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RESEARCH ARTICLE

Deriving Power Consumption Models From Energy Bills for Optimal Sizing of Hybrid Power in Commercial Buildings

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ABSTRACT In recent years, commercial buildings have turned to installing their own hybrid power plants to reduce extremely high energy costs. Arguments such as the efficiency of producing electricity where it is consumed, and government incentives also supported this process. The most common applications are power plants where one or more of cogeneration, trigeneration and solar panels are used together. However, for these advantages to emerge, the capacity of the hybrid power plant must be determined correctly, and the generated power must exactly match the consumed power. Achieving this is possible by knowing exactly the power consumption profile of the business. Businesses are only aware of monthly consumption information in kWh and only the mean consumption value can be calculated from this value. However, to accurately determine the power plant power to be installed, it is necessary to know the maximum and minimum power consumption values and the duration of these consumptions rather than the mean consumption. In this study, power consumption profiles that can be used as a reference in similar applications were presented for three different commercial buildings consisting of a supermarket, stores section and plaza. For these buildings, for which only monthly energy consumption values are known, the maximum and minimum power consumption values were expressed with mathematical models with the help of meteorological data such as monthly mean temperature and sunshine duration. R-square values obtained were found to be 0.99 for the supermarket, 0.97 for the plaza and 0.99 for stores sections. These high regression values show the reliability of the model and the accuracy of energy consumption predictions and can be used to estimate the energy consumption of similar commercial buildings and determine the capacity of hybrid power plants to be installed. In this way, no time would be wasted waiting for measurements to be taken to obtain the power consumption profile.

INDEX TERMS Commercial buildings, plaza offices, power consumption model, stores, supermarket.

I. INTRODUCTION

Today, one of the places where energy is used most intensively is commercial buildings [1], [2]. Some commercial buildings consume more energy than most factories with the same indoor area [3], [4]. Large shopping malls containing many stores, markets and commercial offices are among the places with the highest energy consumption [5], [6], [7]. Efforts to reduce both energy consumption and energy costs are today's primary goal [8], [9], [10]. To reduce energy consumption, it is necessary to know exactly where the energy is spent [11], [12]. In addition to reducing energy consumption, reducing energy costs is also an important issue for businesses [13], [14]. In the 2000s, the concept of reducing energy costs was synonymous with the concept of reducing energy consumption [15], [16], [17]. However, today these two concepts do not mean the same thing [18], [19]. Nowadays, there have been many developments that make the concepts of energy amount and energy cost different from each other [20], [21]. These were listed as advantages of producing electrical energy in factories which was used energy, competition between commercial

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energy companies, producing electrical energy from renewable resources, achieving very high efficiency values at technologies of cogeneration and trigeneration, varying electrical energy costs depending on its source [22], [23], [24], [25], [26]. All these developments have revealed that it is possible to pay less energy costs despite using more energy [27], [28], [29]. This situation has led businesses to produce their own electrical energy from hybrid and renewable sources to reduce energy costs [30], [31], [32], [33].

However, for a business that produces its own energy to benefit from it at the maximum level, its hourly, daily, and monthly energy consumption profile must be known [34], [35]. Because energy efficiency is essential in this new concept energy production style [36], [37]. The reason for the existence of these systems is not to provide energy to a business that does not have energy, but to provide energy at a much cheaper cost to a business that already uses electrical energy [38], [39]. Then, the energy consumption curve of the commercial building and the production curve of hybrid energy sources should overlap at the maximum level [40], [41]. The condition for achieving this is to know the hourly, daily, and monthly energy consumption profiles of commercial buildings due to just knowing the mean monthly power consumption is not enough [42], [43], [44], [45]. The maximum and minimum power drawn at any given time must be known [46], [47]. In addition, it is necessary to know which parameters power consumption depends on and its change according to these parameters [48], [49], [50], [51]. In this context, there are many studies in the literature [52], [53], [54]. Today's most efficient and fastest applicable hybrid energy production facilities are hybrid systems consisting of a combination of combined heat and power or trigeneration and solar energy [55], [56]. In businesses that use high power heating and cooling in addition to the use of electrical energy, cogeneration and trigeneration applications are investments that have a rapid return if natural gas costs are affordable [57], [58], [59]. Solar energy is an attractive application in regions with high sunshine hours and is a popular renewable resource whose investment cost is decreasing day by day [59], [60].

A facility's electrical energy bill includes only total energy consumption information [61]. However, power plants such as cogeneration plants are more sensitive to peak power demands. Cogeneration and trigeneration systems aim to reduce the energy cost of facilities that consume electricity and heat energy together, instead of just providing electricity to a place that does not have electricity. These systems produce both electricity and heat at the same time. For example, in facilities such as a hospital or hotel, hot water or steam is required as well as electrical energy. Cogeneration produces these two types of energy simultaneously and thus increases energy efficiency [62], [63], [64], [65], [66], [67], [68]. Since cogeneration systems, also called combined heat and power systems, become inefficient when operating at 50% or lower capacities, they must operate at full capacity as much as possible. It is preferred that the power requirement be slightly above what the cogeneration system can provide. In this way, the cogeneration plant always operates at its highest efficiency value, and the remaining small amount of energy is met from the grid. It is critical to determine the correct cogeneration capacity here. Adequate benefit cannot be obtained from low-capacity investment, and an excessive capacity will lead to inefficiency. Many cogeneration investments have become idle because the correct power value could not be determined. Therefore, it is important to know peak demand values and adjust cogeneration capacity according to these values. It is necessary to make long-term measurements and keep records to determine peak demand values. This process is time consuming and costly for investors. Additionally, the profitability of the investment may vary depending on country policies and periodic factors. Therefore, there is no time to waste making measurements [69], [70], [71].

In this study, the power consumption profile was presented to correctly select the capacity of the hybrid power plant to be installed in a business that will produce its own electricity. Power consumption profiles obtained for 3 different types of commercial buildings were modeled mathematically using electricity consumption data recorded over many years. It is aimed to calculate peak power values for businesses that only have energy bill information, considering monthly energy consumption values and environmental parameters, and thus determine the capacity of cogeneration facilities more quickly and accurately.

II. MATERIAL AND METHODS

This study was carried out under real conditions in a shopping mall in Konya, one of the largest commercial buildings in Turkey. The commercial complex has 3 different types of commercial buildings. These were 1 large supermarket, a market section with around 100 stores, and a plaza building with around 100 offices. Each commercial section has its own supply transformer. The supermarket, which had an area of approximately 15000 square meters, had rooftop units that used natural gas for heating and electric energy for cooling. The total indoor area of the high-rise plaza building was approximately 25000 square meters. The building was heated with a natural gas combi boiler and cooled with electric cooling groups. The stores section has an area of approximately 50000 square meters, including its indoor car park. There was one high-capacity HVAC system here. While electrical energy was used to cool this section, both electrical and natural gas equipment were used to heat it. Power consumption of each transformer was measured by ELSTER A1350 electronic meters. Data collection was carried out using the energy monitoring system installed in the facilities. Power values were read and recorded from the meters every 15 minutes for more than 5 years. In this study, publicly accessible meteorological data obtained from official state authorities and reliable international web pages were used. Meteorological data of Konya-Turkey the location where the study was conducted were given in Table 1 [72], [73], [74].

