Load Characteristics of Selected Highly Electrified Iowa Farms

by Landy B. Altman, Jr. and Emil H. Jebe

Department of Agricultural Engineering

Statistical Laboratory

AGRICULTURAL AND HOME ECONOMICS EXPERIMENT STATION, IOWA STATE COLLEGE

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SUMMARY

To gain information about the electrical load characteristics of farms, a sample of 36 farms was selected for study. Farms were chosen from those making considerable use of electrical energy outside the home and using at least 8,000 kwh of electricity per year. These farms and nine of the homes were metered continuously with recording demand meters for a period of 1 year beginning in July 1954. Records of the current used by some of the farm production appliances were obtained with recording ammeters.

Data from the recording meters were analyzed to show the average load characteristics of individual farms and homes, demand patterns of appliances used in production, coincident demands of farms and estimations of future farm load characteristics.

Annual energy consumption averaged 13,854 kwh for the 36 sample farms. Other average load characteristics of the farms were maximum annual 30-minute demand — 8.1 kw, maximum 2-hour demand — 6.5 kw and connected load — 36.5 kw.

On the average, farm energy consumptions and maximum demands were highest in February and lowest in September. Monthly load factors of the individual farms, the ratio of the average load for the month to the 30-minute maximum demand occurring in the month, averaged 25.9 percent for the year. Individual farms had monthly load factors as high as 60.5 percent and as low as 8.3 percent.

The average of the annual maximum 30-minute demands of a subsample of nine selected homes was 6.0 kw. The farm uses of electricity on these nine farms produced an average annual maximum demand of 4.1 kw. The diversity in the times of the annual maximum demands between the homes and farms was such that the combined farm and home annual maximum demand averaged 7.1 kw per farm. Even though the annual maximum demands of the homes and farms did not occur at the same time, both home and farm electrical use, on the average, was high at the time of the system daily peak load.

Average daily load curves of water pumps, poultry brooders, grain elevators and stock waterers are shown. Average daily peak power requirements of these appliances did not occur at the usual time of distribution system maximum demands. Except for elevators, however, considerable use was made of the equipment at the time of the system peak. Heat lamps for pig brooding had an almost constant load for the period that they were in use.

When the 36 farms were considered together, the annual maximum coincident 30-minute demand occurred from 6 to 6:30 p.m. on Feb. 12 and averaged 4.1 kw per farm. The diversity among the farms in time of electrical use was such that the sum of the individual farm annual maximum demands was 1.98 times the annual maximum coincident demand of the 36 farms.

A method of predicting the annual maximum demand of an individual farm from appliances owned and energy consumed was developed. The correlation coefficient between the actual peak demands and those predicted by the proposed method for the sample farms was 0.97.

The problem of estimating future load characteristics of farms was considered. Average load characteristics of comparably equipped Iowa farms might be similar to those in this study if and when average farm energy consumption reaches 14,000 kwh per year.

ACKNOWLEDGMENTS

Load Characteristics of Selected Highly Electrified Iowa Farms[1]

by Landy B. Altman, Jr. and Emil H. Jebe[2]

Growth of electrical loads on farms is dynamic. To keep abreast of the rapid changes in farm loads, to obtain an understanding of their electrical characteristics and to predict changes which will occur with further load growth requires constant study. A knowledge of load characteristics is essential in the design of facilities, in rate determinations, in the operation of distribution systems, in planning load building or promotional activities and in making recommendations on farm wiring systems.

The United States Department of Agriculture in cooperation with the Iowa Agricultural and Home Economics Experiment Station and a number of Iowa power suppliers and farmers has made a series of studies of the load characteristics of Iowa farms. The first (1) was a case study of 16 farms selected on the basis of ownership of majority household appliances. The second study (2) included a stratified random sample of 42 farms all having electric ranges. This report, the third in the series, is based on a study of highly electrified farms making extensive use of electricity in agricultural production operations.

The objectives of the present study are to describe the load characteristics of a selected group of highly electrified Iowa farms, examine the effect of certain farm appliances on these load characteristics and make interpretations of the data that may be useful to power suppliers and others interested in farm electrification. Emphasis is placed on electrical applications used in farm production since less is known about the effect of these applications on farm load characteristics than about household appliances.

SELECTION OF SAMPLE

Load characteristics are usually determined by a detailed examination of a sample of consumers which are representative of a larger group (3). Before a sample can be selected, specific criteria for defining the population to be studied are required. In this study sample farms were selected from those which use large amounts of electrical energy, particularly for agricultural production.

To find out more about energy consumption characteristics of Iowa farms, a systematic survey was made to determine the frequency distribution of electrical energy consumption in 1953. Thirty-one power suppliers serving 106,000 of the approximately 200,000 farms in Iowa furnished data on every fiftieth farm served. The results of this survey are summarized in table 1. The median farm used 2,880 kwh, and the average farm used 3,497 kwh per year. About 10 percent of the farms used more than 8,000 kwh in 1953.

One of the restrictions on the population considered in this study was that only farms using more than 8,000 kwh of electrical energy in 1953 were included. Additional restrictions on farms selected were: that they be served by a power supplier cooperating in the study, that they be reasonably accessible, that electrical energy be used in agricultural production and that the owners be willing for the farm to be metered. These restrictions made a strictly random selection of farms impractical.

Since 8,000 kwh easily may be used in a year in the farm home, selection of farms with high energy

TABLE 1. FREQUENCY DISTRIBUTION AND CUMULATIVE PERCENT OF ANNUAL ENERGY CONSUMPTIONS OF IOWA FARMS IN 1953.[°]

Class interval (kwh)	Frequency (no.)	Frequency (percent)	Cumulative (percent)
0 - 600	127	6.02	6.02
601 - 1,200	298	14.11	20.13
1,201 - 1,800	290	13.74	33.87
1,801 - 2,400	204	9.66	43.53
2,401 - 3,000	172	8.15	51.68
3,001 - 3,600	143	6.77	58.45
3,601 - 4,200	135	6.40	64.85
4,201 - 4,800	116	5.50	70.35
4,801 - 5,400	118	5.59	75.94
5,401 - 6,000	84	3.98	79.92
6,001 - 6,600	77	3.65	83.57
6,601 - 7,200	66	3.13	86.70
7,201 - 7,800	53	2.51	89.21
7,801 - 8,400	51	2.42	91.63
8,401 - 9,000	40	1.89	93.52
9,001 - 9,600	29	1.37	94.89
9,601 - 10,200	23	1.09	95.98
10,201 - 10,800	17	0.81	96.79
10,801 - 11,400	13	0.62	97.41
11,401 - 12,000	21	0.99	98.40
12,001 - 12,600	6	0.28	98.68
12,601 - 13,200	6	0.28	98.96
13,201 - 13,800	5	0.24	99.20
13,801 - 14,400	4	0.19	99.39
14,401 - 15,000	2	0.09	99.48
15,001 - 15,600	4	0.19	99.67
15,601 - 16,200	1	0.05	99.72
16,201 - 16,800	1	0.05	99.77
16,801 - 17,400	2	0.09	99.86
Over 17,400	3	0.14	100.00

