A PRAGMATIC METHODOLOGY TO ESTIMATE HOURLY ENERGY DEMAND PROFILE OF A CASE STUDIED DAIRY FARM; PRIMARY STEP TOWARD PV APPLICATION

یک روش عملی برای تخمین پروفیل ساعتی برق مصرفی در یک گاوداری گاو شیری مورد مطالعه:
گام نخستین در بکار گیری برق فتوولتاییک

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ABSTRACT

On-farm detailed electric load profile is becoming increasingly important in the context of renewable energy source implementation in livestock housing due to rising energy costs along with concerns over greenhouse gas emissions. This study aimed to propose and investigate a pragmatic methodology to determine detailed energy demand profile in dairy farm sizes of 20 to 100 cows as the most common size in Iran. A model was developed based on the case studied dairy farm conditions, including artificial lighting, milking, milk cooling and water pumping subsections. This research prepares the first step toward employing photovoltaic electricity in dairy farms and thereby encouraging sustainable dairy farming.

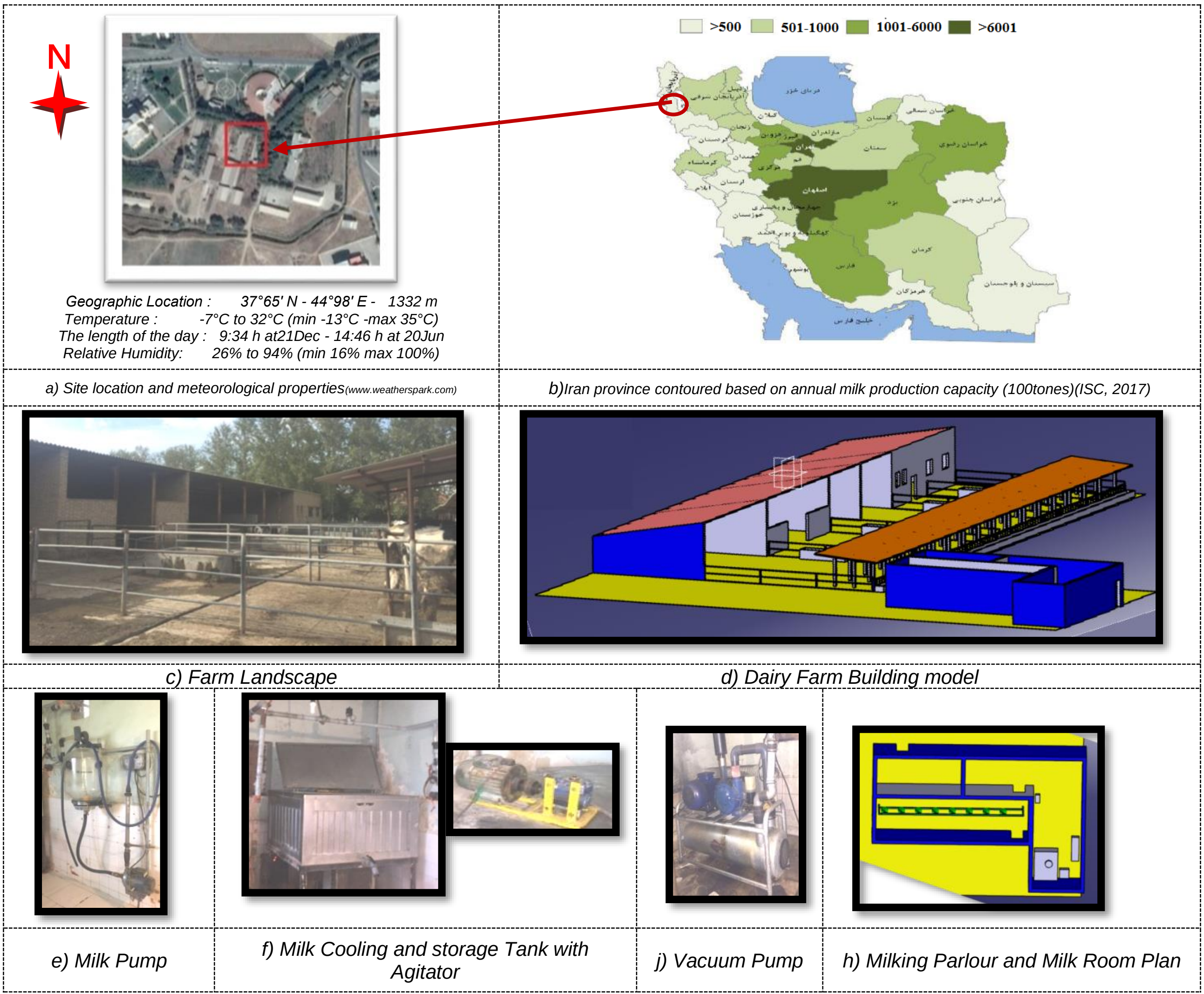
چکیده

با توجه به افزایش قیمت انرژی و نگرانی های ناشی از گازهای گلخانه ای ودر ارتباط با بکار گیری منابع انرژی های تجدیدپذیر در تامین نیاز گاوداری ها، بررسی مفصل پروفیل بار الکتریکی مصرفی از اهمیت روزافزونی برخوردار شده است. هدف از این تحقیق پیشنهاد و تشریح یک روش عملی و قابل اجرا برای تعیین دقیق پروفیل نیاز الکتریکی گاوداری های گاو شیری با گله هایی از 20 تا 100 گاو، که در محدوده غالب گاوداری های ایران هستند، است.