TABLE 1. **Meteorological data.**

Month	Daytime Temperature (°C)	Nighttime Temperature (°C)	Mean Temperature (°C)	Sunshine Duration (hour)	Solar Power (kWh/m^2)	Daylight Duration (hour)
1	6	-7	-0.1	3.3	2.7	9.9
2	12	-5	1.6	4.2	3.6	10.8
3	16	0	5.6	5.3	4.9	12.0
4	21	4	11.3	6.6	6.2	13.2
5	22	8	16.1	8.2	7.2	14.2
6	28	13	20.3	9.9	8.2	14.7
7	33	15	23.7	10.7	8.3	14.5
8	32	16	23.6	10.1	7.6	13.6
9	30	11	19.0	8.6	6.2	12.4
10	21	5	13.1	6.3	4.3	12.2
11	15	-2	6.6	4.6	3.0	10.1
12	9	-7	1.9	3.1	2.4	9.6

III. RESULTS

Mean power consumption values for supermarket, plaza and stores by month were given in Table 2 for mean values.

TABLE 2. **Power consumption for supermarket.**

	Air	Sunshine	Mean Power		
	Temperature	Duration	Supermarket	Plaza	Stores
Month	K	hour/day	kW	kW	kW
1	273.0	3.27	252.6	233.6	309.3
2	274.7	4.24	252.6	194.8	275.9
3	278.7	5.29	243.6	192.2	259.8
4	284.3	6.62	245.6	187.1	350.5
5	289.1	8.20	291.3	276.9	437.5
6	293.3	9.94	325.6	328.6	527.9
7	296.7	10.66	365.8	367.6	556.2
8	296.6	10.07	347.7	316.0	652.1
	292.0	8.55	314.1	307.1	586.8
10	286.1	6.33	277.7	225.5	445.9
11	279.7	4.64	249.4	188.1	322.1
12	275.0	3.05	246.6	193.6	292.3

The effect of air temperature and sunshine duration on energy consumption was checked with multiple regression and the correlation was confirmed as a 3rd polynomic function in Table 3.

There were 3 different types of commercial buildings used for 3 different purposes. The energy consumption profile of each building was different. For this reason, each of them needs to be analyzed one by one.

TABLE 3. **Multi regression for temperature and sunshine duration.**

Regression	Coefficient		
Parameters	Supermarket	Plaza	Stores
Intersection	581946.6	1549265.1	1677855.4
Temperature 1st order	-6071.9	-16279.4	-17381.3
Temperature 2nd order	21.1	57.0	59.9
Temperature 3rd order	0.0	-0.1	-0.1
Sunshine 1st order	72.9	74.0	24.9
Sunshine 2nd order	-13.5	-14.5	-6.3
Sunshine 3rd order	0.7	0.9	0.0
Multiple-R	0.99	0.98	0.99
R-Squared	0.99	0.97	0.99
Adjusted-R	0.97	0.93	0.97

A. SUPERMARKET

The trends of mean power consumption by month, hourly power consumption by month and mean power consumption by hour for the supermarket were given in Figure 1, Figure 2 and Figure 3, respectively. The daily power consumption curve of the supermarket could be considered as an electrical signal. In this case, it will be seen that this signal was a time-invariant signal, and its period was 24 hours. The amplitude of the signal varies depending on environmental and physical conditions. The main of these physical conditions were air temperature and sunshine time. In fact, many parameters such as the number of people in the commercial space, relative humidity of the air, wind speed, and air pressure have an impact on energy consumption. However, when their impact on the process was taken into consideration, it would be seen that they do not have any significance that will affect the modeling accuracy. Moreover, if they were included in the model, the system becomes unnecessarily complex.

When the one-day power consumption of the supermarket was examined, it was seen that the period of the signal was the same for all days, but the amplitude of the signal was different. The power curves for the months were given in Figure 2. Based on these power consumption curves, the simplified power signal model to represent the daily power consumption profile of supermarkets was given in Figure 4.

Power value at any moment; It is equal to the sum of the equations given by (1), as shown at the bottom of the next page. The task of the Heaviside function in these equations is to create a general equation consisting of the sum of all equations by ensuring that only the defined equation is active in the given time intervals. When the daily power consumption signal was examined, it was seen that the signal generally took 2 different values. It was observed that power consumption was at its lowest value, shown as LOW, out of working hours. It was at its highest value, shown as HIGH, in working hours. The mean value of the power consumption indicated by LOW was found to be k_1, and the mean value of the power consumption indicated by HIGH was found to be

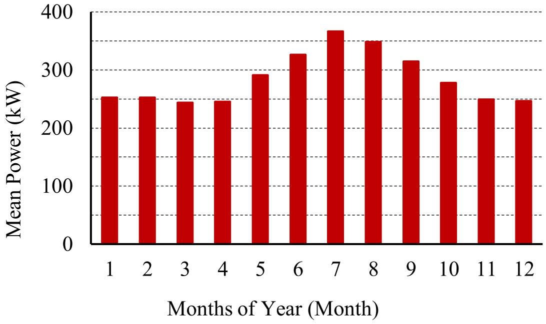

FIGURE 1. Mean power consumption of the supermarket by month.

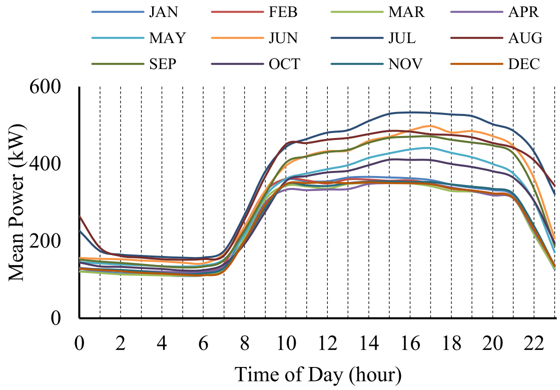

FIGURE 2. Hourly power consumption of the supermarket by month.

