ELECTRIC POWER CONSUMPTION MODEL FOR PALESTINE HOUSE STOKE

H. M. A. Q. Ahmed, U. Atikol
Department of Mechanical Engineering, Eastern Mediterranean University, Gazimagusa, Mersin 10, Turkey.
Corresponding author: Hussein Ahmad, e-mail: huseina@ppu.edu

REFERENCE NO

ELEC-02

ABSTRACT

Palestinian residential sector suffers a limited electricity supply. Therefore, the development of a Palestinian residential power demand model is the focus of the present study, for the purpose of applying demand side management programs to manage power consumption of Palestinian houses. The model is based on domestic appliances of a typical Palestinian house and their respective operational scenarios. The actual power consumptions of ten houses located in Hebron city in West Bank is monitored and was compared with the developed simulation model in MATLAB SimScape software. Effects on power consumption are studied including power factors, and socio-demographic related factors. A detailed case study is carried out where power consumption is monitored through five consecutive days. An average error of 8.44% of model output relative to actual power consumption is obtained. Graphical user interface is built so that end-users could find their expected electrical power consumption.

Keywords:
Bottom-up modeling; Power consumption model; GUI Matlab, Socio-demographic factors

1. INTRODUCTION

Modelling of demand load electric power consumption has been an interesting field for many researchers. Price et al. introduced several terminologies concerning load modelling [1]. For modeling electrical power consumption, two common methods used are; top-down, and bottom up approaches [2]. Bottom up method considers the consumption of individual houses or a group of them. This requires several data about those houses including number of individuals, activity levels, house construction materials and environment conditions [3]. Such data taken from surveys helps estimating past, present, and future power consumption of some geographic region [4].

Electric power consumption models are used for many objectives such as, exploring the potentials of reducing carbon dioxide emissions CO_2 [3] [5] [6], also to investigate the impact of applying measures that increase power efficiencies [7], moreover, power consumption models are used to optimize heating energy required and to investigate related greenhouse gases emissions for some region [8].

This paper presents an electric power consumption model for country Palestine, for the purpose of investigating power consumption, and possibly promoting future applications of a demand side management program accompanied with renewable energy systems, where a bottom-up approach is followed. Palestine is considered one of many developing countries in Middle East, where studies concerning power consumption are uncommon. A study based on power consumption in Algerian residential sector was conducted by Ghedamsi et al. [9]. However, the present work differs from their work as it considers socio-demographic factors. Also the proposed model is built in such a way that power consumption of individual houses can be calculated.

1.1. Problem Definition

Palestine has a limited share of electricity [10], in particular, residential sector consumes about 39% of this share. Also, utility source current of each house is limited by automatic circuit breakers of either 220 AC Volt/25 Ampere or 380AC volt/32 Ampere. This means if a house is consuming above limits, power on that house will go down. Also, such automatic circuit breakers present for houses in groups. Houses' owners are cautiously acquiring electrical devices, especially ones with high currents.

1.2.Objectives

The main purpose of this article is to present a bottom-up electrical power consumption model for country Palestine, regarding residential sector, where developing such a model is the base for a demand side management control program. Other objectives include studying several socio-demographic factors related to power consumption within Palestine. The suggested model is also presented such that any house owner could make inputs through a graphical user interface software and acquire information about his house power consumption.

2. METHODS

2.1.Place of Study

Hebron city is selected for this study because it suffers greatly from the problem of power outages. It is located in the West Bank to the south of Jerusalem by about 35 km (see Fig.1). It is considered today one of the largest cities in the West Bank in terms of population and area, where the population in 2016 about 684 thousand people and an area of 42 km^2. The annual solar radiation rate in the city is estimated by 71.7 MJ/ m2, where a large percentage of this radiation can be used in the production of electric power [10]. The main type of houses in Hebron city are the single houses, with the increase in population density, the limited amount of land permitted for construction and the high prices, people are now moving towards vertical construction.

2.2.Sample and Data Acquisitions

Power consumption patterns of ten houses along 24 hours where measured in Hebron city, Total current and voltage of each house was measured. Also domestic electrical devices currents and voltages were measured to confirm physical models of such devices used within the overall power consumption suggested model. Table 1 summarizes the measurement devices used for acquiring the data of power consumption at each house.

Fig.1. Hebron city located in the West-bank, Palestine

Measured data is analyzed along with data received of questionnaire describing related factors. Those factors include, family income, number of family members, house's surface area and house's electrical loads rating powers.

