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Electricity Tariffs Evaluation using Smart Load Monitoring Devices for Residential Consumer

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***Abstract*— In the current financial climate, focus on energy saving within the home has intensified by the desire to reduce costs. Fossil fuel savings, carbon emission reductions, as well as a permanent fall in electricity prices, are significant incentives for the residential consumers to look at different methods to reduce their energy consumption. Demand Response (DR) is an alternative method which provides an opportunity for consumers to reduce their energy consumption cost by deferring or shifting their electricity usage during peak periods. To this aim, this study evaluates the effectiveness of price-based DR techniques currently available in Western Australia based on the consumer cost of electricity and comfort level. The electricity tariffs are systematically examined, and proper cost analysis is performed using realistic load profiles of a typical household obtained by using smart load monitoring devices. A multi-scenario based approach is conducted to evaluate the electricity tariffs for the typical household. The analysis results show that the Smart Home (SM1) tariff would be the optimum choice for the typical consumer.**

***Keywords*— Electricity tariffs, demand response, time of use tariff, load shifting, standby power loss.**

I. Introduction

Electricity prices are increasing continuously due to aging infrastructures, high investment costs of network upgrade and increase in population. The residential sector, which accounts for about 30–40% of total energy consumption all over the world [1–2] can contribute a significant amount of country's peak demand. For instances, residential sector is responsible for 45% of the network peak demand in UK [3] and more than 50% in New Zealand [4]. The residential sector in Australia contributes to about 25% of total energy consumption and can make up to 45% of the peak demand [5]. An essential aspect of Australian energy consumption patterns is the rapid growth of peak demand compare to average demand. In the time between 2005 and 2011, the peak demand significantly increased at a rate of about 1.8% annually compared to only a percentile growth of 0.5 for total energy [6]. The growth in peak demand causes a strain on the available power generation, transmission and distribution infrastructure, and meeting this peak demand is often associated with high cost. Between 2015 and 2017 the cost of supplying electricity is predicted to increase annually by 7% (according to the Australian Energy Market Commission, 2012) [7].

Reducing consumer consumption during peak demand could result in substantial savings on total power generation and distribution costs [6]. One of the primary methods that can be pursued to reduce peak use of electricity in households is through consumer behavioural modification. Demand response (DR) refers to consumer actions that change the utility load profile in a way that reduces peak demand and improves grid security [8]. Generally, DR programs can be classified into two types: incentive-based (direct load control [9]) and price-based DR programs. The consumer privacy and system scalability are the major issues of direct load control (DLC) DR programs [10]. Price-based programs such as Time of Use Pricing (TOU), Critical Peak Price (CPP) or Real Time Pricing (RTP) do not have consumer privacy and system scalability problems and encourage consumers to adjust their consumption behaviour voluntarily [11]. Price-based DR offers various possibilities for lowering peak demand and may lead to consumer savings on electricity bills. However, the introduction and integration of the price-based DR into the different Energy Markets is complex. It entails a comprehensive approach including consideration of the functional energy performance, economic and environmental aspects from conceptual design through to design realization [7]. Pricing schemes may increase financial risks for some categories of residential consumers especially, low-income consumers if they are unable to shift their peak usages [12-13]. Amongst all the pricing programs TOU pricing is more popular in terms of simplicity and attractiveness to consumers and thus it is the focus of this study.

The issues that currently prevent efficient and flexible pricing from being offered to the residential sector in Australia include the lack of metering capability, the high cost of the metering infrastructure and the low level of consumer understanding of the relationship between energy usage and costs [14]. Currently, majority of the consumer sector is on flat tariffs with no incentives or information provided to encourage them to change in their consumption behaviour. Experiment results show that a consumer with a relatively flat consumption pattern could save around $40 to $60 in a year from by only changing its tariff structure to a time varying tariff. The same consumer could save an extra $100 a year if they can shift around 20 per cent of use from the peak afternoon period (2 pm to 8 pm) to other times [15]. Other households which have high peak time usage patterns can reduce their expenditure by up to $200 a year if they can reduce their afternoon peak time consumption by around 15 percent of original use [7]**.** Research by *CHOICE* [16] reveals that many consumers in Australia are finding it difficult to get a good deal in the electricity market. Evaluation of tariff designs is related to cost reflectivity, simplicity, stability and revenue variability [17]. To facilitate

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the consumer participating in time-based pricings, electricity businesses will need to engage consumers to design tariff packages that meet consumer needs. The greater choice in pricing options helps consumers reduce their costs [18].