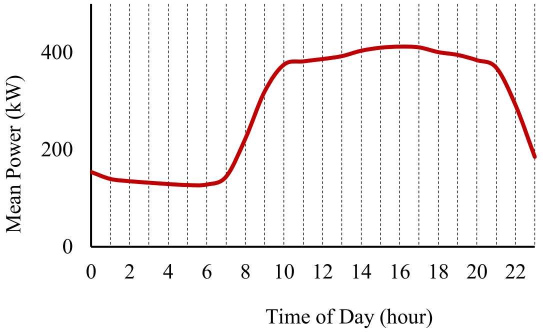

FIGURE 3. Hourly power consumption of supermarket by month.

k_2. It has been observed that both k_1 and k_2 values change depending on air temperature and sunshine duration. Here, k_1 value changes in a narrow range, while k_2 value changes in a very wide range.

Here, $P(t)$ was power as kW, $u(t)$ was Heaviside (or unit step) function, t was hours of day, t_1 was start time of shift, t_2 was opening time for supermarket, t_3 was closing time of supermarket, t_4 was end time of shift. It was transformed to (2) by using the actual working hours of mall.

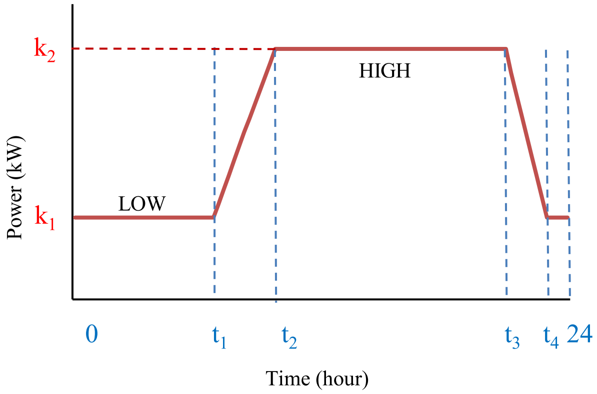

FIGURE 4. Daily power consumption model for supermarket.

If these equations were solved with a simplifying approach, approximately, daily energy consumption could be calculated by integrating. Here, E was daily energy consumption as kWh.

$$\begin{bmatrix} 0 \le t < 7 & E = 7k_1 \\ 7 \le t < 10 & E = 1.5k_1 + 1.5k_2 \\ 10 \le t < 21 & E = 11k_2 \\ 21 \le t < 23 & E = 0.5k_1 + 0.5k_2 \\ 23 \le t < 24 & E = k_1 \end{bmatrix} \quad (2)$$

Then, mean power consumption was calculated by (3). Here, P_{MEAN} was daily mean power as kW.

$$P_{MEAN} = \frac{\sum E}{24} = \frac{(10k_1 + 13k_2)}{24} = 0.42k_1 + 0.54k_2 \quad (3)$$

B. PLAZA

The trends of mean power consumption by month, hourly power consumption by month and mean power consumption by hour for the supermarket were given in Figure 5, Figure 6 and Figure 7, respectively. The daily power consumption curve of the plaza could be considered as an electrical signal. In this case, it will be seen that this signal was a time-invariant signal, and its period was 24 hours. The amplitude of the signal varies depending on environmental and physical conditions. The main of these physical conditions were air temperature and sunshine time. In fact, many parameters such as the number of people in the commercial space, relative humidity of the air, wind speed, and air pressure have an impact on energy consumption. However, when their impact on the process was taken into consideration, it would be seen that they do not have any significance that will affect the

$$\begin{bmatrix} k_1 \cdot u(t_1 - t) & 0 \le t < t_1 \\ [k_1 + (k_2 - k_1)\cdot(t - t_1)/(t_2 - t_1)] \cdot u(t_2 - t) \cdot u(t - t_1) & t_1 \le t < t_2 \\ k_2 \cdot u(t_3 - t) \cdot u(t - t_2) & t_2 \le t < t_3 \\ [k_2 + (k_2 - k_1) \cdot (t_3 - t)/(t_4 - t_3)] \cdot u(t_4 - t) \cdot u(t - t_3) & t_3 \le t < t_4 \\ k_1 \cdot u(t - t_4) & t_4 \le t < 24 \end{bmatrix} = P(t) \quad (1)$$

modeling accuracy. Moreover, if they were included in the model, the system becomes unnecessarily complex.

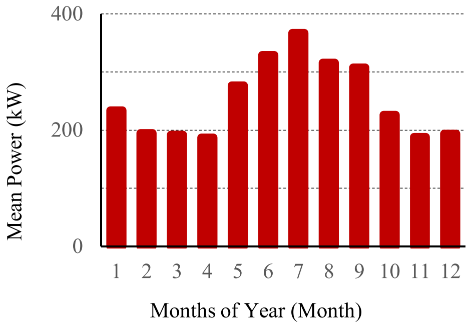

FIGURE 5. Mean power consumption of the plaza by month.

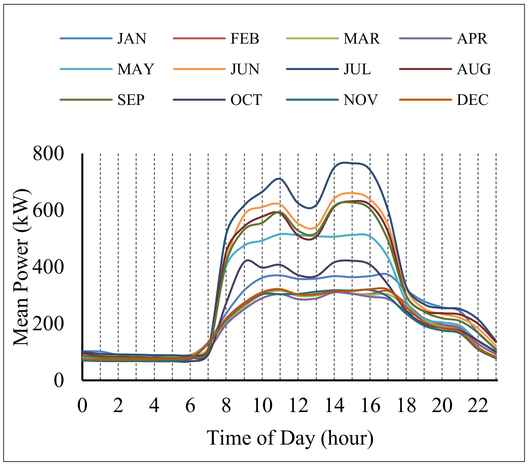

FIGURE 6. Hourly power consumption of the plaza by month.

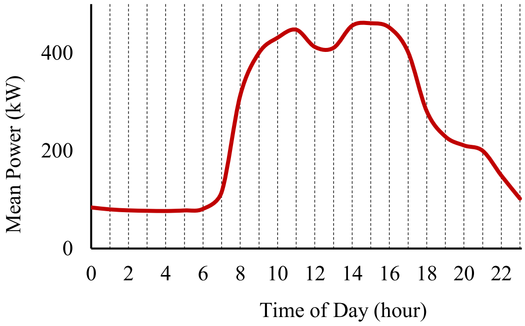

FIGURE 7. Mean power consumption by hour for the plaza.

When the one-day power consumption of the supermarket was examined, it is seen that the period of the signal was the same for all days, but the amplitude of the signal was different. Minimum amplitude values occurred in November and maximum amplitude values occurred in July. The curves for the months of November and July, which express the changing of signal between the minimum and maximum values were given in Figure 6. Based on these power consumption curves, the simplified power signal model to represent the daily power consumption profile of supermarkets was given in Figure 8. Power value at any moment; It is equal to the sum of the equations given by (4), as shown at the bottom of the next page. The task of the Heaviside function in these equations is to create a general equation consisting of the sum of all equations by ensuring that only the defined equation is active in the given time intervals. It has been observed that energy consumption decreases to a certain value during the lunch break.