Questionnaire also included data regarding availability of occupants such as, available family members in day time, available family members at night, family members attending school and family members attending university

2.3.Model

Fig. 2 represents a bottom-up power consumption model built for the Palestinian residential sector. The model includes all expected loads of a typical Palestinian house. For modeling each domestic load, a RCL considered, where model of each domestic electrical load is verified through comparing its power consumption profile with the actual device measured profile.

In Fig. 2. Power is provided through utility grid, limited by a 25 ampere circuit breaker. Power is multiplied by two power factors including the utility grid power factor P_g which can be give the value of 0.7 up to 0.85 [11], and house power factor P_h which depends on houses' appliances. Data required from end-user includes power rating capacity of each appliance, and operational scenario represented by number of hours. Output power consumption profile is given according to this model.

2.3.1. Socio-demographic Factors

Socio-demographic factors effects on power consumption profiled are assumed to be

Table 1. Measurement devices with specifications.

Device	Measured quantity	Specification
Potential Voltage Current Transformers SPT-0375	Voltage	3. Voltage current transformer with 115 to 460-volt AC 4. Linear output voltage proportional to the input voltage, with a linear accuracy of ±1%
Split core AC current sensor	Current	1. The capacity of current measurement is from 0 to 20 Ampere 2. The sensor is compatible with HOBO U12data loggers 3. The sensor approximated response time is 440 [msec] 4. An accuracy of ±4.5% at full scale
HOBO U12 Data Logger	Data logger	1. Two-channel logger with 12-bit resolution 2. Can record up to 43,000 measurements or events. 3. The logger uses a direct USB interface for launching and data readout by a computer

covered within operational scenarios. This includes different factors including; family income, number of individuals, house area, power consumption peak hours, and availability of family members through day and night. For the assumption of socio-demographic factors effects are covered within operational scenario, calculations related to those factors are not considered within the suggested model in Fig. 2.

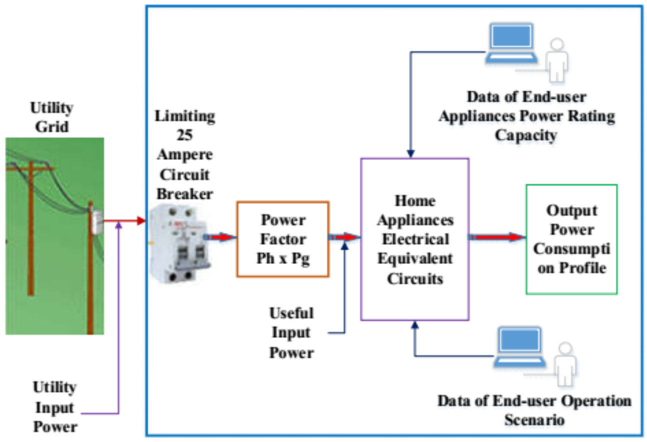


Fig. 2. Suggested power consumption model

2.3.2. Simulated Model

MATLAB toolbox SimScape was used to build equivalent electrical circuits of home appliances. Each electric appliance model included a RCL circuit as shown in Fig. 3, depending on the electric design of the load. For house electrical grid, a block of a single phase 220/50 Hz AC voltage source is used. Electrical elements of each load initially are tuned to match the RMS current of actual load.

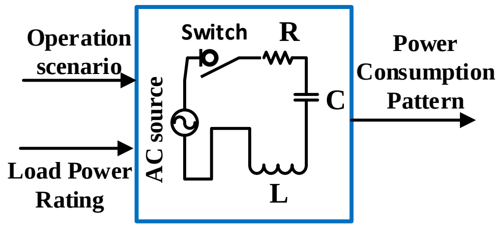


Fig.3. Conceptual Matlab/SimScape appliance model

Then the values of R, C and L are calculated by the model according to the nominal load power rating value which is a model input. Each RCL circuit is controlled by a switch, where its operation is determined by the model input which is the operation scenario of that load. The load operation scenario is inserted to the model through a time line Matlab file. The output power consumption pattern is calculated according to Eq. (1) as follows,

$$Power = P_T \times I_{rms} \times V_{rms} \qquad (1)$$

Where, I_{rms} is RMS AC current, V_{rms} is RMS AC voltage, and total power factor P_T is calculated using Eq. (2),

$$P_T = P_g \times P_h \tag{2}$$

Where, P_g , is grid power factor given the value of 0.8 [11], and P_h is house power factor calculated depending on house appliances.