[°] From data on every fiftieth farm served by 31 power suppliers who distribute electricity to 106,000 farms.
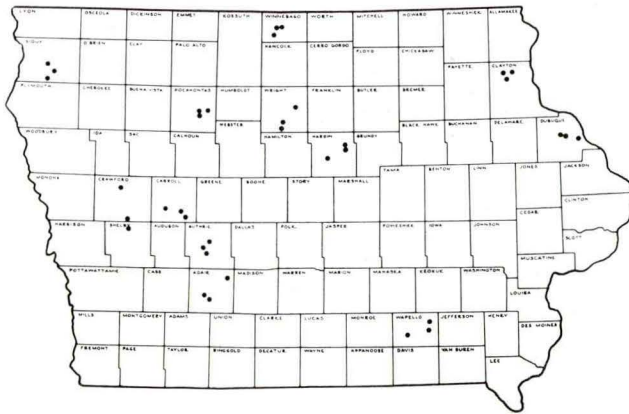
Fig. 1. Locations of farms selected for metering. Electric demand study, Iowa, 1954-55.
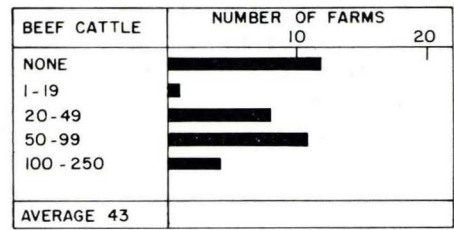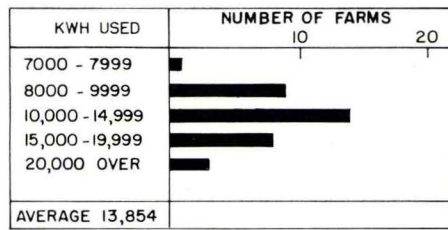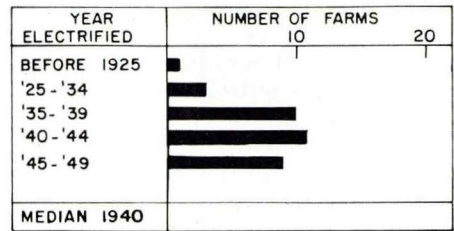
Fig. 2. Sample characteristics relating to farm electrical demands, Iowa, 1954-55.
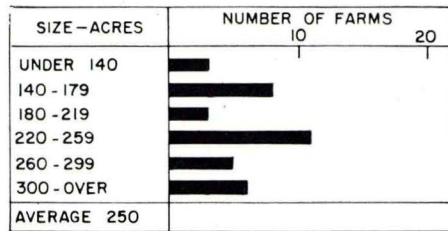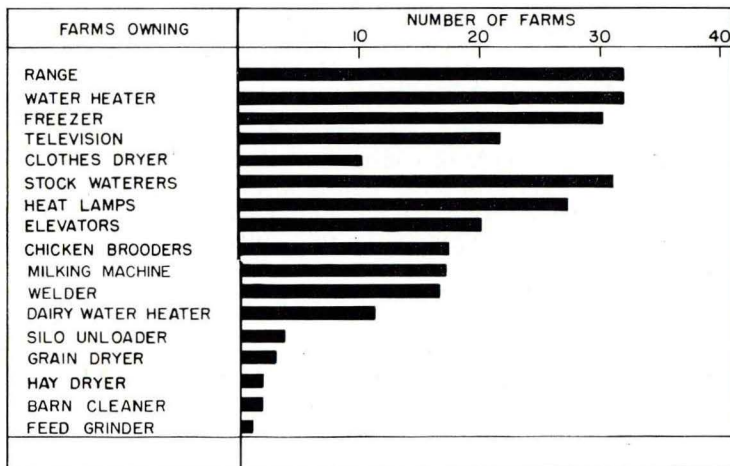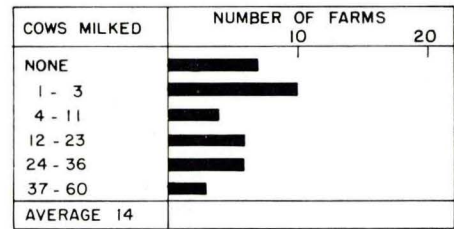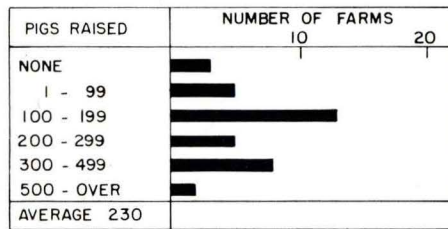

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consumptions for a study of load characteristics does not guarantee that use was made of the electrical energy in farming enterprises. A method of selection was used to choose farms for this study which did make use of electricity for agricultural production purposes.

The following procedure was used to select farms for the study. Each of the 12 cooperating power suppliers prepared a list of the names of nine farmers from the population of interest; i.e., farms using more than 8,000 kwh per year. The power suppliers were asked to include in these lists only farms known to use electricity extensively in farming enterprises. Major items of farm electrical equipment on each of the farms were also listed. Three farms in each locality were chosen from these lists to include major types of farming enterprises. Fig. 1 shows the locations of the farms selected for study.

It is re-emphasized that the group of 36 farms selected for this study comprises a purposely selected sample from the general stratum of interest — farms consuming large quantities of electric power with extensive use in agricultural production operation.

DESCRIPTION OF SAMPLE FARMS

After the farms were selected, an information schedule was filled out on each farm. The various electrical appliances, size of farm, year electrified and size of livestock enterprises were listed. A group of bar graphs showing the distribution of these characteristics is presented in fig. 2. Average farm size, 251 acres, was larger than the state average of 169 acres (4). Number of hogs raised per farm was about 2.5 times the state average of 92 and the number of cattle sold about 3.5 times the state average of 22 (5). Generally these farms were in the top 10 percent in agricultural production as well as in their use of electrical energy. In all but three instances, a single family lived on each farm.

Attempts at classifying farms according to major livestock specialty were unsuccessful because of diversity in livestock types and because of shifting interest between kinds of livestock. The farm with the largest number of hogs raised per year (2,000) also had 1,000 laying hens. The largest dairy farm (60 cows) also raised 100 hogs and 65 beef cattle per year.

DATA OBTAINED

The 36 farms were metered continuously with recording demand meters for 1 year beginning with July 1954. Block-interval, recording demand meters were used. Each meter recorded the demand of an entire farm by 30-minute periods. A photograph of one of the meter installations is shown in fig. 3.

