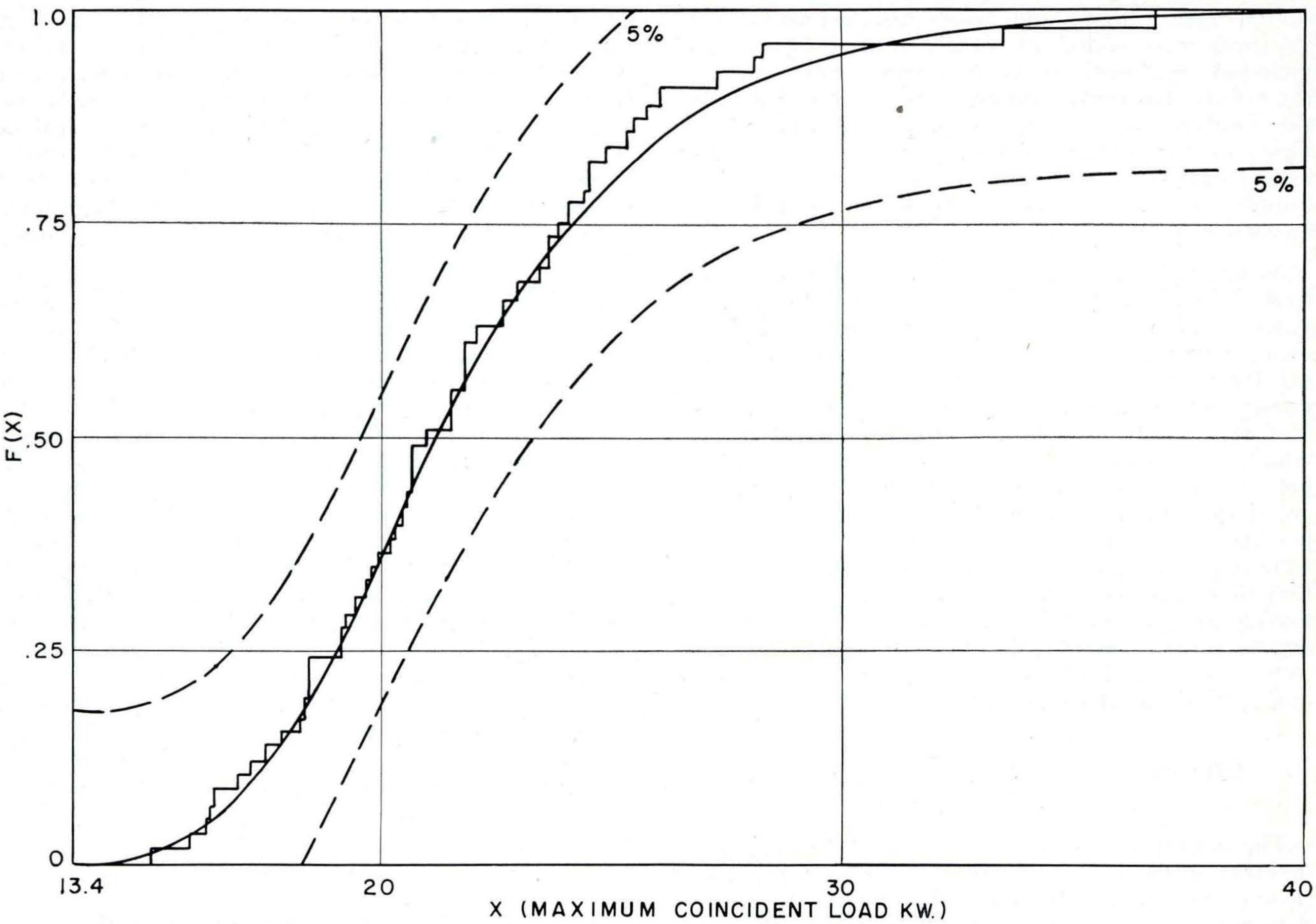

Fig. 8. Preliminary application of extreme value theory to maximum coincident loads. The sample step function shown is for 57 (n) such maximum values and the 13 (k) farms being summed. The solid line is the fitted extremal distribution, southeastern Iowa farms, 1952.

quently in use except on a farm which used water from the household heater in the dairy enterprise.