بر مبنای شرایط موجود در یک مطالعه موردی انجام شده، مدلی شامل زیر بخش های روشنایی مصنوعی، شیردوشی، سرمایش شیر و پمپاژ ساخته شد. این تحقیق گام نخستین در بکارگیری برق فتوولتاییک در گاوداری های گاو شیری را فراهم می سازد که به واسطه آن کمک به توسعه پایدار گاوداری های گاو شیری می شود.

INTRODUCTION

Iran dairy farms are moving toward modern livestock systems equipped with specialized facilities and scientific management practices. Transition from traditional-scale dairy farms towards larger and more specialized dairy systems would result in a significant increase of on-farm electricity demand. Milk production in Iran dairy farms has reached 4,100 tons per year, during 1989-2015, with an eight-fold increase, along with a five-fold increase of herd size, thanks to implementing new technologies and management practices *(ISC, 2017)*. Holstein Friesian is the dominant breed of modern dairy cattle in Iran, with daily lactating capacity (LC) ranged in 20-30 kg *(Atashi et al, 2012)*. Moreover, Iran has begun to move toward deployment of decentralized small scale PV plants as a part of its renewable energy plans. Any attempts toward gaining the photovoltaic electricity or energy saving through optimization approaches need detailed understanding of demand load. The intermittent nature of solar energy highlights the importance of hourly demand profile which determines the PV system performance in lessening or entirely covering the demand load.