In addition to the metering of the entire farm, the homes on nine of the 36 farms were also metered for 1 year with recording demand meters. Other data obtained included recording ammeter charts showing the operation of some of the electrical equipment used in agricultural production. Motors on elevators and water pumps, heating elements on stock waterers and poultry brooders and heat lamps for pig brooding were metered for 2-week periods.
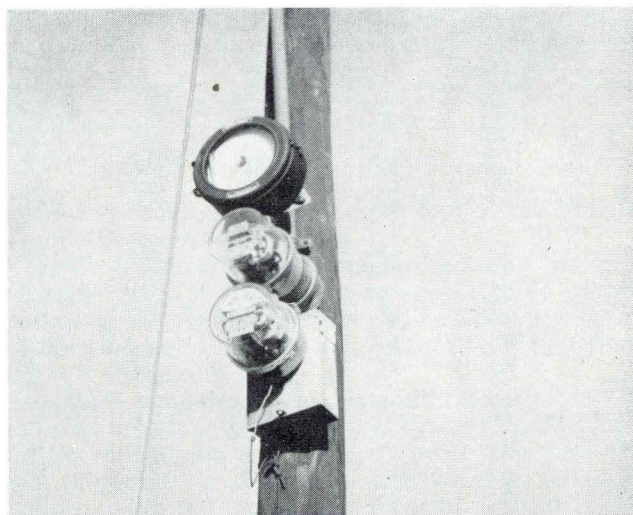
Fig. 3. Recording demand meter installation. The moving element of the bottom meter actuates a contact device. The top meter counts and records the impulses received from the contact device by half-hour periods. The center meter is the power supplier's watt-hour meter used in billing.

LOAD CHARACTERISTICS OF INDIVIDUAL FARMS AND HOMES

Summaries, analyses and discussions of data obtained in this study are presented in three sections — the load characteristics of individual farms and homes, demand patterns of appliances used in production and the coincident or diversified demands of farms.

ANNUAL ENERGY CONSUMPTION

The annual maximum 30-minute and 2-hour demands, annual energy consumptions, connected loads and service entrance sizes of the 36 sample farms are shown in table 2. Average energy consumption was 13,854 kwh.

One farm used only 7,112 kwh during the record-keeping period. Although this farm used 9,759 kwh in 1953, a change in equipment shortly after the study started resulted in lower energy consumption in 1954-55 than in 1953. The farm was kept in the study, however, since it still met the requirements for selection.

The two farms with the largest energy consumptions used 33,093 kwh and 31,707 kwh for the year (table 2, col. 4).Each used about 2,000 kwh per month except in February and March when pigs were being brooded. During March energy consumptions for the two farms were 5,766 and 5,610 kwh. In February farm No. 2 used 7,594 kwh.

SERVICE ENTRANCE SIZE

Only six of the sample farms had 100-ampere service entrances (table 2, col. 6). An entrance switch of this size served a connected load of 65 kw and an annual energy consumption of 33,000 kwh. A 60-ampere entrance handled a connected load of 43 kw and an annual energy consumption of 16,700 kwh.

TABLE 2. MAXIMUM DEMANDS, ANNUAL ENERGY CONSUMPTIONS, CONNECTED LOADS AND SERVICE ENTRANCE SIZES OF SAMPLE FARMS, JULY 1954 - JUNE 1955.

Farm number	Max. annual 30-min. demand (kw)	Max. annual 2-hr. demand (kw)	Annual energy consumption (kwh)	Connected load (kw)	Service entrance size (amp)
1	19.0	17.9	31,707	59.3	100
2	17.0	12.8	33,093	65.2	100
3	14.8	12.6	15,715	58.9	100
4	10.6	8.8	15,902	43.3	60
5	10.5	9.5	12,387	35.9	60
6	10.4	8.6	16,748	35.7	60
7	9.9	8.1	18,149	44.7	100
8	9.6	8.1	16,180	42.1	60
9	8.9	7.3	13,076	43.8	60
10	8.4	7.1	15,577	34.6	60
11	8.4	7.3	9,621	43.1	60
12	8.2	5.6	12,025	41.0	60
13	8.1	7.5	14,142	23.7	60
14	7.9	6.0	20,092	47.8	100
15	7.8	6.4	15,848	29.6	60
16	7.7	5.7	10,395	33.3	60
17	7.5	6.4	17,845	42.9	100
18	7.4	6.1	9,971	34.9	60
19	7.2	5.6	8,213	25.1	60
20	7.2	5.1	14,561	27.2	60
21	7.0	4.4	11,078	30.9	60
22	6.9	4.2	8,649	27.9	60
23	6.6	5.7	14,505	35.6	60
24	6.6	6.0	16,465	32.6	60
25	6.5	5.6	13,527	27.9	60
26	6.4	5.5	15,727	40.1	60
27	6.4	4.5	12,817	39.0	60
28	6.3	4.5	10,662	40.1	60
29	6.3	4.5	10,005	30.0	60
30	6.0	4.4	8,847	24.1	60
31	6.0	4.5	10,676	39.1	60
32	5.9	4.1	9,771	23.0	60
33	5.7	3.5	8,124	34.6	60
34	5.1	3.7	7,112	35.7	60
35	4.8	4.3	8,251	33.2	60
36	3.9	3.3	11,219	7.2	60
Average	8.1	6.5	13,854	36.5	

MAXIMUM DEMAND

Maximum annual 30-minute and 2-hour demands are rather closely related (table 2, cols. 2 and 3). The maximum 2-hour demand may be approximated by multiplying the maximum 30-minute demand by 0.8, although in some cases the error may be considerable.

Maximum 30-minute demands of the sample farms averaged 8.1 kw, and maximum 2-hour demands averaged 6.5 kw. The highest demand, 19.0 kw, occurred on the farm with the second highest energy consumption, farm No. 2, at a time when pigs were being brooded. Maximum 2-hour demand for this farm was 17.9 kw. Lowest 30-minute and 2-hour maximum demands, 3.9 and 3.3 kw, respectively, occurred on farm No. 36 which used 11,219 kwh during the year. Only 1,094 kwh were used in the house; the remainder, 10,175, was used in the dairy enterprise.

AVERAGE INDIVIDUAL FARM LOAD CHARACTERISTICS BY MONTHS

Average maximum 30-minute and 2-hour demands and energy consumptions are shown by months in fig. 4. The energy consumption data were adjusted so as to put each month on a 30-day basis.

The maximum 30-minute demands of the low month, September, averaged 73 percent of those of the high month, February. The variability between months in average energy consumption was much greater than the variation between monthly maximum demands. Average September 1954 energy consumption was only 44 percent of that in February 1955.

The range and mean of some of the load characteristics of individual farms by months are shown in table 3. Monthly load factors, ratio of the average load for the month to the maximum 30-minute demand occurring during the month, for the 36 individual farms averaged 25.9 percent for the year. Individual farms had monthly load factors as high as 60.5 percent and as low as 8.3 percent. Average monthly maximum demands ranged from 5.4 kw in September to 7.3 kw in February. Individual farm demand factors, the ratio of the maximum 30-minute demand to the connected load, were as high as 0.54.
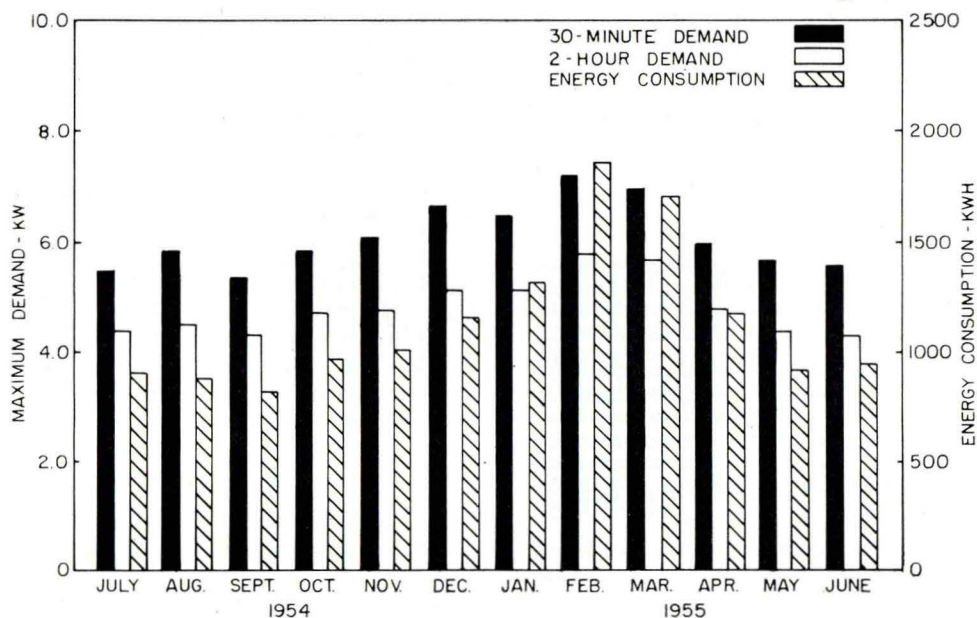