2.4. Case Study

A house which is located in Wadi Abu Dajan, an area to the northwest of Hebron, is selected for a case study. The surface area of the house is 130 m^2, family income is 1000-1500$, and number of family members are 4. The monthly electric consumption of the house is approximately equal to the average consumption of a Palestinian house of about 8-9 KWh/day [12]. Power consumption of this house was measured through 5 consecutive days. Simulation results of this house are also calculated through carefully provided data of operational scenario and verified devices models which's characteristics were compared to actual ones. Home appliances considered are summarized in Table 2, along with power rating, load type, and manufacturing brand. Table 2 presents the type of appliances in a typical Palestinian house except for air condition, and dishwasher, those are possessed by high monthly income Palestinian families, of above 1500$.

Table 2. Load appliances of a typical Palestinian house, along with expected power rating, energy consumption comparison.

#	Device	Power (watt)	Load type	Manufacturer
1	Washing Machine	1800	Resistive, Inductive	LG
2	Hair Dryer	2000	Resistive	Super Solano
3	TV	200	Capacitive	LG
4	Electric house water heater used in Kitchen	2400	Resistive	Mega
5	Electric Oven	2400	Resistive	Universal
6	Water pump	560	Inductive	Italy
7	Water electric Boiler	2000	Resistive	Mienta
8	Vacuum Cleaner	1800	Inductive	Hommer
9	Electric Iron	1900	Resistive	Ariete
10	Refrigerator	160	Inductive	LG
11	Lighting System	500	Leds	Different

For accurately modeling devices summarized in Table 2, model parameters of each device are adjusted to match current measured from each actual device when same voltage applies. Relative error is calculated as follows:

$$error = \frac{(E_{Mt} - E_{At})}{E_{At}} \times 100\% \tag{3}$$

Here actual measured total energy E_{At} is energy measured using current, and voltage measuring devices, whereas model output total energy E_{Mt} was calculated through SimScape.

2.5. Graphical User Interface (GUI)

Fig. 4 shows graphical user interface contained the SimScape Matlab program of the bottom-up power consumption model developed in subsection 2.3.2, where user can enter data of power rating of their devices and operational scenarios, to acquire power consumption profile, without a need to learn Matlab programming language or to type any command. This provides less complexity for end-users to acquire information on power consumption according to their inputs. Also, Fig.4 provides an example of GUI output power consumption pattern for a coustmer who entered the power rating and the expected operational scenario of his electric loads in GUI display required fields.

3. RESULTS AND DISCUSSION

3.1. Socio-demographic Factors Affecting Power Consumption

For socio-demographic factors affecting power consumption of a house in Palestine several factors were investigated including, family income, number of family members, and house area. Fig. 5 shows data concerning those factors along with average power consumption on daily basis for the ten houses sample.

From Fig.5. The following can be observed:

- Two dominant factors to affect power consumption are family income, and house area. Where house 1, and 9 consumes largest power share, and has highest income, and largest area surface.
- It can be noticed that there is a proportional relation between surface area of house and power consumption; when surface area increases, power consumption increases.
- While house areas are the same, income level has noticeable effect on power consumption levels. This is apparent when observing house 4 and 5.
- Number of family members has no effect on power consumption levels. Notice house 6 with 9 family members. In spite that it has highest occupants number, having an area of 120 m^2 and an income of 1000-1500$, it has the lowest power consumption among other houses.