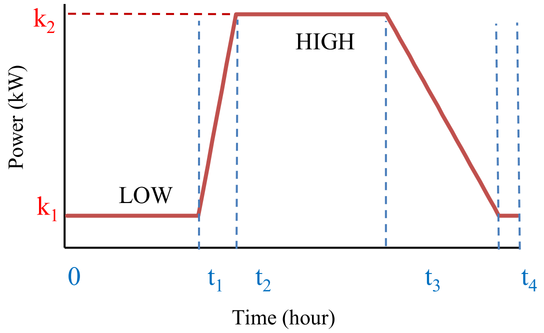

FIGURE 8. Daily power consumption model for plaza.

Here, $P\,(t)$ was power as kW, $u\,(t)$ was Heaviside (or unit step) function, t was hours of day, t_1 was start time of shift, t_2 was opening time of plaza, t_3 was end time of shift, t_4 was closing time of plaza. Then it was transformed to (5) by using the actual working hours of mall. If these equations were solved with a simplifying approach, approximately, daily energy consumption could be calculated by integrating. Here, E was daily energy consumption as kWh.

$$\begin{bmatrix} 0 \leq t < 7 & E = 7k_1 \\ 7 \leq t < 9 & E = k_1 + k_2 \\ 9 \leq t < 17 & E = 8k_2 \\ 17 \leq t < 23 & E = 1.5k_1 + 1.5k_2 \\ 23 \leq t < 24 & E = k_1 \end{bmatrix} \tag{5}$$

Then, mean power consumption was calculated by (6). Here, P_{MEAN} was daily mean power as kW.

$$P_{MEAN} = \frac{\sum E}{24} = \frac{(10.5k_1 + 10.5k_2)}{24} = 0.44k_1 + 0.44k_2 \tag{6}$$

C. STORES

The trends of mean power consumption by month, hourly power consumption by month and mean power consumption by hour for the stores were given in Figure 9, Figure 10 and Figure 11, respectively. The daily power consumption curve of the plaza could be considered as an electrical signal. In this case, it will be seen that this signal was a time-invariant signal, and its period was 24 hours. The amplitude of the signal varies depending on environmental and physical conditions. The main of these physical conditions were air temperature and sunshine time. In fact, many parameters such as the number of people in the commercial space, relative humidity of the air, wind speed, and air pressure have an impact on energy consumption. However, when their impact on the process was taken into consideration, it would be seen that they do not have any significance that will affect the modeling accuracy. Moreover, if they were included in the model, the system becomes unnecessarily complex.

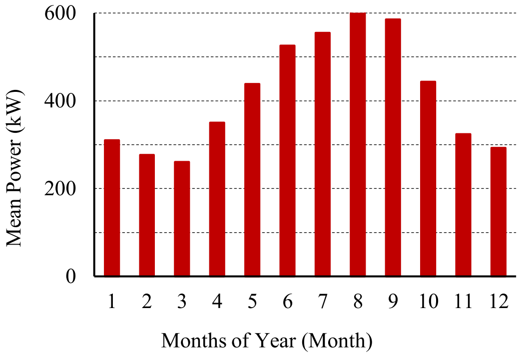

FIGURE 9. **Mean power consumption by month for the stores.**

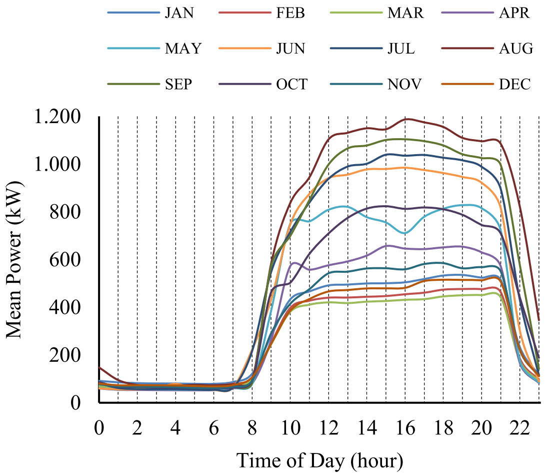

FIGURE 10. **Hourly power consumption of the stores by month.**

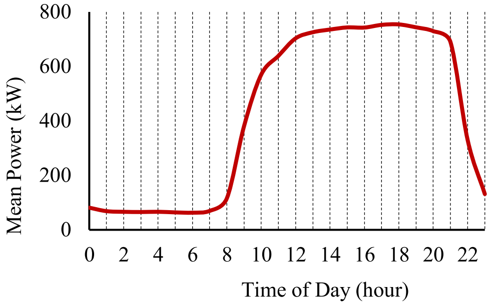

FIGURE 11. **Mean power consumption by hour for the stores.**

When the one-day power consumption of the supermarket was examined, it was seen that the period of the signal was the same for all days, but the amplitude of the signal was different. The curves for the months which express the changing of signal between the minimum and maximum values were given in Figure 10. Based on these power consumption curves, the simplified power signal model to represent the daily power consumption profile of supermarkets was given in Figure 12.

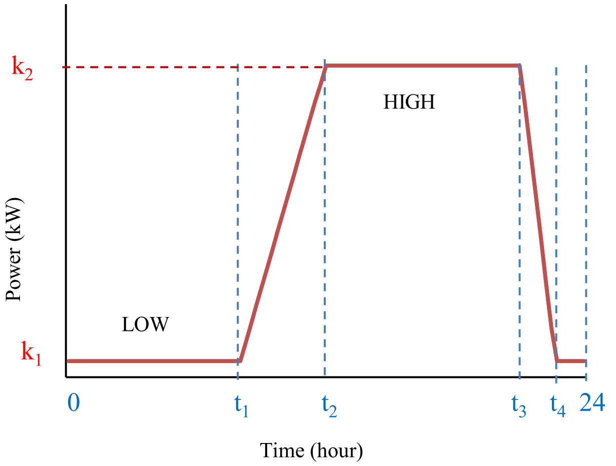

FIGURE 12. **Daily power consumption model for stores.**

Power value at any moment; It is equal to the sum of the equations given by (7), as shown at the bottom of the next page. The task of the Heaviside function in these equations is to create a general equation consisting of the sum of all equations by ensuring that only the defined equation is active in the given time intervals.