A considerable amount of literature has been published on electric energy audit in dairy farms all over the world *(Edens et al, 2003; Ludington and Johnson, 2003; Hörndahl, 2008; Murgia et al, 2008; Sefeedpari et al, 2014; Bartolome et al, 2015; Upton et al. 2015; Pradhanang, 2015; Hosseinzadeh et al, 2016)*. Energy Utilization Index (EUI) of kWh/cow/year and kWh/hl, which have been commonly used for benchmarking energy needs in dairy farms, are achieved in range of 142-1760 and 2.27-7.71, respectively. Reviewing the literature, it has been revealed that the results are not or are only partially comparable, due to different taken assessment boundaries, management practices, diversity of machinery, production systems, working habits and maintenance, as well as ambient conditions. As a matter of fact, generally applicable methods for calculating energy input in animal husbandry are still missing *(Kraatz 2012)*. On the other hand, most of these researches have only been led to results with time horizon of yearly or monthly resolution. These time horizons are originated from the fact that, the audit procedure of the researches is usually based on the farm electricity bill evaluation or through filling pre-designed questionnaires forms by farmers. To the authors' best knowledge, there has been relatively little literature focusing on the issues of hourly profile of on-farm electricity demands. Hörndahl measured the sub hourly profile of electricity use in four complete dairy farms in Sweden *(Hörndahl, 2008)*. Moreover, Murgia et al. analyzed a set of fourteen dairy farms ranging from 40 to 300 milking cows in Sardinia region of Italy, for one year with reference to the main operations (milking, milk cooling, lighting, ventilation, manure handling) and the equipment used *(Murgia et al, 2008)*. The first systematic study of hourly demand profile for dairy farms was reported by Upton *(Upton et al, 2014)*, however, there are a number of dairy farm hourly demand profiles which have been adopted through the use of real-time data recording *(Houston et al, 2014)* or by taking the robust assumptions*(Nacer et al, 2016)*. Nevertheless, Upton et al. developed a mechanistic model for demonstrating electricity consumption in Irish dairy farms on monthly average hours i.e. one day is a representative for a whole month, which may not be practical to implement in renewable energy plant. In this study, a new technique is suggested to extend the previous works.



a) Site location and meteorological properties(www.weatherspark.com)

b)Iran province contoured based on annual milk production capacity (100tones)(ISC, 2017)

c) Farm Landscape

d) Dairy Farm Building model

e) Milk Pump

f) Milk Cooling and storage Tank with Agitator

j) Vacuum Pump

h) Milking Parlour and Milk Room Plan

Fig. 1 - Case Study; educational dairy farm, Urmia University

The original idea for writing this paper has been emerged as a primary step for conducting techno-economic analysis of grid-connected photovoltaic system in typical dairy farms in Iran. However, the case study of the farm, which is located on Urmia university site in north-west cold region of Iran as depicted in Fig. **1**-a,b, was applied to define the realistic framework of study. The geographical site location and meteorological properties of Urmia city were depicted in Fig. **1**-a. Indeed, the specific objective of this research is to develop a pragmatic mathematical methodology to represent energy consumption in major operational demand subsections to estimate the met electricity demand load by generated PV electricity. The presented methodology can be adopted on a range of Iran dairy farms, to feed the promise optimization approaches and to offer more detailed hourly load profile of electric energy demand.