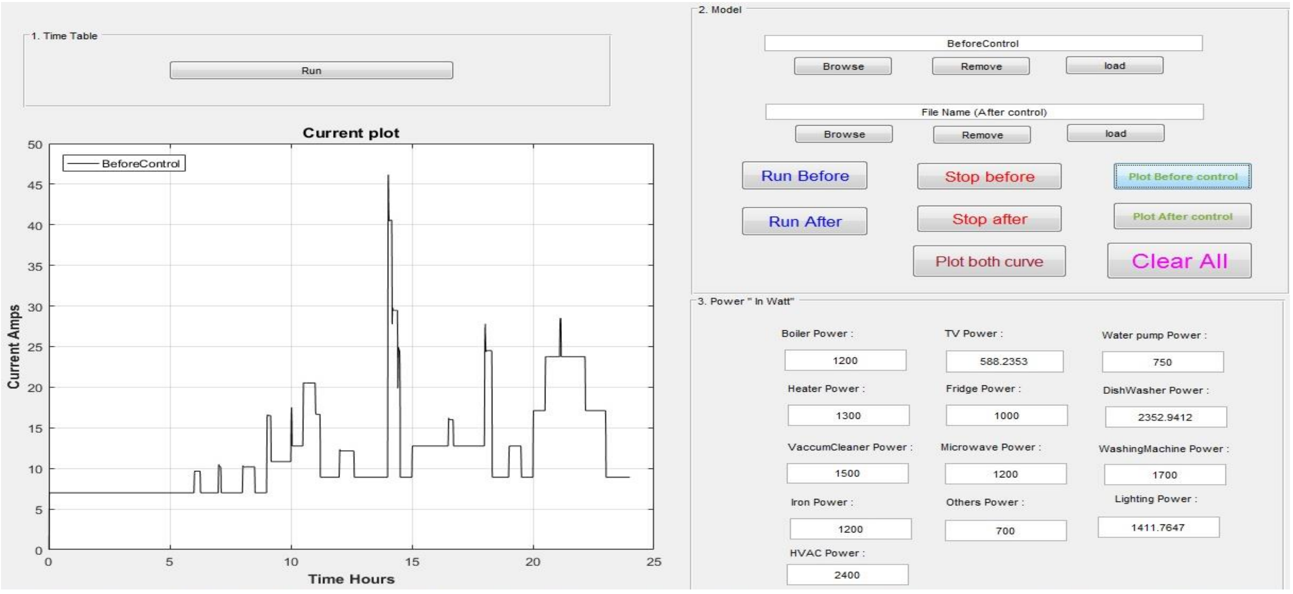
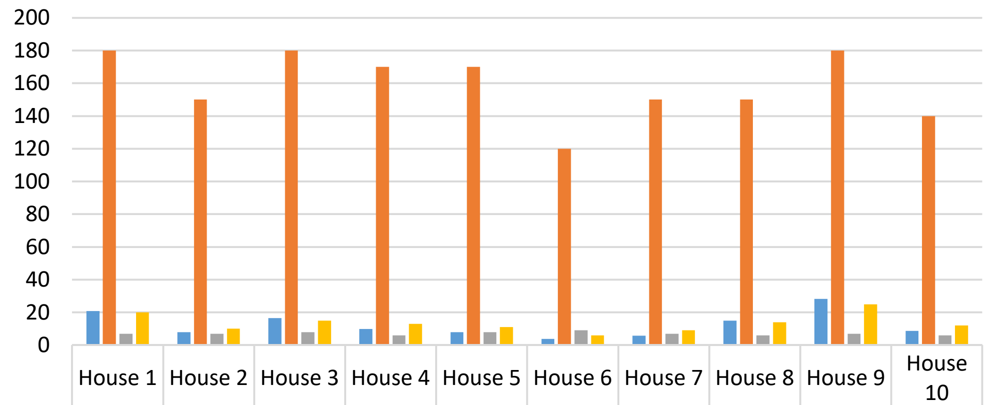


Fig. 4. Graphical user interface of bottom-up power consumption model

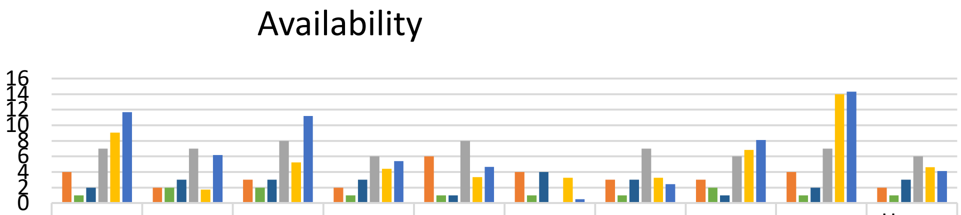


	House 1	House 2	House 3	House 4	House 5	House 6	House 7	House 8	House 9	House 10
Total Consumption kWh	20.75	7.91	16.42	9.84	8	3.75	5.7	14.93	28.28	8.74
House area in m^2	180	150	180	170	170	120	150	150	180	140
Number of family members	7	7	8	6	8	9	7	6	7	6
Income in $	20	10	15	13	11	6	9	14	25	12

Fig. 5. Socio-demographic factors affecting power consumption of a house in Palestine. Regarding income, 10 means >1500$, 5 means 1000$-1500$.