CLOTHES DRYERS

In January 1952, before starting the regular metering schedule of this study, the clothes dryers on nine farms in southeastern Iowa were metered with recording ammeters for a period of 2 weeks. Table 9 shows the hours of use of the dryers by farms for the days of the week. It may be noted that 45 percent of the dryer use occurred on Mondays. The average daily load curve of the nine clothes dryers for two Mondays is shown in fig. 9. From 9 to 9:15 a.m. the clothes dryers had a group demand factor of 0.41.

TABLE 9. CLOTHES-DRYER USE BY DAYS OF THE WEEK FOR A 2-WEEK PERIOD IN JANUARY 1952.

	Use per day (hours)							Use per week
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	(hours)
Mean	2.1	0.2	1.1	0.6	0.3	0.4	0.1	4.8
High	5.8	1.7	3.1	2.2	1.0	1.2	0.3	9.3
Low	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1

SUMMARY

Forty-two farms in southeastern Iowa on which electric ranges were used were included in this study. Electric services on these farms were metered with recording demand meters for 1-week periods during alternate months for 1 year beginning in May 1952. Other metering of ranges, water heaters and clothes dryers was done with recording ammeters. Data were tabulated by 15-minute periods of the day by weeks.

Equipment availability limited the size of the sample. Therefore, the data presented have limited applicability. Results might be quite different for other geographical areas, and possibly for the same general area, if a larger and better-distributed sample could be taken. The results of this limited study, however, may be useful to those concerned with supplying electrical energy to farms since little information on the load characteristics of farms is available.

The electric load characteristics of the individual farms varied widely even though all had ranges. Connected loads averaged 27.8 kilowatts and ranged from 17.9 to 51.4 kilowatts. Loads for the metered periods averaged 913 watts and ranged from 110 to 3,280 watts. Individual farm load factors averaged 0.19. When the 42 farms were considered as a group, the average of the six monthly load factors was 0.50. Average demand factors were relatively stable from month to month. The average demand factor at the time of the observed individual farm peak demand was 0.220.