Fig. 4. Average maximum 30-minute and 2-hour demands for electricity and average energy consumptions of 36 farms by months, Iowa, 1954-55.

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TABLE 3. LOAD CHARACTERISTICS OF SAMPLE IOWA FARMS BY MONTHS, JULY 1954 - JUNE 1955.

Month		Average load (kw)	Load factor° (percent)	Demand factor°	Max. monthly 30-min demand (kw)	Max. monthly 2-hr. demand (kw)
1954						
July	Mean	1.25	22.7	0.158	5.5	4.3
	High	2.92	42.3	0.416	10.5	9.2
	Low	0.55	8.4	0.095	3.0	2.2
Aug.	Mean	1.23	20.8	0.169	5.9	4.5
	High	3.04	38.7	0.416	10.6	9.7
	Low	0.57	10.4	0.101	3.0	1.9
Sept.	Mean	1.16	21.5	0.152	5.4	4.3
	High	2.23	44.1	0.374	10.5	8.8
	Low	0.45	6.3	0.089	2.7	2.1
Oct.	Mean	1.35	22.9	0.166	5.9	4.7
	High	4.35	38.3	0.236	14.0	12.8
	Low	0.65	10.0	0.100	3.0	2.0
Nov.	Mean	1.42	23.3	0.173	6.1	4.8
	High	3.60	38.3	0.443	15.2	12.4
	Low	0.72	12.4	0.098	3.0	2.3
Dec.	Mean	1.60	23.9	0.191	6.7	5.1
	High	3.39	43.0	0.457	13.0	10.8
	Low	0.83	10.2	0.117	3.3	2.6
1955						
Jan.	Mean	1.83	28.2	0.189	6.5	5.1
	High	3.72	47.5	0.513	11.0	10.3
	Low	0.91	16.8	0.106	3.7	2.8
Feb.	Mean	2.61	35.8	0.208	7.3	5.8
	High	11.30	60.5	0.540	19.0	16.4
	Low	0.91	20.7	0.123	3.9	2.8
March	Mean	2.40	34.3	0.200	7.0	5.7
	High	7.75	60.0	0.485	18.4	17.9
	Low	0.77	11.8	0.124	3.5	2.8
April	Mean	1.64	27.3	0.174	6.0	4.8
	High	4.73	43.3	0.416	14.8	12.6
	Low	0.69	15.3	0.100	2.9	2.6
May	Mean	1.26	22.1	0.181	5.7	4.4
	High	2.41	48.9	0.431	11.8	9.1
	Low	0.54	8.3	0.101	1.6	1.3
June	Mean	1.33	23.7	0.181	5.6	4.3
	High	4.82	53.6	0.375	10.2	9.3
	Low	0.62	10.1	0.097	2.7	2.3
Average	Mean	1.59	25.9	0.179	6.1	4.8
	High	4.52	46.5	0.425	13.3	11.6
	Low	0.68	11.7	0.104	3.0	2.3

° Based on 30-minute maximum demands.

COMPARISON OF THE LOAD CHARACTERISTICS OF THE HOME WITH THE FARM

The homes of nine of the 36 farms were metered with recording demand meters for a period of 1 year. Again, the selection was not strictly random. Each of nine power suppliers selected a farm on the sole basis of probable ease with which the meters could be installed in the home.

The saturation of appliances on the subsample of nine farms was about the same as for the entire sample. There were eight ranges, seven water heaters, six freezers, six television sets and three clothes dryers in the nine homes. Other electrical equipment on the nine farms consisted of 27 heat lamps, 17 stock waters, five each of elevators, chicken brooders and milking machines, four welders, two dairy water heaters, one silo unloader and one hay dryer. This appliance

TABLE 4. COMPARISON OF AVERAGE ANNUAL LOAD CHARACTERISTICS OF THE SAMPLE IOWA FARMS WHOSE HOMES WERE METERED SEPARATELY WITH FARMS WHOSE HOMES WERE NOT SO METERED, JULY 1954 - JUNE 1955.

Average annual load characteristics	9 farms with home metered	27 farms with home not metered
Maximum 30-minute demand, kw	7.1	8.5
Connected load, kw	33.9	37.4
Average load, kw	1.47	1.63
Energy consumption, kwh	12,789	14,209
Demand factor	0.21	0.23
Load factor, percent	21	19

TABLE 5. COMPARISON OF AVERAGE ANNUAL LOAD CHARACTERISTICS OF FARM AND NONFARM (HOME) USES OF ELECTRICITY ON NINE IOWA FARMS, JULY 1954 - JUNE 1955.

Average annual load charactertistic	Farm use	Nonfarm (home) use	Farm and home use
Maximum 30-minute demand, kw	4.1	6.0	7.1
Average load, kw	0.57	0.90	1.47
Energy consumption, kwh	5,031	7,758	12,789
Load factor, percent	14	15	21

saturation may be compared with that of the 36-farm sample by referring to fig. 2.

Table 4 compares the average of some of the load characteristics of the nine farms with those of the remaining 27. On the average, the load characteristics of the nine farms chosen were not very different from the rest of the farms.

Table 5 compares the annual load characteristics of the nine homes with those of the nine farms. The load factors of the farm and home are nearly the same (14 and 15 percent, respectively). The homes in this subsample accounted for an average of 61 percent of the total use of electricity, with home use ranging from 9.8 percent to 94 percent of the total.

A comparison of the annual load factors and maximum demands for the farms and homes in table 5 brings out an important point: The annual maximum demands of home and agricultural production uses of electricity did not occur at the same time on a given farm. The average annual maximum demand of the homes was 6.0 kw and that of the farms was 4.1 kw, while the average annual maximum demand of the combined home and farm uses of electricity was 7.1 kw.

PREDICTING MAXIMUM DEMANDS OF INDIVIDUAL FARMS

Matching the size of the distribution transformer at a farm to the load served is one of the operating problems facing rural distribution system management. Transformers which are too small result in poor voltage to farmers and excessive numbers of burned-out transformers. Oversized transformers cause unnecessary line loss and investment.