3.2. Availability of Family Members at Day and Night Effect on Power Consumption

The effect of family members' availability in the house at day and night is investigated. Factors related to availability are divided into, available family members in the day, available family members in the night, family members attending school, and family members attending university. These factors are considered along with power consumption at both day and night. This is summarized in Fig.6.



	House 1	House 2	House 3	House 4	House 5	House 6	House 7	House 8	House 9	House 10
No. of day family members	4	2	3	2	6	4	3	3	4	2
No. of members at univ.	1	2	2	1	1	1	1	2	1	1
No. of school members	2	3	3	3	1	4	3	1	2	3
No. of night family members	7	7	8	6	8	0	7	6	7	6
Day cons. kWh	9.07	1.74	5.22	4.42	3.34	3.25	3.26	6.83	13.98	4.63
Night cons. kWh	11.68	6.17	11.2	5.42	4.66	0.5	2.44	8.1	14.3	4.11

Fig. 6 Availability of occupants' effect on power consumption through day and night

From Fig. 6, the following can be observed:

- Power consumption at day or night is proportional for number of family members who are available at the time.
- The night energy consumption increased with the increase in family members that are university students, such as the case of houses 2, 3 and 8 where the university student's number was 2 compared to the rest of the houses where one family member is at university. In this situation the night consumption increased mainly due to the need for the lighting system to perform the university assignments and readings.
- Power consumption is also proportional to the number of family members together in school and university.

3.3 Overall Power Consumption

Fig. 7a and Fig. 7b show the sum of power consumption of all ten houses of the sample at both day and night. Where results in Fig. 7 are calculated through measured power consumption data of each house of the 10 houses sample taken.

From Fig. 7. The following can be observed:

- From 4:30 AM early in the morning to about 9:00 AM. During this period some of family members need to use some of the electrical loads such as, electric water boiler and lighting system, besides housewife need to use the electric oven and kitchen water heater to prepare breakfast.
- Small peak periods from 10:00 AM to 11:00 AM where the housewife starts cleaning the house using extra loads like vacuum cleaner and may prepare breakfast for the family members who stays at home like children grand mother and father.
- From 4:30 PM to about 10:30 PM. This is the period where the family members return back from their working or studying places. In this period the electric loads such as electric water boiler, electric oven, lighting system, TV and other loads are in operation. Besides during this period, the housewife usually operates the washing and dishwasher machines.

Those findings coincide with the findings of Palestine Energy and Natural Resources Authority (PENRA) [12].

3.4 Power Consumption Results of Actual and Modeled House.

To compare results from built model and actual data, power consumption for a single house is measured through five consecutive days, also simulation results of total power consumption at each day is calculated. Table 3 summarizes power consumption of a house within sample