The transformers which served three of the farms

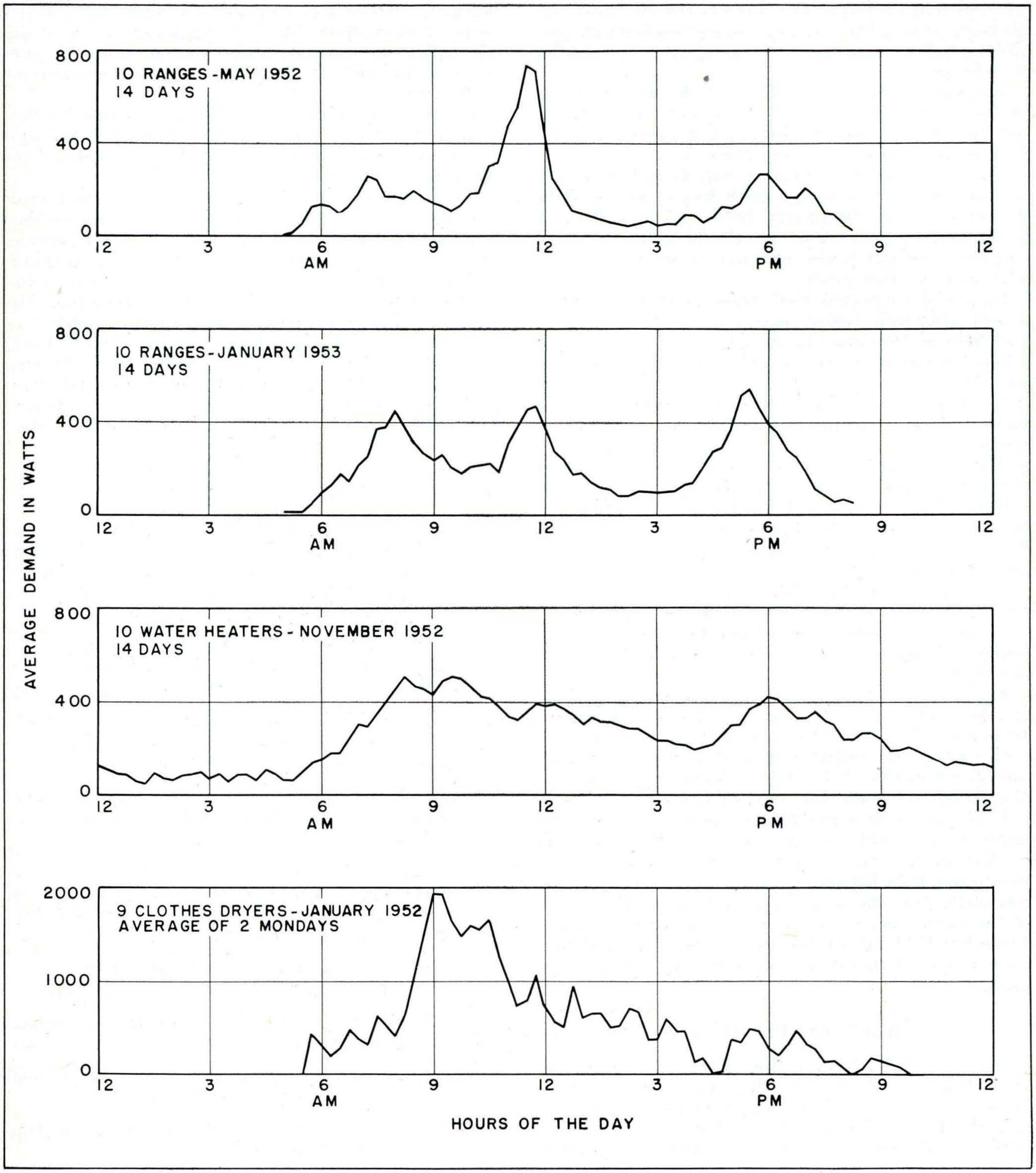

Fig. 9. Average daily load curves of ranges, water heaters and clothes dryers on farms in southeastern Iowa.

were sometimes overloaded. Five of the 10 transformers larger than 3 kilovolt-amperes had loads which possibly could have been served adequately by smaller transformers.

The effect of the day of the week on the magnitude of the individual farm daily maximum demand was not significant; however, Monday had more individual farm demand peaks than any other day.

The daily peak demand of an individual farm usually occurred between 6 a.m. and 9:30 p.m. On Sundays it occurred more frequently before 10 a.m. than at other times. During winter months the individual farm weekday demand peaks occurred more often after 3 p.m. than at other times.

Increased connected load usually did not result in a proportionately higher maximum demand. Regression lines of individual farm maximum 15-minute and 2-hour demands on connected loads and maximum monthly energy consumptions are presented. Maximum demands may be more closely predicted from monthly energy consumption than from connected loads.

The maximum coincident demand was highest during winter months. In January 1953, each of the farms contributed an average of 2.1 kw to the system demand at the time of the maximum coincident demand. In July and September 1952, these amounts were 1.8 and 1.6 kw respectively.

Present methods for estimating expected maximum coincident demand for varying numbers of customers are based on empirical procedures. Further studies are being considered to examine the fundamental nature of this problem.

Peak range use occurred just before noon in May and just before 6 p.m. in January. There was less diversity in time of range use in May than in January, with each range contributing a maximum of approximately 800 watts to the group coincident demand in May compared with 600 watts in January.

Each of the 10 water heaters metered contributed approximately 400 watts to the system demand peak in November 1952. Peak water heater use for this month occurred between 8 and 10 a.m. and averaged 500 watts. On nine farms in January 1952, 45 percent of the clothes-dryer operating time was on Mondays. From 9 to 9:15 a.m. on this day, an average of 41 percent of the clothes-dryer connected load was being used.

ACKNOWLEDGMENTS

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Credit is particularly due the Iowa farm families who cooperated in this study by allowing their farms to be metered and by filling out a connected load schedule on their farms.

The following electric distributors and their electrification advisors or metermen made major contributions to this study by contacting farmer cooperators and by setting and moving the metering equipment:

T. I. P. Rural Electric Cooperative, Brooklyn, Iowa; Southeast Iowa Cooperative Electric Association, Mt. Pleasant, Iowa; Marshall County Rural Electric Cooperative, Marshalltown, Iowa; Grundy County Rural Electric Cooperative, Grundy Center, Iowa; Eastern Iowa Power and Light Cooperative, Wilton Junction, Iowa; Iowa Power and Light Company, Oskaloosa, Iowa; Iowa Electric Light and Power Company, Marshalltown, Iowa.

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