Metering of individual farms to determine maximum demands for correctly sizing transformers is not economical. The usual practice when sizing transformers is to place each farm in a classification based on the major equipment owned. Farms with similar equipment are given the same size transformers. Since many small appliances and actual energy consumption usually are not considered, the maximum demands of farms within the same classification vary widely.

Transformers in service may not be increased in size until voltage problems develop or until the transformer burns out through overloads. Since overloads of short duration do not lessen the service life of a transformer (6), primary side transformer fusing usually is well above the service rating and does not prevent burnouts caused by overloads. Internal secondary breakers may protect the transformer but may require many service calls. Overload indicators, such as a red signal light, require the patrolling of lines to identify the overloaded transformers. No practical method of identifying underloaded transformers has been suggested.

If a reliable method of predicting the maximum demand of a farm from readily procurable information were developed, systematic sizing of transformers to the load could take place. This should result in better and more economical electrical service to farmers.

Several methods of relating various load characteristics to maximum demand have been tried. In a previous study of 42 farms (2), it was found that an average of 54 percent of the variation in maximum demands could be associated with the variation in energy consumption of the farms. When connected load was used as a single predictor, 41 percent of the variation in maximum demands could be explained by this load characteristic. Combining energy consumption and connected load resulted in only a trivial increase in percentage of the variation explained. These predictors either singly or in combination did not provide a reliable guide for matching transformer size with expected demand.

If an equation for estimating the maximum annual demand could be developed to relate information on energy consumption and appliances owned, reasonably good results might be obtained. Energy consumption may explain about half the variation in maximum demands of a farm. The number and kind of appliances installed should explain much of the remaining variation. Both types of information are available to or readily obtainable by the power supplier.

These ideas suggest that a suitable equation might be set up that expresses the annual peak load of a farm as a function of the presence or absence of certain major or key appliances and energy consumption. Some appliances might be present in quantity; i.e., two or more. Similar problems have been considered by other researchers in this general area.[3] When such a model has been set up, equations usually are derived for estimating the unknown parameters by application of the principle of least squares.[4] Solution of the equations then provides the information for writing an estimating or predicting equation.

Such an equation for predicting the maximum demand of a farm was derived from the limited data available in this study. It is presented mainly as an example in methodology although it may have application in some situations. The equation obtained was:

$$\hat{Y} = 3.398 + 1.233\ X_1 - 0.282\ X_2 + 2.096\ X_3 \\ - 0.845\ X_4 + 0.857\ X_5 + 0.529\ X_6 + 0.00213\ X_7 \\ + 5.714\ X_8 - 0.0321\ X_9 + 0.001799\ X_{10}\ [5]$$

where $\hat{Y}$ = the predicted annual 30-minute maximum demand of an individual farm in kilowatts and
X_1 = number of ranges,

[3] Schiller and Pridmore (7) give the energy consumption of a number of appliances determined statistically from records of the energy consumption of individual consumers and from a survey of the appliances used. A similar procedure is used in this paper except that demands rather than energy consumptions of appliances are estimated. In addition, another factor contributing to total demand of the farm, namely energy consumption, is included as a predictor.

[4] Details are omitted here. A suitable single reference is Anderson and Bancroft. Statistical theory in research. McGraw-Hill Book Co., Inc., N. Y. 1952.

[5] The standard errors of the regression coefficients are 0.437, 0.514, 0.476, 0.382, 0.411, 0.546, 0.163, 0.977, 0.0307 and 0.000195, respectively. The standard errors are larger than the partial regression coefficients for X_2, X_6 and X_7. Thus, in these three instances, the true regression coefficients actually might be zero. The effect of these appliances on maximum demands of farms also is included in the energy consumption.

X_2 = number of water heaters,
X_3 = number of clothes dryers,
X_4 = number of freezers,
X_5 = number of dairy water heaters,
X_6 = number of crop dryers,
X_7 = number of stock waterers,
X_8 = number of feed grinders,
X_9 = number of heat lamps and
X_{10} = number of kilowatt hours used in the month with highest energy consumption.

The multiple correlation coefficient between the actual peaks and those predicted from the equation was 0.97. Thus, about 95 percent, $(0.9726)^2\ (100)$, of the variation in annual maximum demand is associated with variation in these predictors for the 36 sample farms. While the predicted and metered maximum demands are in very close agreement for the sample farms, an examination of the equation shows that it cannot be given wide application in its present form. The high value of the constant, 3.398, is above the maximum demand of many small farms. When the value of the regression coefficient of X_{10}, 0.001799, is multiplied by the maximum monthly energy consumption and added to 3.398, the predicted maximum demand easily reaches 4 kw without any of the appliances used in the equation being present. Clearly, this demand is much higher than would be expected on many farms. However, the maximum demands of the selected farms in this sample averaged 8.1 kw. Thus, the equation may be useful for predicting the maximum demands of farms similar to those from which it was derived; i.e., comparably equipped Iowa farms which use in excess of 8,000 kwh of electrical energy per year.

Further examination of the equation and the data from which it was derived may raise a question about the coefficient for feed grinders, 5.714. Only one electrically powered feed grinder was used on the 36 sample farms. This grinder used a 7½-hp motor. At the time it was in use, a 5-hp motor on a mixer and several motors on elevators were often used. Since a wide range of motor sizes may be used with feed grinders, a coefficient based on only one farm reporting a feed grinder has little value. It was included in this case to help account for the high demand on this particular farm. With a sample including a number of feed grinders, a more reasonable coefficient could be estimated. If sufficient data were available, the equation could be extended to include a range of motor sizes.

The low coefficient, 0.529, for crop dryers may be noted. The five crop dryers in this study used four motors of 5 hp and one of 3 hp on the fans. Since they may operate continuously for several weeks, it would seem that the coefficient for this appliance should be higher. One reason for the low value is that crop dryers are used in the summer and fall when other demands are low. Further, crop dryers have reasonably good monthy load factors — allowing more of the demand to be explained by the regression coefficient times the maximum monthly energy consumption and by the constant term than is the case with a feed grinder.

The negative regression coefficients for the water

heater (—0.282), heat lamps (—0.0321) and freezers (—0.845) are difficult to explain. It may be that these appliances contribute relatively more to the monthly energy consumption than to the peak load in comparison with other appliances. The negative coefficients for X_2, X_4 and X_9 would correct for the extra contribution of the monthly energy consumption, the variable X_{10}, to the peak load when these appliances are present. Also there is a standard error associated with each of the coefficients. Since the negative coefficients for water heaters and heat lamps are not large relative to their standard errors, their true regression coefficients may be near zero (footnote 5).

Equations based on other models may describe the effect of energy consumption and presence of certain appliances on maximum demand better than the linear model used. Such equations could force the predicted demand to be zero when there is no energy consumption. Demand data for farms with low energy consumptions were not available for use in the exploration of these possibilities.

LOAD CURVES OF APPLIANCES USED IN AGRICULTURAL PRODUCTION

Recording ammeters were used to obtain records of the electrical demands of grain-elevator motors, stock drinking-water heaters, heat lamps used in pig brooding and poultry brooders. Ammeters were available for use by nine of the power suppliers cooperating in the study. In some instances, none of the three farms at a location made use of a particular appliance during the time interval chosen for the metering.