Following price changes at different time periods may be confusing to consumers. A scheduling technique, either manual or automated [19], is needed to help consumer managing their loads. Innovative use of information technology [20] could permit users to access their power usages and a key driver of changing electricity consumption patterns. Some pilot studies indicate that if consumers are provided with direct feedback on their power consumption, it induces a change in their consumption behaviour [21]. Access to real load consumption data from households facilitate consumers to economize on their energy usages and help them to identify a suitable price-based tariff based on their need. To this aim, this study uses smart energy measuring devices for effective tariff evaluation. This study investigates some price-based electricity tariffs that are available in Western Australia and analyse their impacts on a typical residential consumer.

II. METHODOLOGY

Daily load profile has a critical impact on the evaluation and selection of tariff design. To obtain daily load profiles for a typical residential consumer, smart measuring devices are installed to measure the energy consumption of different electric appliances of the household. The smart system is a ZigBee-based wireless technology developed by Power Tracker [22], developed based on IEEE802.15.4 standard [23]. The consumer can access consumption information through online or in home display. This system provides near real-time power consumption information (every sixty seconds) and generates daily, weekly, monthly and yearly historical data. The smart load monitoring system consists of three main units: Smart Energy Gateway, Smart Clamps and Smart Appliances. Smart Energy Gateway is an all-in-one router which allows secured wireless internet access for real-time power management. The Gateway receives data wirelessly from the Smart Clamps and Smart Appliances and sends to the server. Smart Clamps allow metering entire home electricity usage by deploying in a power cabinet and can be also connected with the Solar system. Smart Appliances allows to measure and control the consumption of connected home devices which can be turned on/off remotely. The application diagram Fig. 1 shows how the whole system can be connected to home electric appliances.

The measurements are carried out over a week. By default, the Power Tracker devices have measured the real-time power of individual appliances with a resolution of 60 seconds. The area under the power vs. time graph is calculated to determine the total energy consumption of an appliance over the course of a day. Riemann sums method [24] is use to calculate energy from the power curve. A Riemann Sum is an effective method for approximating the total area underneath a curve on a graph. Fig. 2 represents the graphical illustration of Riemann Sums for calculating energy from a power curve graph to illustrate how the energy calculations are performed.

$$\text{Area of rectangles} = \sum_{i=0}^{n-1} f(x_i)\Delta x \quad (1)$$

where, n is the number of rectangles, $f(x_i)$ is the height of the rectangular for i = 0, 1,....,n-1; Δx is the width of the rectangle.

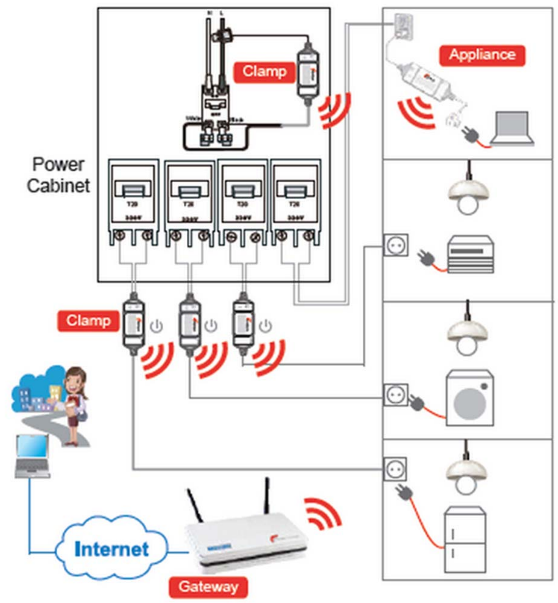

Fig. 1. Smart load monitoring and control system using Power Tracker [13].