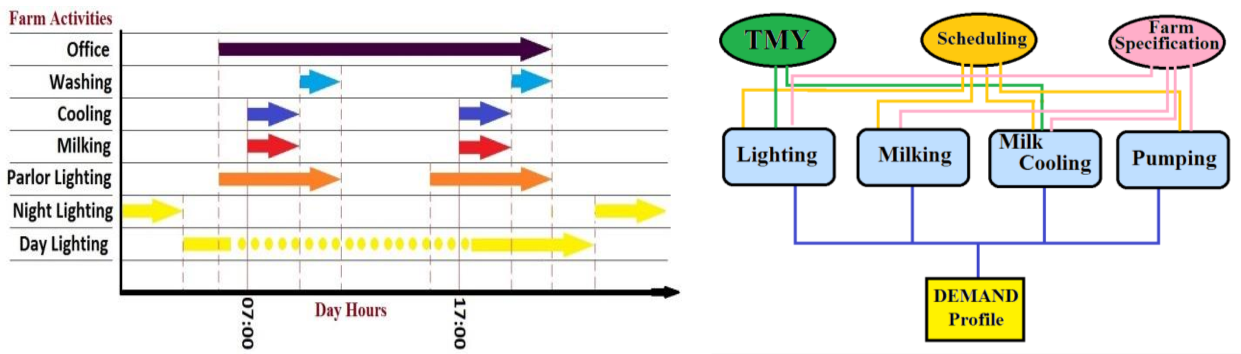
MATERIAL AND METHODS

We started by investigating the technical specification of electrical appliances which exist in case studied farm. As most of dairy farms, the electrical appliances are comprised of artificial lighting lamps, water and milk pumps, milking system and milk cooling storage tank as shown in Fig.1. The required technical characteristics of different appliances are presented in Table 1. The selected dairy farm can keep 50 lactating cows; however, regarding its educational function, this amount is not fixed during the year. The proposed methodology to estimate energy consumption in the dairy farm is illustrated in Fig.2-bas a computational flowchart, where a time scheduling of farm activities is available (Fig.2-a). We consulted with expert opinions and considered the personal dairy staff judgments to choose the most prevalent and right activities timing. Regarding the aims and extent of this research, a computational model was developed to predict the electricity demand profile as a function of several parameters including farm location, ambient temperature, herd size and LC, as well as the technical specifications of electrical appliances presented in Table1. The calculation was performed on the basis of eight unit milking parlor as demonstrated in Fig.1-h. However, the applied methodology is independent of the number of milking units. Fig. **2**-a illustrated time scheduling of activities engaged in electricity demand profile of the dairy farm with twice milking per day within 10 hours, in the morning and evening. This time scheduling is strongly conditional on farm management plan. The model was then uploaded into the TRNSYS software. TRNSYS is an extremely flexible component-based software package used to simulate the behavior of transient systems. TRNSYS was selected based on both the time scheduling capability and the advantage of using TMY meteorological database. Additionally, a very useful feature in TRNSYS is the ability to define equations within the input file which are not in a component. According to Fig. 2-b, the calculation of each four sub sections was done by defining simple algebraic equations within input files and linking them to the TYPE109, as TMY reader, and several TYPE517, as hourly time scheduling components of different activities. Furthermore, TRNSYS provides a trustworthy simulation package to study the real-time interaction of the grid-connected PV electricity generation with farm demand load.

Table 1

Technical specification of electrical appliances demonstrated in Fig.1

Farm Activity	Electrical Appliance	Commercial Brand	Technical Specification
Milking	Vacuum Pump	CAMAK-AGM112M	4 kW - 1425 rpm
Milk Cooling	Compressor & Fan	Paykan	4.75 kW, Scroll Compressor
	Agitator	SYN MOTOR+Gearbox	0.75 kW - 1440 rpm
Pumping	Milk Pump	LOWARA-CEAM70/5/A	0.55 kW - 30~80 lit/min - 28.8~20.2 m
	Water Pump	PUMPIRAN	2 kW - 2 m^3/h - 50 m
Artificial Lighting	Fluorescent Tube Lamp		2× 32 W



a) Farm Activities Time Scheduling *b) Computational flowchart*

Fig. 2 - Activity time scheduling and computational model structure

Artificial Lighting Demand

In summary, a regime of 16 hours of light followed by 8 hours of darkness, with maximum illumination of 5 lux, is suggested for dairy farm barns to optimize cow activity, feed intake and milk production. There are also some recommendations in standards and regulations concerning the adequate illumination level and also technical specification of different lamps *(ASAE, 1996; Bickert et al., 2000; NMHC, 2006; INSO, 2013; CIGR, 2014; Rajaniemi et al., 2015; DairyNZ, 2015)* which give almost same suggestions for applying artificial lighting in different parts of dairy farms. There are different types of lighting lamp technologies. The fluorescent lamps prevail in Iran as all over the world because of their durability and affordable cost as recommended by Iranian national standardization organization *(INSO, 2013)*. Table 2 presents the detailed technical specification of the artificial lighting subsection of farm demand which would be used in TRNSYS calculation algorithms. According to the required level of illumination and considering the illumination characteristics of utilized lamps, the lighting share of electricity consumption profile can be calculated based on the time scheduling of farm activities and the number and lamp powers. Moreover, depending on the farm location and time of the year the length of daylight period varies and was taken into account in lighting consumption calculation.