Information on the average demands by hours of the day of groups of similar appliances is of value in determining the effects of particular appliances on system demands. Such information is used in planning load development activities. Data on the appliances metered in this study are shown in fig. 5. It should be noted in examining the curves that the appliances probably were not operated continuously. The demands shown are the average of a number of appliances and do not indicate the load of a single appliance when it is in operation.

The data for studying appliance demand were obtained in amperes. Since other data are presented in watts, the appliance demands were converted to watts by multiplying by 115 or 230 volts and by 0.8 for motor-driven appliances to provide for power factor.

GRAIN-ELEVATOR MOTORS

Five grain-elevator motors were metered simultaneously from Oct. 30 to Nov. 5, 1954. Typical use was for 5 to 10 minutes each half-hour from 7:30 a.m. to noon and from 12:30 to 5 p.m. The average demand in watts for the motors by hours of the day, omitting Sunday, is shown in fig. 5.

Of the motors metered, two were 5 hp, two were 3 hp, and one, 2 hp. Maximum instantaneous demands omitting starting currents were 37, 24 and 20 amperes, respectively, for the 5, 3 and 2-hp motors. Minimum running currents were 14.4, 14.8 and 9.6 amperes, respectively, for the three motor sizes.

Twenty of the 36 farms in the study used motors on elevators. Even with this high saturation, average
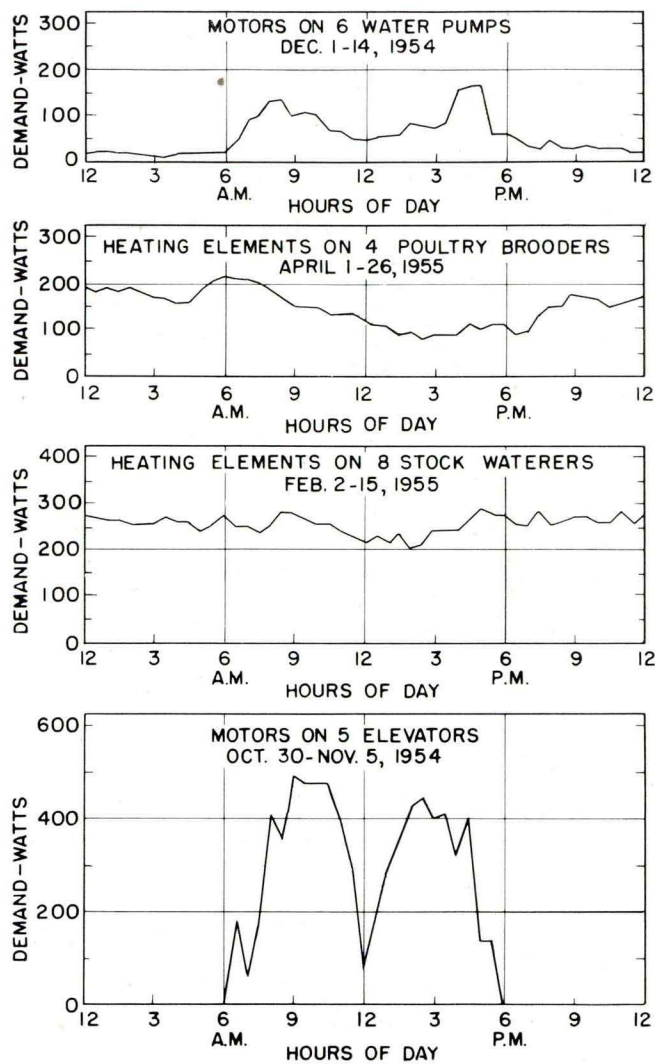

Fig. 5. Average demand for electrical energy of four production appliances by hours of the day, Iowa, 1954-55.

30-minute maximum demands of the individual farms in September, October and November — periods of maximum elevator use — were well below average winter maximum demands and only slightly above summer demands.

If the 36 farms are considered as a "system," the maximum system demand occurred from 6:30 to 7 p.m. in September and from 6 to 6:30 p.m. in October and November. Usual elevator use occurred earlier in the day than the time of the system maximum demand, and the elevator motors made almost no contribution to the monthly maximum demand of the system. It may be concluded that the elevator motor has good load characteristics from the standpoint of the power supplier. Generally, it may be added to existing farm loads without requiring additional transformer or service capacity.

MOTORS ON WATER PUMPS

A water system using motor-powered pumps is found on most modern farms. The 36 farms in this study used 34 motors on pumps supplying pressure

tanks, 12 motors on soft-water pumps and 14 motors on pump jacks. Median sizes were ½ hp for the motors on pressure and soft-water systems and ⅓ hp for motors on pump jacks.

The motors on six of the pumps on pressure systems were metered with recording ammeters for the period Dec. 1-14, 1954, to determine the demand pattern of water use.

Average load in watts of these motors by hours of the day is shown in fig. 5. The average use at the time of the system peak in December, 5:30 to 6 p.m., is relatively low. Average water-pump motor use may be compared with the average farm demand at other hours of the day in December by comparing figs. 5 and 6.

HEATED STOCK WATERERS

The use of heating elements for keeping stock-watering equipment free of ice is one of the more widely used farm applications of electricity in Iowa. Sixteen farms in this study had 25 electrically heated poultry waterers; 10 had immersion stock tank heaters; and 21 had 36 automatic stock waterers. Only five of the farms did not make use of electrically heated stock waterers in one form or another.

The thermostatically controlled heating elements on seven automatic stock waterers and one stock tank heater were metered from Feb. 2-14, 1955. The stock tank heater was of 1,000-watt capacity and was installed in a 12-foot diameter wooden tank. It operated almost continuously for the 2-week period. The heating elements on the automatic waterers averaged 667 watts in size and were seldom on continuously for 30 minutes.

The average electrical demand of these waterers by hours of the day is shown in fig. 5. The almost constant average load, with a slight dropping off during the late morning and afternoon, should be noted. It may be readily seen that these devices have excellent load characteristics.

HEAT LAMPS FOR PIG BROODING

Another of the widely adopted farm applications of electrical energy was the use of infrared lamps in pig brooding. Lamps were all of 250-watt capacity. Thirty of the 36 farms in this study — all but three of the farms raising hogs — made use of this appliance. One of the farms operated 35 lamps at one time for a period of several weeks. Most of the heat-lamp use was in February, March and early April. Pigs are farrowed on some farms at all seasons of the year, and use is made of heat lamps during all of the colder months.

The energy used by heat lamps on four farms was metered for a 2-week period in late March and early April. Three of the four farms left the lamps on continuously during the period they were being used. The other farm turned off the lamps during most of the daylight hours. Generally, a curve of the pattern of use of heat lamps would be a horizontal straight line for the periods that the lamps are being used.

The load characteristics of heat lamps in pig brooding are good from an individual farm or system viewpoint. However, if large numbers are used on a farm at one time, a larger transformer and service entrance may be required than would otherwise be the case. The bulk of this load comes during seasons when system loads are heavy. It is one of the reasons that farm demands and energy consumptions are high in February and March. The trend toward multiple farrowing is causing a wider spread in time of pig brooding electrical demand. The result of this change will be an improvement in the effect of this appliance on system load factors.