Here, $\boldsymbol{P}(\boldsymbol{t})$ was power as kW, $\boldsymbol{u}(\boldsymbol{t})$ was Heaviside (or unit step) function, $\boldsymbol{t}$ was hours of day, $\boldsymbol{t_1}$ was start time of shift, $\boldsymbol{t_2}$ was opening time of stores, $\boldsymbol{t_3}$ was closing time of stores, $\boldsymbol{t_4}$ was end time of shift. Then, it was transformed to (8) by using the actual working hours of stores. If these equations were solved with a simplifying approach, approximately, daily energy consumption could be calculated by integrating. Here, $\boldsymbol{E}$ was daily energy consumption as kWh.

$$\begin{bmatrix} 0 \le t < 8 & E = 8k_1 \\ 8 \le t < 12 & E = 2k_1 + 2k_2 \\ 12 \le t < 21 & E = 9k_2 \\ 21 \le t < 23 & E = k_1 + k_2 \\ 23 \le t < 24 & E = k_1 \end{bmatrix} \tag{8}$$

Then, mean power consumption was calculated by (9). Here, P_{MEAN} was daily mean power as kW.

$$P_{MEAN} = \frac{\sum E}{24} = \frac{(12k_1 + 12k_2)}{24} = 0.5k_1 + 0.5k_2 \tag{9}$$

$$\begin{bmatrix} k_1 \cdot u(t_1 - t) & 0 \le t < t_1 \\ [k_1 + (k_2 - k_1) \cdot (t - t_1)/(t_2 - t_1)] \cdot u(t_2 - t) \cdot u(t - t_1) & t_1 \le t < t_2 \\ k_2 \cdot u(t - t_2) \cdot u(t_3 - t) & t_2 \le t < t_3 \\ [k_2 + (k_2 - k_1) \cdot (t_3 - t)/(t_4 - t_3)] \cdot u(t_4 - t) \cdot u(t - t_3) & t_3 \le t < t_4 \\ k_1 \cdot u(t - t_4) & t_4 \le t < 24 \end{bmatrix} = P(t) \tag{4}$$

IV. PREDICTION OF MEAN POWER CONSUMPTION

Energy consumption for these businesses was generally constant. The changes that occur correspond to changes in air temperature and sunshine duration. If the air temperature and lighting times are known, energy consumption can be predicted. Here, energy consumption changes were linear. Consumption could be predicted using linear equations by (10). The application here was quite common and was applied successfully in many different areas [75]. Here ***x*** was the coefficient matrix that forms the weight of linear changes on the output. ***A*** was the input matrix. ***B*** was the output matrix.

$$x \cdot A = B \tag{10}$$

The input matrix consists of the parameters of sunshine duration, air temperature and the total area of the commercial building. Here the size of the coefficient matrix depends on the input matrix and contains 3 pcs of ***x*** expressions. The power consumed at any moment is calculated by (11).

$$\begin{bmatrix} x_{11} & x_{12} & x_{13} \end{bmatrix} \cdot \begin{bmatrix} Air\ Temperature \\ Sunshine\ Duration \\ Area \end{bmatrix} = \begin{bmatrix} Power \end{bmatrix} \tag{11}$$

If multiple regression is applied with an approach such that the R square value is above 0.9, the power value can be calculated by (12) using the 3rd order polynomial of these parameters.

$$[P_{MEAN}] = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} \end{bmatrix} \cdot \begin{bmatrix} T^1 \\ T^2 \\ T^3 \\ S^1 \\ S^2 \\ S^3 \end{bmatrix} + [C] \tag{12}$$

Here, ***T*** was the air temperature in K. ***SS*** was the sunshine duration in hours. ***P_{MEAN}*** was the power in kW. ***C*** was the constant indicating the regression intercept. It has been removed because the field value was fixed. The use of this formula was unnecessary. However, it could be used in calculations such as specific energy consumption. For each power parameter to be calculated, a new row consisting of three terms is added to the coefficient matrix. After this, the phase of solving the coefficient matrix was started. To determine the content of the coefficient matrix in the most accurate way, as many equations sets as possible should be used. Here, the coefficient matrix consisting of ***x*** terms was done by the MATLAB solution. The mean power consumed by supermarket on any day could be predicted by (13).

$$P = \begin{bmatrix} -6071,9 & 21,1 & 0.0 & 72.9 & -13.5 & 0.7 \end{bmatrix} \cdot \begin{bmatrix} T^1 \\ T^2 \\ T^3 \\ SS^1 \\ SS^2 \\ SS^3 \end{bmatrix} + [581947] \tag{13}$$

The mean power consumed by plaza on any given day could be predicted by (14).

$$P = \begin{bmatrix} -16279.4 & 57.0 & -0.1 & 74.0 & -14.5 & 0.9 \end{bmatrix} \cdot \begin{bmatrix} T^1 \\ T^2 \\ T^3 \\ SS^1 \\ SS^2 \\ SS^3 \end{bmatrix} + [1549265] \tag{14}$$

The mean power consumed by stores on any given day could be predicted by (15).

$$P = \begin{bmatrix} -17381.3 & 59.9 & -0.1 & 24.9 & -6.3 & 0.0 \end{bmatrix} \cdot \begin{bmatrix} T^1 \\ T^2 \\ T^3 \\ SS^1 \\ SS^2 \\ SS^3 \end{bmatrix} + [1677855] \tag{15}$$

V. SIMPLIFICATION AND GENERALIZATION

Energy consumption of commercial buildings comes from the needs of heating, ventilation, air conditioning, refrigeration, lighting, cooling of food and beverages, freezing of some foods, cash registers and electrical appliances from offices. The parameters affecting this consumption are meteorological factors such as total surface area, outside air temperature during the day and at night, daylight hours indicating whether the days are long or short, net sunshine hours, and the amount of solar energy received from the sun. Apart from this, the number of people is also a consumption parameter as it imposes a heating and carbon dioxide burden on buildings where many people reside at the same time. Generally, only electrical energy is used for cooling. However, it is possible to use both electricity and natural gas for heating. For this

$$\begin{bmatrix} k_1 \cdot u\,(t_1 - t) & 0 \leq t < t_1 \\ [k_1 + (k_2 - k_1) \cdot (t - t_1)/(t_2 - t_1)] \cdot u\,(t_2 - t) \cdot u(t - t_1) & t_1 \leq t < t_2 \\ k_2 \cdot u\,(t_3 - t) \cdot u(t - t_2) & t_2 \leq t < t_3 \\ [k_2 + (k_2 - k_1) \cdot (t_3 - t)/(t_4 - t_3)] \cdot u\,(t_4 - t) \cdot u(t - t_3) & t_3 \leq t < t_4 \\ k_1 \cdot u(t - t_4) & t_4 \leq t < 24 \end{bmatrix} = P(t) \tag{7}$$

reason, it should be taken into consideration that in consumptions based solely on electrical energy, the heating load will not be included in these energy consumptions. It is necessary to evaluate the effect of these parameters one by one. The total surface area of buildings is a specific constant for that facility and will result in a constant energy consumption per square meter. Working hours determine the time the facility will consume energy at full capacity. As this period increases, energy consumption increases. Working hours affect energy consumption as a constant coefficient. Increasing the amount of solar energy means warming. Increasing temperature will reduce energy consumption in winter and increase energy consumption in summer. Daylight duration is the time between sunrise and sunset and determines whether the days are long or short. Increasing daylight value means decreasing electricity consumption due to the decrease in lighting load for naturally illuminated buildings. The increase in monthly net sunshine duration causes buildings to become warmer. For this reason, while it reduces energy consumption in winter, it causes energy consumption to increase in summer. The number of people in commercial buildings does not change much throughout the year, except for some special days. Although extreme values could be reached on these special days, these days do not have a significant weight in total consumption.