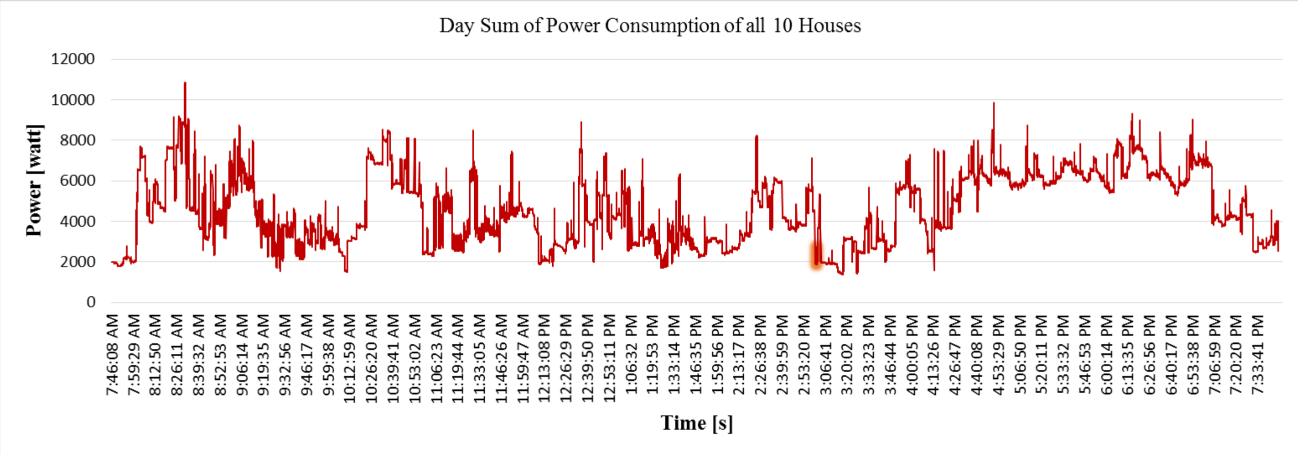


Fig. 7a. Power consumption sum of total 10 houses at day time

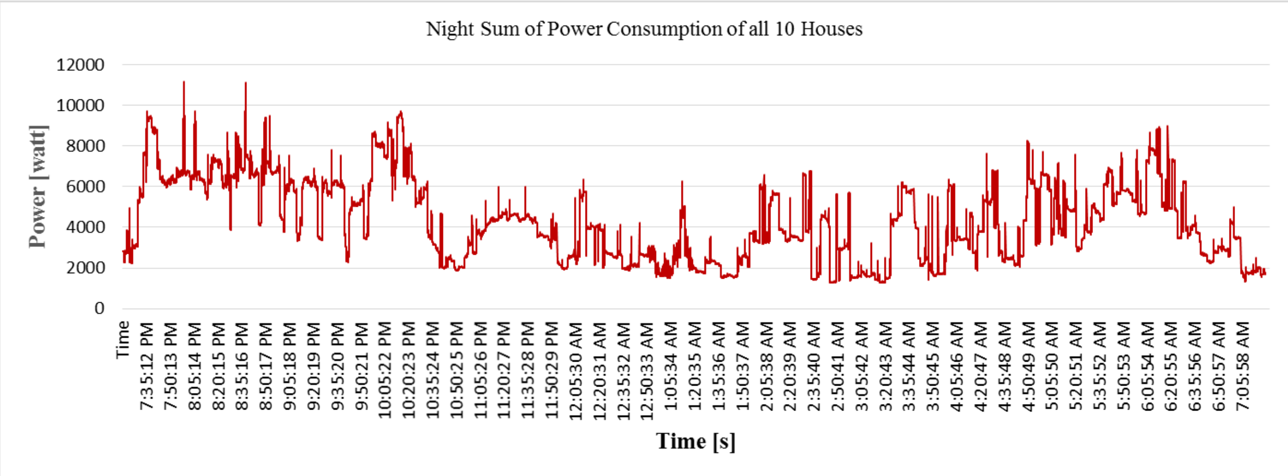


Fig. 7b. Power consumption sum of total 10 houses at nigh

taken, for five consecutive days both at day and night. Table 3 also presents the error of consumption through simulation for each day. Error is calculated according to Eq. (3).

Table 3 comparison between the model power output and the actual measured power for five consecutive days on a single house

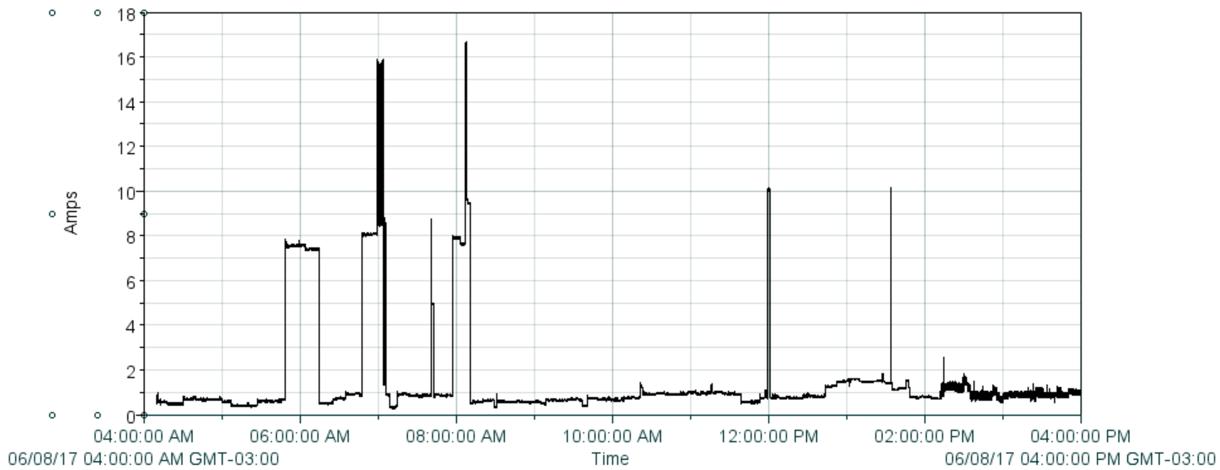
Day	Model day con. [kWh]	Model night con. [kWh]	Actual day con. [kWh]	Actual night con. [kWh]	Total Error 100%
Thursday	3.75	3.46	3.15	3.10	15.20
Friday	3.65	1.47	3.00	1.75	7.80
Saturday	2.18	1.56	2.10	1.54	2.70
Sunday	2.85	1.80	2.58	1.85	5.00
Monday	2.18	1.45	2.00	2.10	-11.50

+ error means model power > actual power, - error means model power < actual power.