POULTRY BROODERS

Iowa is the leading egg producing state in the United States (4). The production comes mainly from many small flocks rather than from a few large ones. Electric poultry brooding is popular in Iowa. Seventeen of the farms in the study had electric brooders of the hover type.

The energy used by brooders on four farms was metered with recording ammeters from April 16 through April 26, 1955. The wattages of the heating elements of the brooders were 1,300, 1,000 and two of 750 watts. The farms using the 750-watt brooders raised 470 and 400 chicks while the farms having the 1,000- and 1,300-watt brooders raised 278 and 350 chicks, respectively. The average electrical demand of the brooders by hours of the day is shown in fig. 5. The highest demands were early in the morning and at night. Most poultry brooding was done after the annual system peaks which occurred in the winter months in Iowa. Use of this appliance fits in well with the annual load curve of most rural distribution systems.

COINCIDENT DEMANDS

The maximum demand of an individual farm is of concern to the farmer in designing a suitable farm-wiring distribution system and to the electric distribution company in sizing the transformer and service wiring. This section on maximum coincident or simultaneous demand of a group of farms is of primary interest to those concerned with power distribution and generation.

AVERAGE COINCIDENT DEMANDS OF THE SAMPLE FARMS

The averages of the monthly coincident demands by hours of the day of the 36 farms in the study are shown in fig. 6. Each line is the average of 432 observations. These observations consist of the 12 weekday values for each 30-minute period of the day for the 36 farms in the study. In tabulating information for this section, data for every other week of each month were recorded. Sundays were excluded because it was shown in an earlier study that farm demands on Sundays differed from those of weekdays (2).

The changes in demand pattern with seasons of the year are shown in these curves. The shift in the time of the evening peak load with seasonal changes in hours of daylight, the increased nighttime use of electricity in winter and the annual peak load in February may be noted. This peak averaged 3.57 kw per farm for the 12 days tabulated and occurred from 6 to 6:30 p.m.
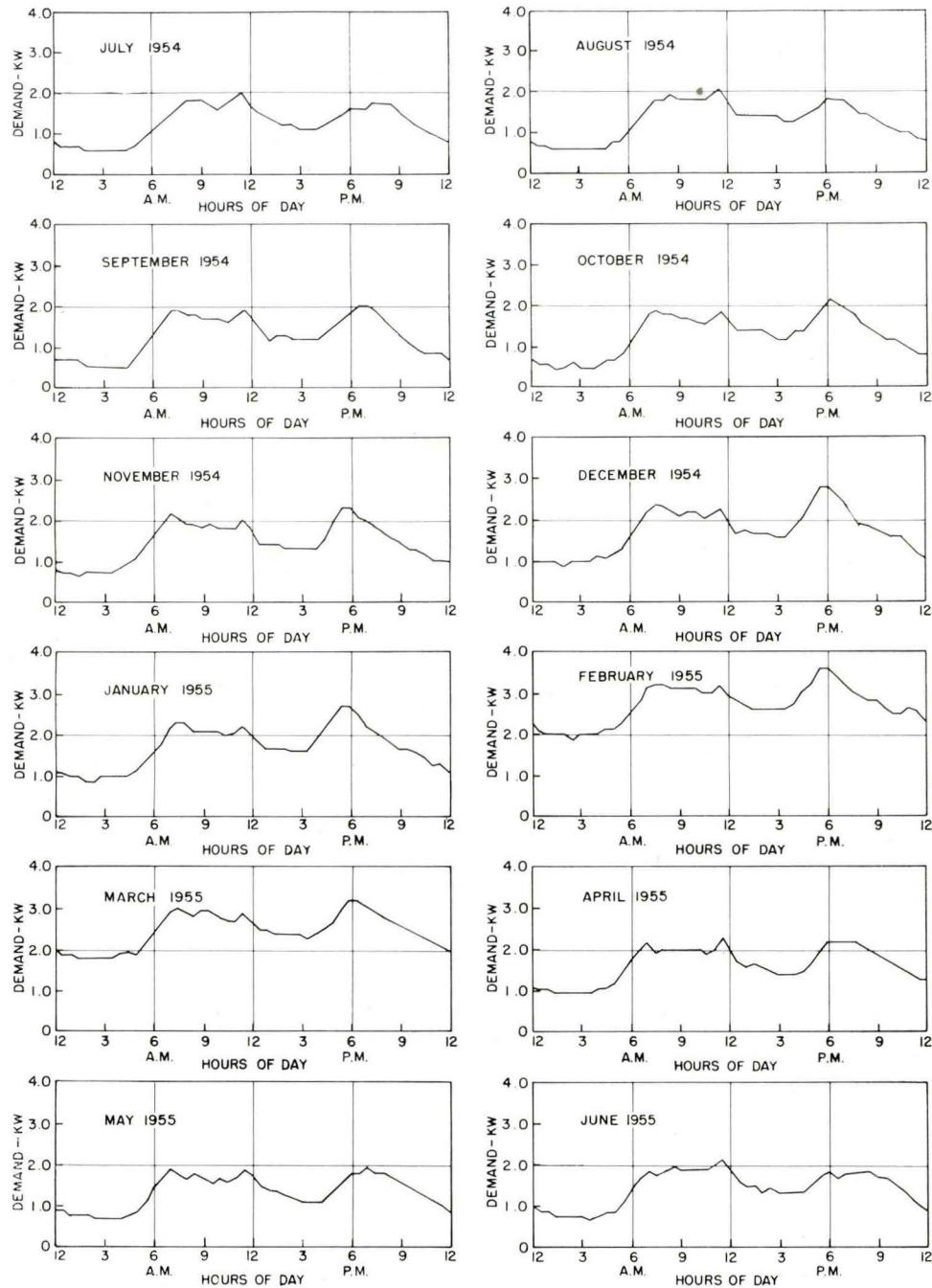
Fig. 6. Average demand for electrical energy of 36 farms by month and hours of the day, Iowa, 1954-55.

Considering each farm as a part of a 36-farm system, the diversity factor, the ratio of the sum of the maximum demands of individual farms to the maximum coincident demand of the 36-farm system, was 1.98. If the maximum demands of all of the farms had occurred during the same 30-minute period, the demand upon the system would have been about twice the amount actually metered.

The annual load factor of the 36-farm system, the ratio of the average load for the year to the annual coincident maximum demand of the group, was 39 percent. The monthly load factors of the 36-farm system, the ratio of the average load for each month to the coincident 30-minute maximum demand occurring during each month, averaged 64 percent for the year. Monthly load factors ranged from a low of 57 percent in December to a high of 74 percent in March and April.