Table2

Artificial Lighting characteristic details for studied dairy farm based on the recommendation by *(Bickert et al, 2000)*

Farm Areas	Recommended illumination level (lux)	Area (m^2)	Lamp Size	Illuminated Area*** (m^2)	Required Number	Wh/hour	Wh/hour PerCow
Barns day-light (feeding)	100 (day)	760	2 × 32W	16	47	3008	60.16
Barns day-light (resting)	150 (day)	366	2 × 32W	12	30	1920	38.4
Barns night-light (resting)	5 (night)	1126	2 × 32W	320	4	256	5.12
Milking Parlor	538	47	4 × 32W	8	6	768	independent of cow numbers
Milk & Utility Room	215	62	2 × 32W	8	8	512	
Staffroom	538	22	4 × 32W	8	3	384	

Milking Demand

Based on the current common technology in milking machines, the electric energy consumption referred to the electromotor which drives the vacuum pump, providing a vacuum that alternates with atmospheric pressure to draw milk from the teats, imitating the calf suckling. The oil lubricated centrifugal vane vacuum pumps without variable speed control and automatic shut-off valves are implemented here. The size of the milking machine defined with the volume rate of vacuumed air which needed to keep the drop of vacuum level lower than 2kPa *(Mein et al., 1992)*. It is assumed that a vacuum drop of 2 kPa has little or no effect on milking performance. ASAE standards suggest a constant value of 850 l/m for the milking systems with milking stalls less than 10 units *(ASAE, 1996).* This proposal would meet the current industry concern that small systems seem to be under-pumped but large systems are over-pumped. However, ISO standards proposed the base requirement 30 l/m per each milking unit plus extra amounts of 400 l/m for vacuum drop, altitude, leaks and wear *(ISO, 2007).* This extra value is recommended for the vacuum configuration without automatic shut-off valves in the cluster claw, for configuration with automatic shut-off valves it would be 200 liters per minute.

For supplying the air volume rate of 640 liters per minute, based on the current Iran market brands, a machine with the nominal power about 3 or 4 kW would be needed. The vacuum pumps are used to wash the milking machine, as well. In TRNSYS calculations, electric energy consumption of the milking machine can be calculated simply by multiplying the nominal power consumption by its working time. On average, having an eight unit milking machine, each eight cows need 10-15 minutes to be milked and the washing process takes less than 30 minutes, as well.

Milk Cooling Demand

Fresh milk is normally harvested at 39°C and must be cooled down to 4°C within two hours since milking *(INSO, 2013)*, to arrest the bacterial growth and maintain the quality of harvested milk in order to meet the health and safety standards for human nourishment. Bulk milk coolers are used to chill the milk from its harvest temperature by consuming electric energy. The milk is pumped continuously to the insulated storage tank, where it can be kept, with occasional agitation, until collection. The cooled milk is collected in the insulated storage tanks which are able to keep the milk cool with 3 degrees temperature increase more than initial state, after 12 hours. The system cooling efficiency depends strongly on the cooling system coefficient of performance (COP). It was reported that, the COP value for a milk cooling system as a part of its research on energy audit process, was between the range of 1.62 to 2.43, for milk refrigeration units without any kinds of pre cooler *(Pradhanang, 2015)*.

In addition, Sapali et al. declared COP of 3 for milk chilling as an energy intensive practice *(Sapali et al., 2014)*. However, the COP and the cooling capacity strongly depend on the ambient temperature and the chilled water temperature. To calculate milk cooling EUI in kWh/kg-milk, the procedure outlined in *(Upton et al, 2014)* was adopted here. Modified Carnot cycle (ideal refrigeration cycle) formula as described by *(Henze et al., 1997)*, was implemented to define COP as an ambient temperature dependent variable in Eq.1.

$$\mathrm{COP} = \left|\frac{\mathrm{T_{evp}}}{\mathrm{T_{am}} - \mathrm{T_{evp}}}\right| \times \alpha \tag{1}$$

$$\mathrm{Q_{mc}} = \frac{\mathrm{C_m} \times \Delta \mathrm{T}}{\mathrm{COP} \times 3600} \tag{2}$$