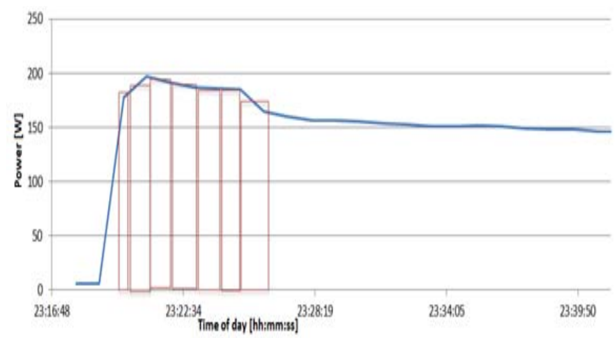

Fig. 2. Energy calculation from a refrigerator demand curve using Riemann Sum method.

Electricity tariff selection is performed for the household by estimating weekly and monthly electricity cost based on three different tariffs provide by Synergy [25], an utility company in the Western Australia. Two of the tariffs are TOU tariffs which are Power Shift (PS1) and Smart Home (SM1) tariffs and third one is flat tariff which is Home Plan (HP1). The cost of per kilowatt-hour (kWh) of each pricing plan is depicted in Table 1.

Power Shift (PS1) tariff: PS1 is divided into three time periods namely super-peak, peak, and off-peak periods. The Peak period times are different for weekend and weekdays. The super peak weekdays charge is a CPP, this to try account for unusual occurrences when exceptionally high peak demand is expected.

TABLE I. SYNERGY ELECTRICITY TARIFFS FOR RESIDENTIAL CONSUMERS

Power Shift (PS1)	(cents)/kWh	Smart Home (SM1)	(cents)/kWh	Home Plan (HP1)	(cents)/kWh
Supply charge/day	48.5989	Supply charge/day	48.5989	Supply charge/day	48.5989
Super Peak Weekdays 2pm-8pm	44.0703	Peak Weekdays 3pm-9pm	49.2855	Electricity charge	26.474
Peak Weekday 7am-2pm Weekday 8pm-10pm Weekend 7am-10pm	 23.7643 23.7643 23.7643	Shoulder Weekday 7am-3pm Weekend 7am-9pm	 25.8122 25.8122		
Off-peak All days 10pm-7am	12.1295	Off-Peak All days 9pm-7am	13.5772		

Smart Home (SM1) tariff: SM1 has four different time periods to consider namely Peak, Off-peak, Weekday shoulder and Weekend shoulder. The weekday and weekend shoulder periods are currently charged at the same rate.

The Home Plan (HP1) tariff: HP1 is a flat tariff. The consumer gets charged a flat rate of their electricity consumption regardless of the time of day they use electricity or how much they use.

This study considers three scenarios to evaluate the effectiveness of the three electricity tariffs on the consumer energy cost minimization. *In the first scenario*, the weekly and monthly cost differences between the three pricing plans are compared without considering any change of consumption behaviour. *In the second scenario,* the weekly and monthly costs of the different pricing plans are compared with considering consumer consumption behavioural changed. *In the third scenario,* the costs of the pricing plans are compared with both consumer behavioural changed and standby energy loss omitted. Fig. 3 illustrates the electricity tariff optimization steps.

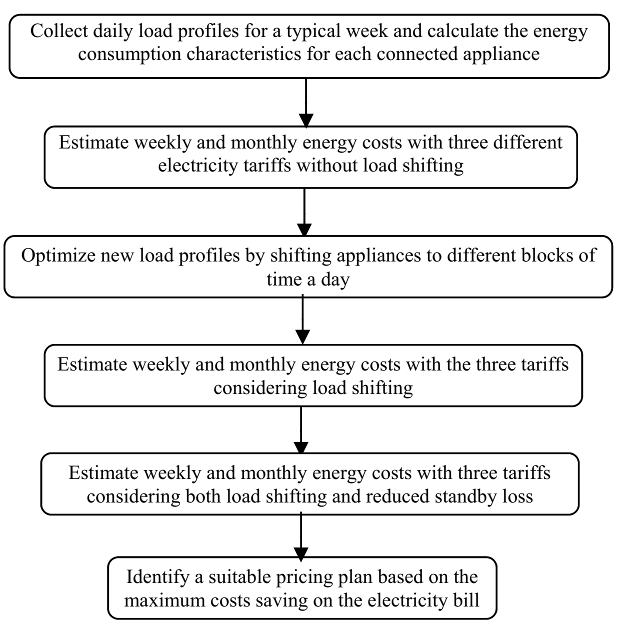

Fig. 3. Systematic flow chart of the research methodology.