Considering the single and combined effects of all these parameters on energy consumption, the parameter that makes the difference in daily energy consumption is the outdoor temperature. Because all other parameters are almost constant throughout the day. For example, all lighting in markets is always on, even if daylight hours change. It is seen that the value of the temperature parameter during the daytime when the commercial building is in operation is important, rather than its mean value. In this case, it would be a correct approach to generalize by creating a model of energy consumption of commercial buildings by considering all parameters except daylight hours as constant. Changes in electricity consumption of supermarkets, plazas and stores depending on daytime temperatures were given in Figure 13, Figure 14 and Figure 15, respectively. As could be seen from these figures, energy consumption was at a minimum value when daytime temperatures were about 20°C. If the temperature drops below or rises above this value, consumption increases. This increase occurs exponentially. This point where energy consumption is minimum is the thermal comfort point. At the thermal comfort point, all other parameters are constantly active, but heating, cooling and ventilation loads are not active. Therefore, this global minimum point represents the minimum fixed consumption point of the commercial building. If the outside air temperatures change, the amount of energy that will provide thermal comfort will come additionally to the system. During the hours when the facility is closed, the lowest fixed essential needs are in effect. These consumptions increase as we move away from the thermal comfort point. These flotations may not see due to low consumption.

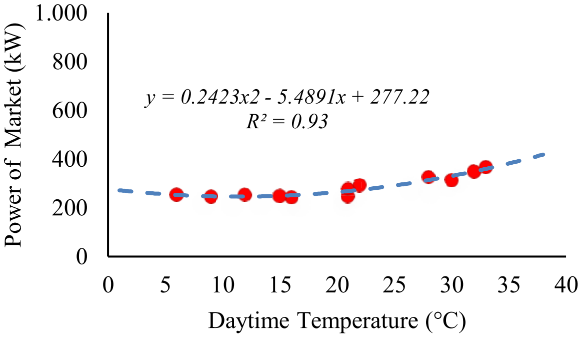

FIGURE 13. **Power of market for daytime temperature.**

After statistical analysis of all variables, it was seen that only the mean temperature value was significant in terms of p-value. By excluding other variables from the circuit, the power equation could be written as a 2nd order polynomial that depends only on temperature. For markets, all systems were generally always active. The only factor that changes the power consumption was the cooling load in summer and heating load in winter. Therefore, there was a power consumption dependent on the outdoor temperature, which increases quadratically as one moves away from the comfort temperature.

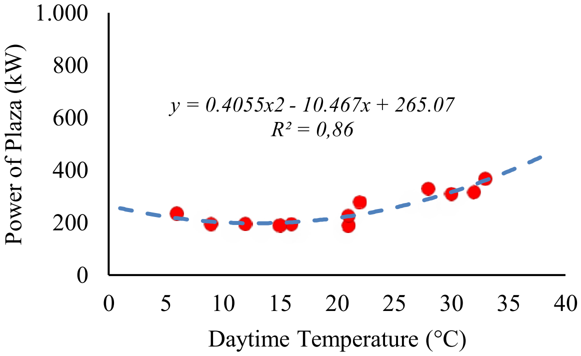

FIGURE 14. **Power of plaza for daytime temperature.**

Plaza power consumption was like market consumption. The p-values of variables other than ambient temperature were not statistically significant. Plaza power consumption could be written as a 2nd order polynomial depending on the ambient temperature. This consumption increases rapidly as we move away from the thermal comfort point.

Only a temperature-dependent polynomial equation was written for stores, but the R-squared value remained low. It is necessary to evaluate the lighting loads and heating needs of stores separately. Because excessive sunshine increases the need for cooling. On the other hand, when the daylight value increased, the need for lighting decreased. For this reason, the increase in daylight hours or the increase in solar energy value, which also supports heating in cold weather, has reduced energy consumption. It has been observed that the effect of sunshine duration and solar energy value are

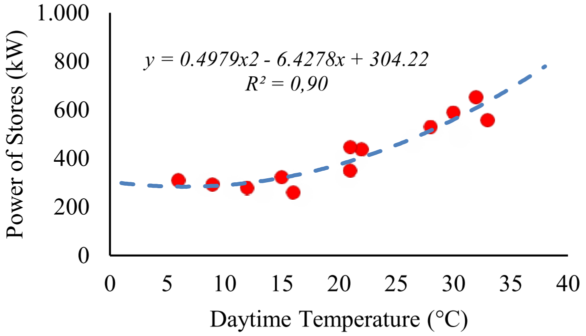

FIGURE 15. Power of stores for daytime temperature.

similar. The 3rd order polynomial of solar energy value and sunshine duration gave the most significant equation in terms of p-value. In this case, the R-squared value increased to a value of 96%. In fact, R-squared values close to 99% could be obtained for all three commercial buildings by using higher order polynomials of these variables.

However, the statistical condition of having a p-value of 0.05 or less was not met. Another alternative equation (16) for stores was significant in terms of both R-square value and p-value. Here, S was sunshine duration in hours, E was solar energy in kWh per square meter, and P was power in kW.

$$P = -297.5S + 65.3S^2 - 3.1S^3 - 103.6E + 956.1 \qquad (16)$$

VI. OBTAINING DEMAND POWER FROM ENERGY BILL

Energy consumption values obtained from monthly electrical energy bills and realized monthly demand power consumption values for supermarkets, plazas and stores were given in Table 6, Table 5 and Table 6, respectively. For each commercial buildings, k_1 was lowest mean power consumption, and k_2 was highest mean power consumption. The mean annual power value was obtained by dividing the total energy consumed during a year by 8760 (365 days x 24 hours). Monthly demand power values of commercial buildings were obtained as a coefficient multiplier of the annual mean power consumption value. In this way, the optimum unit power that would continuously operate the cogeneration facility at 50% to 100% capacity could be determined by predicting the requested load by month. The model could be generalized for facilities to be established in other locations by updating it according to ambient temperature and other environmental parameters.

As seen in Table 4, it was not possible for the cogeneration plant to operate during the time when supermarkets were closed. While supermarkets were open, the variation in power consumption by month remained within reasonable limits. It was possible to install a cogeneration unit with a power of 1.77 times the annual mean power value, which was the maximum power consumption value. In this case, the facility would be utilized to the maximum extent and a highly efficient operation would be achieved while the lowest loading value of the unit would remain at 67%.