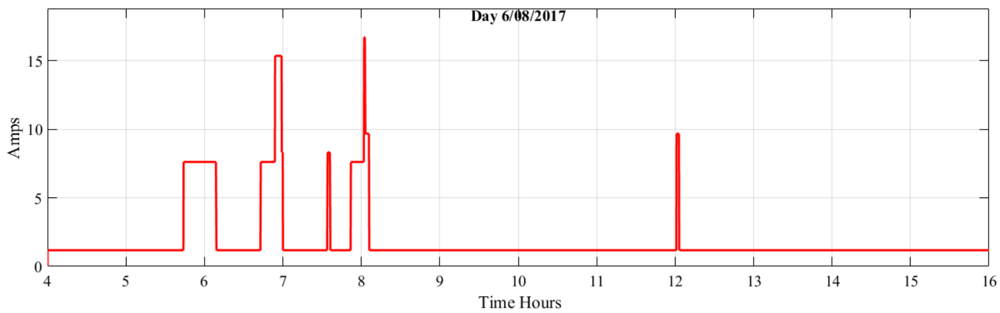
From Table 3, the average total error for power consumption along the 5 consecutive days is equal to 8.44%. Error mainly presents because of high starting current of actual devices, and inacuracies of recording periods of operation of the loads. Error is also due to inacuracy in modeling thermal devices which does not necissarily operate during operational periods such as refrigerators and HVAC is due to startup currents of the electric loads that are not included in the model.

Figure 8 shows a sample of power consumption profile during day time , from both actual measurements (Fig.8a), and model output (Fig.8b). When comparing both results, we can notice an impluse that doesn't present in simulated results; this is because of startup currents that are not included in the model.

Power consumption profiles shown in Fig. 9a, and 9b, show the night time of same day where occupants carry out most of their activities. Steady power consumption means mostly only lighting and refrigerating systems are operated.

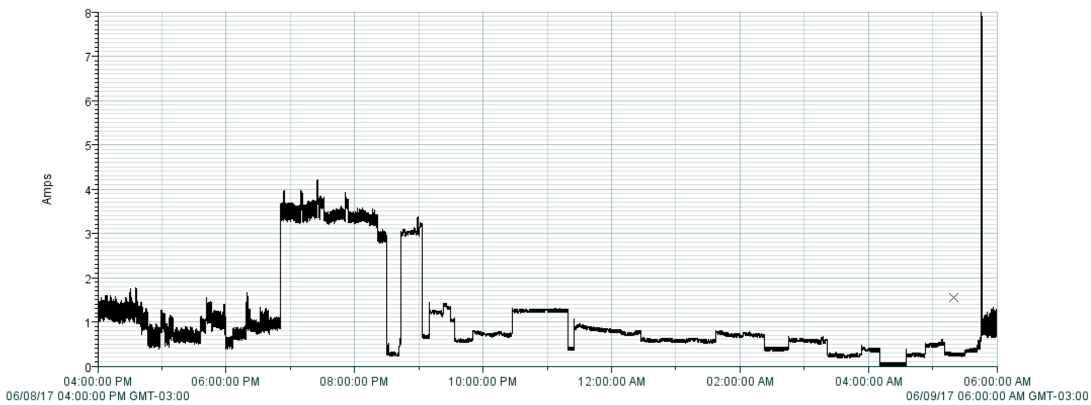


(a)

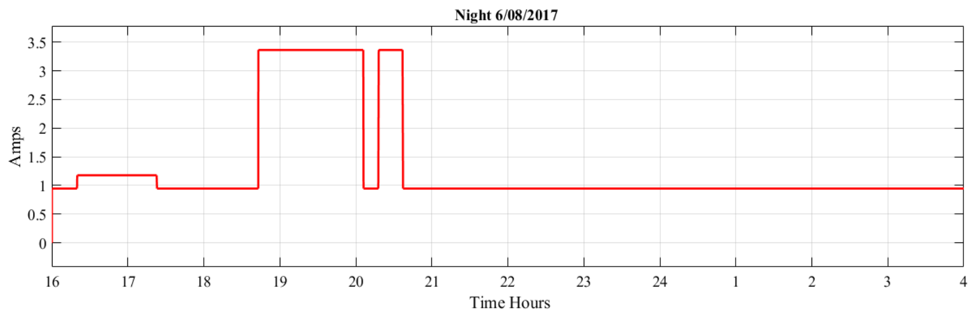


(b)