DEMANDS OF HOMES AND FARMS

The average daily demand pattern of nine of the sample farms divided into the parts used in the house and outside the house is shown by months in fig. 7. The dotted lines represent the average farm use of
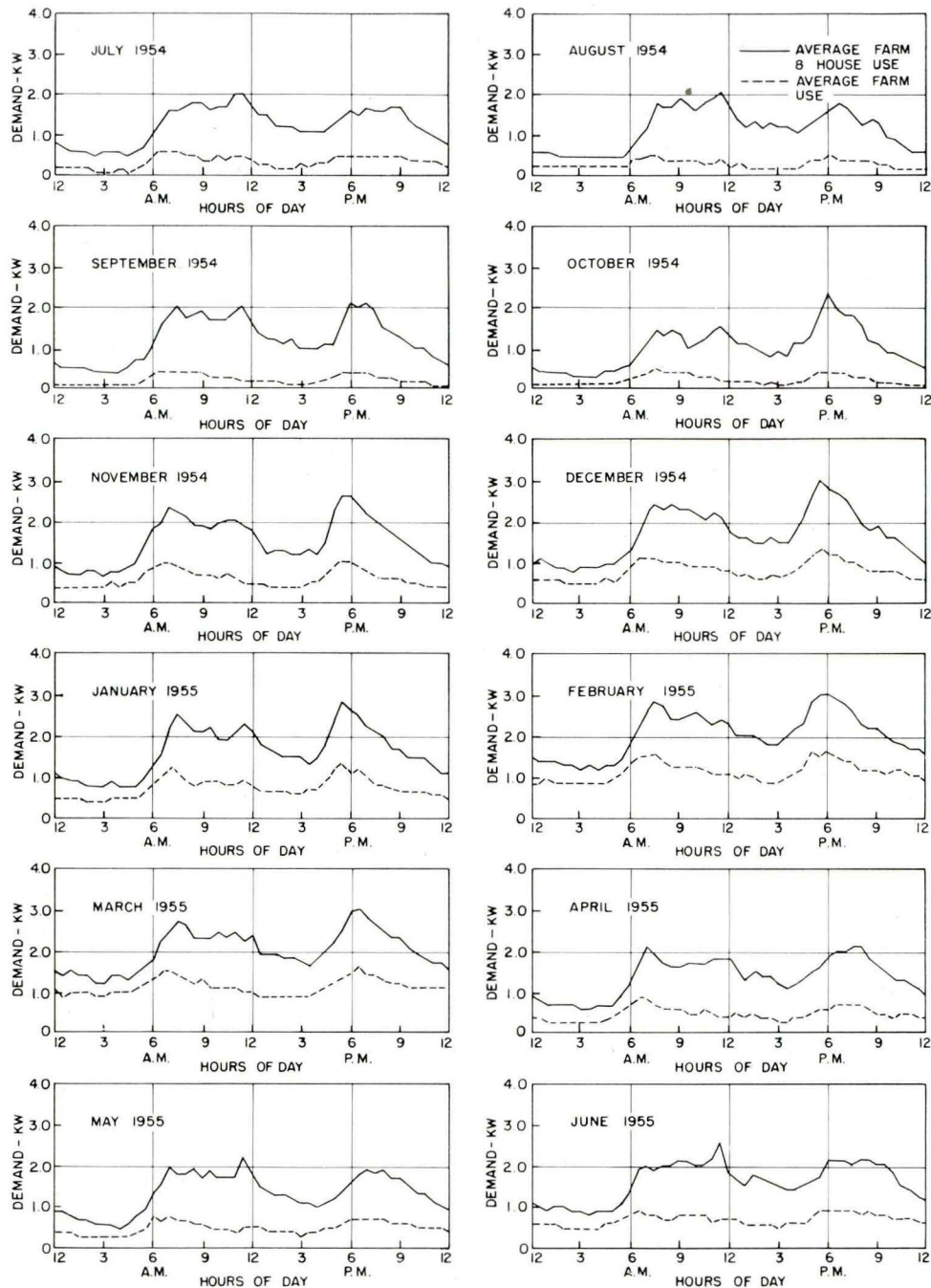
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Fig. 7. Comparison of average demand for electrical energy of nine farms with that of the house and farm by hours of the day and month, Iowa, 1954-55.

electricity by 30-minute periods of the day for 12 weekdays of each month. The solid lines represent the average of the combined demands of the nine farms and homes for the same days. The average demands of both reached maximums at the times that distribution systems serving farms in this area normally have their peak demands.

The high degree of diversity between the time of the annual peak demand of the home and farm on individual farms was explained in an earlier section. In contrast with this, note the lack of diversity be-

tween the farm and home in the time of the average daily peak demand. From the power distributor's viewpoint, there is little diversity in time of use of electrical energy between home and agricultural uses of electricity.

FUTURE LOAD CHARACTERISTICS OF FARMS

There is much current discussion about the future load characteristics of farms. Information on this subject is required for the orderly expansion of genera-

tion and distribution facilities and for use in making recommendations and setting standards for farm wiring.

The latter problem is particularly pressing at present. The most common size of farm service entrance, 60 amperes, is not adequate to handle the loads on some farms. Many farm wiring systems have deteriorated or are obsolete and need replacement. Recommendations and regulations are now being formulated on the minimum size of service entrances to require for new construction and for replacement wiring (8, 9). The problem is difficult since recommendations should provide a farm wiring system which will be adequate for load growth and yet not be unduly expensive to the farmer whose load does not grow as rapidly as expected.

Predictions of the average energy consumption of farms at future dates have been made (10, 11, 12). Data on the energy consumptions of farms are available from billing records over a period of years. Estimates of future energy consumptions are usually made by extrapolations from trend lines indicated by these records of load growth. Predictions may be based on the linear extension of the trend or on a percentage growth each year.

Records of changes with time of other load characteristics, particularly maximum demands, are not generally available. Lacking a trend line for these characteristics on which to base predictions, the following method of predicting load characteristics makes use of estimates of energy consumptions of farms at future dates.

First, estimate the average energy consumptions of farms in the area of interest for various future dates. Then, select a special sample from the more modern and well-equipped farms in such a way that the appliance saturation and energy consumption of the sample might be approximated by the average farm after a period of years. Obtain, through metering, the load characteristics of the sample farms. Finally, assume that the load characteristics of average farms will be similar to those of the sample farms when the average energy consumption reaches that of the specially selected sample.

Whether or not the load characteristics of the sample farms and of the average farm some years hence will be similar, depends largely upon the appliances used on the sample farms. Probably most load growth will result from higher saturations of existing appliances. Some of the newer uses of electricity today will have more widespread use in the future. Use of equipment yet to be developed or invented most likely will be confined at first to a small percentage of farms. Should definite ideas be held as to the probable saturation of particular appliances, then a proper proportion of farms with this appliance would be included in the chosen sample.

The method of choosing the sample used in this study, that is purposive selection from the high 10 percent of farms in energy consumption and from those using electricity in farm production enterprises, may be a suitable one for estimating future load characteristics. Should the load characteristics of the farms in this study be average for some Iowa areas when annual energy consumption averages 14,000 kwh per farm, then the average load characteristics of these farms might be as follows: Annual maximum 30-minute demands would average about 8 kw and connected electrical loads about 40 kw per farm; about half the farms could still use a 60-ampere service entrance; annual load factors of individual farms would average about 20 percent and monthly load factors about 25 percent; the diversity in time of electrical use of farms would be such that monthly load factors of distribution lines serving 36 farms might average about 65 percent; and some 40 percent of the energy might be used in farm enterprises.

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