TABLE 4. Power coefficient for supermarket.

Months	Days (pcs)	Energy Bill (kWh)	Monthly Mean (kW)	Annual Mean (kW)	k₁ (kW)	k₂ (kW)	Monthly Mean Coefficient	k₂ Coefficient
1	31	187415	252.6	284.4	115.2	354.6	0.89	1.25
2	28	169675	252.6	284.4	121.6	348.9	0.89	1.23
3	31	180866	243.6	284.4	114.1	339.8	0.86	1.19
4	30	176428	245.6	284.4	123.5	337.7	0.86	1.19
5	31	216544	291.3	284.4	138.6	407.0	1.02	1.43
6	30	234047	325.6	284.4	149.5	456.7	1.14	1.61
7	31	269992	365.8	284.4	172.5	502.3	1.29	1.77
8	31	264971	347.7	284.4	176.4	468.1	1.22	1.65
9	30	225671	314.1	284.4	140.3	446.4	1.10	1.57
10	31	208166	277.7	284.4	131.6	388.8	0.98	1.37
11	30	179166	249.4	284.4	121.6	347.2	0.88	1.22
12	31	183876	246.6	284.4	119.1	344.3	0.87	1.21

$$\begin{bmatrix} PEAK_{JAN} \\ PEAK_{FEB} \\ PEAK_{MAR} \\ PEAK_{APR} \\ PEAK_{MAY} \\ PEAK_{JUN} \\ PEAK_{JUL} \\ PEAK_{AUG} \\ PEAK_{SEP} \\ PEAK_{OCT} \\ PEAK_{NOV} \\ PEAK_{DEC} \end{bmatrix} = \begin{bmatrix} \Delta T_{JAN} & SS_{JAN} \\ \Delta T_{FEB} & SS_{FEB} \\ \Delta T_{MAR} & SS_{MAR} \\ \Delta T_{APR} & SS_{APR} \\ \Delta T_{MAY} & SS_{MAY} \\ \Delta T_{JUN} & SS_{JUN} \\ \Delta T_{JUL} & SS_{JUL} \\ \Delta T_{AUG} & SS_{AUG} \\ \Delta T_{SEP} & SS_{SEP} \\ \Delta T_{OCT} & SS_{OCT} \\ \Delta T_{NOV} & SS_{NOW} \\ \Delta T_{DEC} & SS_{DEC} \end{bmatrix} \cdot \begin{bmatrix} 0,0114 \\ 0,0504 \end{bmatrix} + \begin{bmatrix} 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \\ 0,5757 \end{bmatrix} \qquad (17)$$

The mean power of a supermarket is calculated by dividing the annual energy consumption by 8760. Monthly PEAK demand values were estimated by (17) with the help of monthly mean daytime air temperatures and sunshine duration (SS) data for the location where the market is located. (18) gives the demand power to be consumed as a coefficient multiplier of the mean power. More accurate results are achieved by using the absolute value of the difference between the actual temperature and the thermal comfort temperature (ΔT). Thermal comfort temperature is generally taken as 20°C. PEAK was in coefficient, ΔT was in °C, and SS was in hour.

TABLE 5. Power coefficient for plaza.

Months	Days (pcs)	Energy Bill (kWh)	Monthly Mean (kW)	Annual Mean (kW)	k_1 (kW)	k_2 (kW)	Monthly Mean Coefficient	k_2 Coefficient
1	31	174469	233.6	250.9	90.0	357.1	0.93	1.42
2	28	130846	194.8	250.9	75.2	303.2	0.78	1.21
3	31	145259	192.2	250.9	78.7	298.2	0.77	1.19
4	30	131090	187.1	250.9	73.5	290.0	0.75	1.16
5	31	202250	276.9	250.9	76.8	503.3	1.10	2.01
6	30	236104	328.6	250.9	90.8	605.0	1.31	2.41
7	31	274388	367.6	250.9	91.7	684.8	1.47	2.73
8	31	234393	316.0	250.9	83.6	571.6	1.26	2.28
9	30	225919	307.1	250.9	80.1	570.9	1.22	2.28
10	31	171910	225.5	250.9	60.1	400.9	0.90	1.60
11	30	89746	188.1	250.9	69.6	304.5	0.75	1.21
12	31	144949	193.6	250.9	74.7	305.7	0.77	1.22

As seen in Table 5, it was not possible for the cogeneration plant to operate while the plaza was closed. While the plaza was open, the change in electricity consumption by month occurred in a wide range. If a cogeneration system with a power of 2.32 times the annual mean power value, which was the maximum power consumption value, was installed, the system could be ensured to operate continuously under sufficient load. However, in this case, the amount of energy that was missing and still needs to be supplied from the grid was quite high. Here, the correct value of the cogeneration unit power could only be determined by using current optimization methods. Although it increases the investment amount, a more successful result could be achieved by installing more than one unit. In cases where seasonal power consumption increases significantly and this increase was caused by the energy spent for cooling, trigeneration was a very efficient alternative to cogeneration. In cogeneration, the cost spent on heating was generally free. In trigeneration, since electrical cooling was replaced by thermal cooling, electrical power consumption also decreases. This situation also reduces peak demand consumption in summer to lower levels. Then, it was possible to load a single cogeneration unit more efficiently.

The mean power of a supermarket is calculated by dividing the annual energy consumption by 8760. Monthly PEAK demand values were estimated by (19) with the help of monthly mean daytime air temperatures and sunshine duration *(SS)* data for the location where the market is located. (18) gives the demand power to be consumed as a coefficient multiplier of the mean power. More accurate results are achieved by using the absolute value of the difference between the actual temperature and the thermal comfort temperature (ΔT). Thermal comfort temperature is generally taken as 20°C. Here, PEAK was in coefficient, ΔT was in °C, and SS was in hour.

$$\begin{bmatrix} PEAK_{JAN} \\ PEAK_{FEB} \\ PEAK_{MAR} \\ PEAK_{APR} \\ PEAK_{MAY} \\ PEAK_{JUN} \\ PEAK_{JUL} \\ PEAK_{AUG} \\ PEAK_{SEP} \\ PEAK_{OCT} \\ PEAK_{NOV} \\ PEAK_{DEC} \end{bmatrix} = \begin{bmatrix} \Delta T_{JAN} & SS_{JAN} \\ \Delta T_{FEB} & SS_{FEB} \\ \Delta T_{MAR} & SS_{MAR} \\ \Delta T_{APR} & SS_{APR} \\ \Delta T_{MAY} & SS_{MAY} \\ \Delta T_{JUN} & SS_{JUN} \\ \Delta T_{JUL} & SS_{JUL} \\ \Delta T_{AUG} & SS_{AUG} \\ \Delta T_{SEP} & SS_{SEP} \\ \Delta T_{OCT} & SS_{OCT} \\ \Delta T_{NOV} & SS_{NOW} \\ \Delta T_{DEC} & SS_{DEC} \end{bmatrix} \cdot \begin{bmatrix} 0,0396 \\ 0,1870 \end{bmatrix} + \begin{bmatrix} 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \\ 0,1714 \end{bmatrix} \tag{18}$$

As seen in Table 6, it was not possible for the cogeneration plant to operate when the stores were closed. During the period when the stores were open, the variation in electricity consumption by month occurred within a wide range, just like in the plaza building. If a cogeneration system with a power of 2.08 times the annual mean power value, which was the maximum power consumption value, was installed, the system could be ensured to operate continuously at sufficient load. However, in this case, the amount of energy that was missing and still needs to be supplied from the grid was quite high. Here again, installing more than one cogeneration unit or a trigeneration unit instead may be a more profitable investment. Because the main source of the peak demand load was the energy spent for cooling the environment.