Eq.2 introduced $\mathrm{Q_{mc}}$ as EUI for milk cooling process as $\mathrm{kWh/kg}$ in hourly time horizon. The variable $\mathrm{T_{evp}}$ is the characteristic evaporator temperature of the refrigeration system, which assumed to be 268 $\mathrm{K^0}$ and $\mathrm{T_{am}}$ was the hourly ambient temperature which depends on the farm geographical location and time of the year, from TMY database implementing in TRNSYS simulations. Furthermore, the coefficient of α was considered as an adjustment factor to account for inefficiencies in real world systems according to *(Upton et al, 2014)*. Hence, the COP variation is bound to ambient temperature, evaporator temperature and insufficiency factor. The milk cooling share of total demand load would be calculated with respect to the number of milked cows in each hour and their LC.

Pumping Demand

Both milk and water must be pumped during a day in each dairy farm. Water usually used with the purpose of drinking, cows and milking machine washing and also in cleaning the farm. The amount of hot water required for washing purpose varies from farm to farm and depends on the size of the milking herd and the type and size of the milking system. The estimation of fresh water use for different farm sections is reported in literature with a wide variation *(Looper and Waldner, 2002; Kramer et al, 2008; CIGR, 2014; Schroeder, 2015; DairyNZ, 2015)*.

Table 2

Approximate required water volume for drinking, washing and cleaning in typical dairy farms

(Bickert et al, 2000)

Water Use	Water Volume	
Drinking	76-114	Liter/cow/day
Bulk Tank	113-151	Liter/wash
Milking Parlor Pipeline	283-473	Liter/wash
Miscellaneous Task	113	Liter/day
Cow preparation	7.5	Liter/washed cow
Parlor Floor	2100-8100	Liter/milking
Milk Room Floor	38-76	Liter/day
Toilet	19	Liter/flush

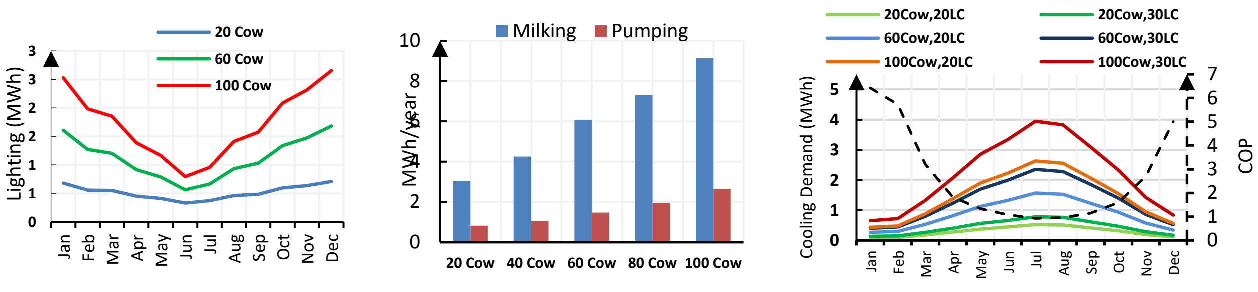
However, the studied farm uses the university network of water pipes; the electrical demand needed for pumping the required water amount was calculated regarding the specification of a centrifugal water pump, kept as an auxiliary setup. Therefore, energy used in this section focuses solely on pumping equipment operation. The amount of electricity consumption per each liter of pumped fluid (p) can be calculated in TRNSYS simply by applying Eq.3 regarding the corresponding schedule timing.

$$\mathrm{p} = \frac{\mathrm{P}}{\mathrm{Q} \times \eta} \tag{3}$$

Where, Q is the nominal rate of pump in [m^3/h], P is the nominal power of pump in [kW] and η_{pump} is the pumping efficiency, according to Table 3.