Fig. 8 Power profile Thursday 6/08/2017day time (a): actual measurement (b): model output



(a)



(b)

Fig. 9 power profile Thursday 6/08/2017 night time (a): actual measurement (b): model output

4. CONCLUSIONS

A power consumption model has been built for country Palestine. Factors affecting power consumption are investigated, including socio-demographic factors, and availability of house occupants. Having applied a bottom-up physical model makes available for every end user have an estimate of their electrical power consumption, for which a graphical user interface is built. A detailed case study where power consumption was observed through five consecutive days is done, to further verify the suggested model, from which an average error of 8.44% of model output results relative to actual power consumption. Model can be used for sizing residential renewable energy systems. It also can be used for applying demand side management programs. Moreover, model can help designated authorities with strategic planning of future power demand. The new suggested model can be further improved by the means of considering start up currents when modelling electrical devices, also by accurately modeling thermal devices with internal control programs, including refrigerators and HVACs.

Acknowledgements

The authors gratefully acknowledge use of the measurement devices of Renewable Energy and Environment Research Unit at Palestine Polytechnic University.

.

Nomenclature

P_g Utility grid power factor

P_h House power factor

I_{rms} RMS AC current (A)

V_{rms} RMS AC voltage (V)

P_T Total power factor

E_{At} Actual measured total energy (kWh)

E_{Mt} Model output total energy (kWh)

References

[1] Price, W. W., Chiang, H. D., Clark, H. K., Concordia, C., Lee, D. C., Hsu, J. C., & Srinivasan, K., Load representation for dynamic performance analysis, *IEEE Transactions on Power Systems*, Vol. 8, No. 2, 1993, pp. 472-482.

[2] Swn, L. G., & Ugursal V. I., Modeling of end-use energy consumption in the residential sector: A review of modeling techniques, *Renewable and sustainable energy reviews*, Vol.13, No. 8, 2009, pp.1819-1835.

[3] Johnston D. A physically based energy and carbon dioxide emission model of the UK housing stock, Ph.D. thesis, Leeds Metropolitan University, UK, 2003.

[4] Wilson D, Swisher J., Exploring the gap: top-down versus bottom-up analyses of the cost of mitigating global warming, *Energy Policy*, 1993, pp. 249–63.

[5] Firth Sk, Lomas KJ, Wright AJ., Targeting household energy-efficiency measures using sensitivity analysis, *Building Research & Information*, Vol. 38, No.1, 2010, pp. 25-41.

[6] Natarajan S, Levermore GJ., Predicting future UK housing stock and carbon emissions, *Energy Policy*, Vol. 35, No. 1, 2007, pp. 5719–5727.

[7] Farahbakhsh H., Ugursal VI., Fung AS., A residential end-use energy consumption model for Canada, *International Journal of Energy Research*, Vol. 22, No. 13 1998, pp.1133–1143.

[8] Snakin JPA., An engineering model for heating energy and emission assessment: the case of North Karelia, Finland, *Applied Energy*, Vol. 67, No. 4,2000, pp. 353–381.

[9] Ghedamsi, R., Settou, N., Gouareh, A., Khamouli, A., Saifi, N., Recioui, B., & Dokkar, B., Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach, *Energy and Buildings*, Vol. 121, 2016, pp. 309-317.

[10] PCBS, Palestinian Central Bureau of Statistics, 2015.

[11] Abualkhair, A., & Université de Genève, Centre universitaire d'étude des problèmes de l'énergie., The current status of the energy sector in Palestine, with a special focus on the electricity sector, Centre universitaire d'étude des problèmes de l'énergie, 2006.

[12] Palestinian Energy And Natural Resources Authority – PENRA, إرشادات للمواطن للتخفيف من أزمة الطاقة, Retrieved July 29, 2017,from http://www.penra.gov.ps/index.php?option=com_c

ontent&view=article&id=763%3A2012-11-14-10-03-29&catid=27%3A2012-11-14-08-37-30&Itemid=61