The mean power of a stores section is calculated by dividing the annual energy consumption by 8760. Monthly PEAK demand values were estimated by (19) with the help of monthly mean solar energy *(SE)* and sunshine duration *(SS)* data for the location where the market is located. (19) gives the demand power to be consumed as a coefficient multiplier of the mean power. Here, PEAK was in coefficient, SE was

TABLE 6. Power coefficient for stores.

Months	Days (pcs)	Energy Bill (kWh)	Monthly Mean (kW)	Annual Mean (kW)	k_1 (kW)	k_2 (kW)	Monthly Mean Coefficient	k_2 Coefficient
1	31	229923	309.3	418.0	83.7	511.0	0.74	1.22
2	28	205188	275.9	418.0	74.6	456.5	0.66	1.09
3	31	194909	259.8	418.0	63.6	432.8	0.62	1.04
4	30	185817	350.5	418.0	55.3	630.2	0.84	1.51
5	31	338985	437.5	418.0	57.4	788.9	1.05	1.89
6	30	374377	527.9	418.0	61.2	960.9	1.26	2.30
7	31	414605	556.2	418.0	61.2	1000.5	1.33	2.39
8	31	473726	652.1	418.0	86.8	1138.7	1.56	2.72
9	30	437752	586.8	418.0	68.5	1062.2	1.40	2.54
10	31	336075	445.9	418.0	67.3	788.7	1.07	1.89
11	30	233105	322.1	418.0	67.5	561.7	0.77	1.34
12	31	216992	292.3	418.0	73.4	491.7	0.70	1.18

TABLE 7. Comparisons of real and predicted values.

	Demand	Supermarket	Plaza	Stores
Real (kW)	Min	338	290	417
	Max	502	685	1139
	Cogen	502	580	834
	Trigen	427	580	834
Predicted (kW)	Min	338	296	435
	Max	495	672	1091
	Cogen	495	592	869
	Trigen	421	572	869
Difference	Min	0%	-2%	-4%
	Max	1%	2%	4%
	Cogen	1%	-2%	-4%
	Trigen	1%	1%	-4%

in kWh/m^2, and SS was in hour.

$$\begin{bmatrix} PEAK_{JAN} \\ PEAK_{FEB} \\ PEAK_{MAR} \\ PEAK_{APR} \\ PEAK_{MAY} \\ PEAK_{JUN} \\ PEAK_{JUL} \\ PEAK_{AUG} \\ PEAK_{SEP} \\ PEAK_{OCT} \\ PEAK_{\mathrm{NOV}} \\ PEAK_{DEC} \end{bmatrix} = \begin{bmatrix} SE_{JAN} & SS_{JAN} \\ SE_{FEB} & SS_{FEB} \\ SE_{MAR} & SS_{MAR} \\ SE_{APR} & SS_{APR} \\ SE_{MAY} & SS_{MAY} \\ SE_{JUN} & SS_{JUN} \\ SE_{JUL} & SS_{JUL} \\ SE_{AUG} & SS_{SUG} \\ SE_{SEP} & SS_{SEP} \\ SE_{OCT} & SS_{OCT} \\ SE_{NOV} & SS_{NOW} \\ SE_{DEC} & SS_{DEC} \end{bmatrix} \cdot \begin{bmatrix} 0,4195 \\ 0,4195 \\ 0,4195 \\ 0,4669 \\ 0,4195 \\ 0,4195 \\ 0,4195 \\ 0,4195 \\ 0,4195 \\ 0,4195 \\ 0,4195 \\ 0.4195 \\ 0,4195 \end{bmatrix} \quad (19)$$

VII. DETERMINING POWER OF COGENARATION AND TRIGENERATION

In Table 7, ideal cogeneration and trigeneration powers were selected according to the actual values and the presented model. The results obtained show that the presented model was quite successful in accurately determining the cogeneration and trigeneration power.

Cogeneration and trigeneration systems are energy efficiency investments and must operate at 50% or more load. It is general practice to always operate at 100% capacity, slightly below the required power, and have the remaining amount supplied from the grid. Therefore, the most important issue in these investments is determining the correct power value. The cogeneration and trigeneration operating times given in this study are 11 hours, 8 hours and 9 hours respectively for supermarkets, plazas and offices. The power of the cogeneration system to be installed in a facility that is exposed to different loads according to months is limited to 2 times the lowest power value to be drawn. When trigeneration facilities are installed, the electrical energy spent for cooling will decrease. Although it varies depending on the COP values of the selected cogeneration and absorption cooling group, there will generally be a decrease of around 15% in peak consumption during the summer months. This will reduce seasonal fluctuations, allowing a smaller power plant to be built and operated more efficiently.

VIII. CONCLUSION

Understanding the power consumption model of commercial buildings enables business investments to reduce energy costs, especially hybrid power plant investments, to yield more successful results. In this study, the energy consumption of a supermarket, plaza and stores were examined in detail and power consumption models were created. The resulting models have M-regression values of 0.99, 0.98 and 0.99 for supermarket, plaza, and store sections, respectively. R-square values of these models were obtained as 0.99, 0.97 and 0.99, respectively. These results show that the proposed model was at a level that could be used as a reliable reference in feasibility and investments for similar commercial buildings. In addition, these results show that the proposed model was at a level that could be used as a reliable reference in feasibility and investments for similar commercial buildings.

The demand power calculation method presented in the study can be applied to supermarkets, plazas and stores in different locations. First, the mean power value is calculated from the energy consumption. Then, it is sufficient to place meteorological data such as the location's solar energy value, sunshine duration, and daytime temperature values into the relevant formulas. Future studies are planned to verify the model in commercial buildings located in different locations and with long-term power consumption records.

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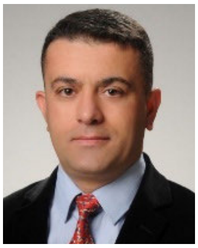

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