RESULTS

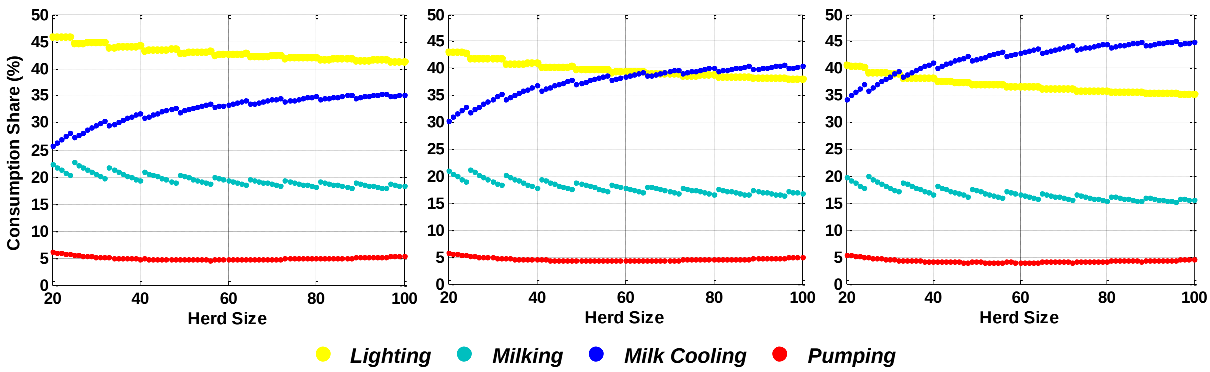
We have introduced a new approach to estimate hourly electrical consumption in each subsection of artificial lighting, milking, milk cooling and pumping. As mentioned earlier, it has been adjusted in the methodology that the estimation of demand profile would be a function of herd size, LC of cows, geographical and meteorological parameters of farm location and time scheduling of farm activities. A positive correlation was found between estimated demands in subsections and the main inputs of the model, as demonstrated in Fig.3. As follows from the Fig.3-a,b,c, all subsections of current methodology are strongly depended on the farm herd size. However, for cooling subsection, there is also direct dependency of cooling demand on cow's LC, which is illustrated in Fig. 3-c as three values of LC which ranged on the regular Holstein LCs. It has been found that with increasing the herd size from 20 to 100 lactating cows, almost 2 fold of linear increase in milking and pumping shares of electric demand would be expected, as illustrated in Fig. 3-b. Furthermore, the dominant effect of meteorological factors also was depicted on the cooling and lighting demands, in Fig.3. From Fig.3-a, it can be seen that the variation of day length during the months of the year would cause significant changes in lighting electric demand of the farm. In addition, it has been perceived that deviation from flat trend with regard to herd size, in Fig.3-a, is justified by the fact that a portion of lighting is devoted to the milking parlor which is almost invariable through the year. The results thus demonstrated in Fig.3-c are compatible with the fact that the COP of cooling system is strongly influenced by the ambient temperature according to Eq.1-2, where, the smaller COP, the higher cooling electric demand would be expected.



(a)Lighting demand (b) Milking and Pumping demand (c) Milk Cooling demand

Fig. 3 - The detailed and illustrated influence of different sub-sections

In Fig.4, the demand share of each subsection is plotted against herd size in varying LCs. The minimum around 5% share is devoted to pumping and maximum value to either lighting or cooling. The main point here is that cooling demand increases with expanding the herd size from 20 to 100 cows. Lighting, on the other hand, decreases by 5% as well. The cooling share overweighs the lighting share as pinpointed in Fig. 4b-c.



a) 20 kg/Cow/Day b) 25 kg/Cow/Day c) 30 kg/Cow/Day

Fig. 4 - Demand consumption share variation versus farm herd size for different LCs

Electric demand of Urmia university farm is detailed in Fig.5. The case studied farm consumes 29,435 kWh annually, its maximum value being in August. The profile is of critical significance in time scheduling and decision making strategies. As elucidated in Fig.5, top row, overall shape of daily electric demand is bimodal, i.e. two peaks around the milking time. The effect of day length on the demand in lighting subsection is well predicted (Fig.5); in midwinter and 4 hours before twilight 100 lux would be needed for barn lighting. In midsummer, however, only 2 hours of artificial lighting would be sufficient. In mid row of Fig.5, variation of lighting demand on daily resolution is showed. Milking parlor and pumping have constant load on the demand over the year despite considerable water consumption fluctuations. As shown in the lowest row ofFig.5, the effect of ambient temperature on cooling demand is quite significant. Generally speaking, the dominant demand is dedicated to cooling in warm months of the year and lighting in cold months. In the case studied project here, the lighting system consumes the most electricity, 42% of the farm total demand. This is of great importance in consumption optimization and control strategies to reduce energy demand.

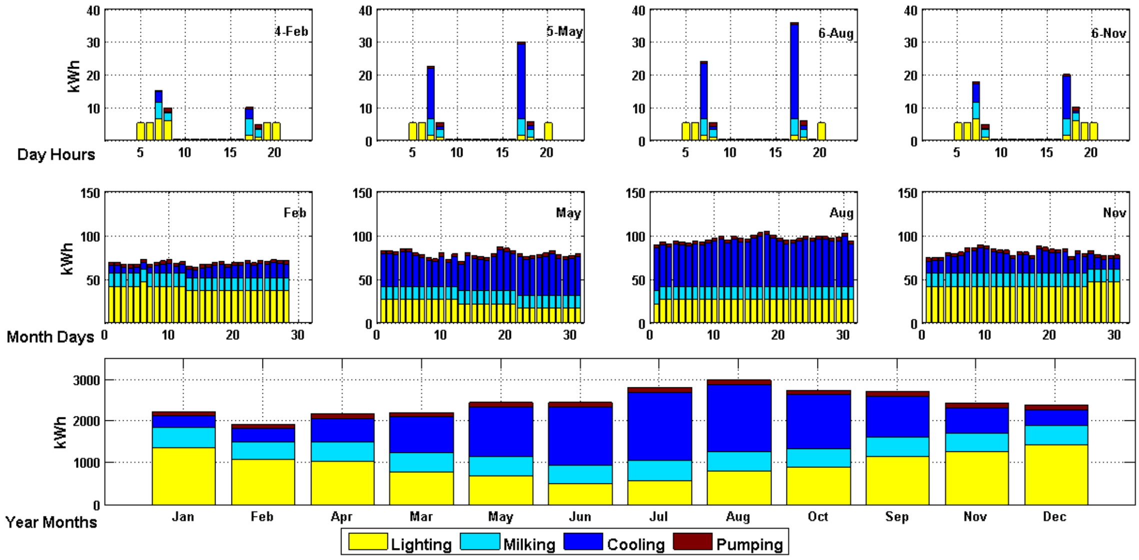


Fig. 5 - Electric demand load of case studied dairy farm

(herd size-50 cows, lactating capacity of 30 kg/Cow/Day);

Hourly, daily and monthly demand profiles for middle seasons days, middle seasons months and whole year, respectively

CONCLUSIONS

Estimating the hourly demand profile of electricity consumption in dairy farms was the main target as the primary step toward applying PV system in dairy farms. To achieve this objective, a typical dairy farm was selected as a reference to define the simulation framework. A methodology was presented as a computational program combining the models of artificial lighting demand, milking demand, milk cooling demand and pumping demand, which was developed in TRNSYS. Further investigation was conducted on farms with herd size of 20 to 100 cows as the most common size in Iran dairy farms. It has been demonstrated that the electrical demand has the overall shape of bimodal, i.e. two peaks around the milking time in the morning and evening. Summing up the results, it can be concluded that the most part of electric energy is consumed in lighting and milk cooling sections. In small herd size and low LC, the lighting is dominant consumer and with increasing the LC the milk cooling would be the main consumer in smaller herd size. Moreover, the effect of ambient temperature and day length, respectively, on milk cooling demand and artificial lighting demand is quite significant and governs the total demand variation during a year, where the maximum demand is registered in August. The proposed method can be readily used in practice and the findings are of direct practical relevance. An important finding to emerge in this study is the detailed consumption share of each subsection which can be used in economical evaluation of equipment replacements through enhancement plans. This research was concerned with PV application; however, the results should be applicable also to energy efficiency intervention strategies.

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