III. CASE STUDY

Power Tracker smart load measuring devices are installed in a private house in the suburb of Ferndale in Perth. The Ferndale house is a small three bedrooms, one bathroom villa and occupied by five people. Power consumption data is collected over a seven-day period from 20 November to 26 November 2015. The weather during that week ranges from mid twenty degrees Celsius to mid thirty degree Celsius. Sunday, the 22nd of November was the hottest day experienced over that seven-day period, the temperature has reached 35.3 degrees Celsius. The connected household electric appliances and their measured energy consumption over the seven-day period are presented in Fig. 4.

The total energy consumption of the household over the week is 73.94 kWh. As can be seen from Fig. 4, refrigerator, air conditioner (AC) and dishwasher are the top three energy users of the house, followed by dishwasher, TV and washing machine. The daily consumption profile of each day of that week is shown in Fig. 5. It shows that the typical household usage more energy in the afternoon and evening periods than the other periods of the day. It is due to family members' usage behaviour.

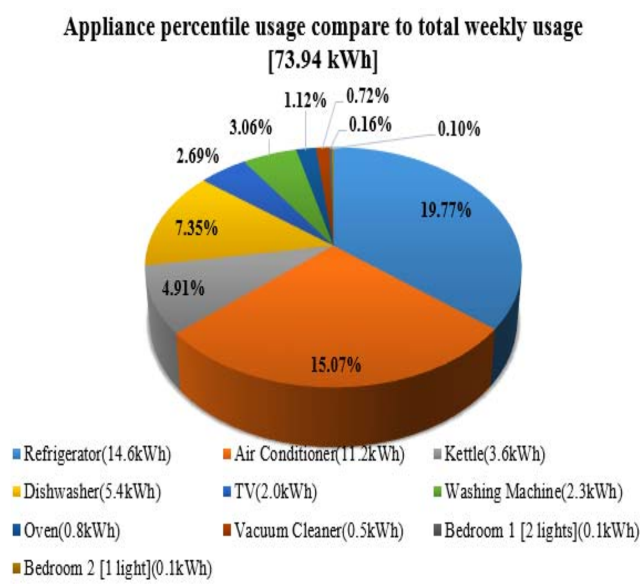

Fig. 4. Comparison of energy consumption for different appliances.

Most of the family members go to work early in the morning and return home early in the afternoon. During the afternoon period when family members are at home, most of the major appliances (AC, dishwasher, washing machine and kettle) are operated by them. The household has almost similar consumption characteristic throughout the weekdays. However, the highest peak energy usage and the longest peak period usage are observed on weekends, Saturday and Sunday respectively.

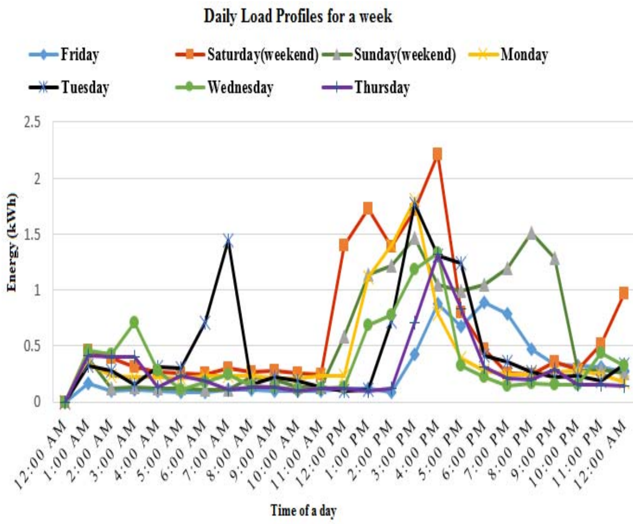

Fig. 5. Daily load profiles for a week.

Fig. 6 shows the comparison of the daily energy usage over the week. The highest consumption days are Saturday and Sunday with the daily totals of 15.60 kWh and 14.07 kWh respectively. It could reflect the fact that the family members were home for the weekend which resulted in higher energy usage.

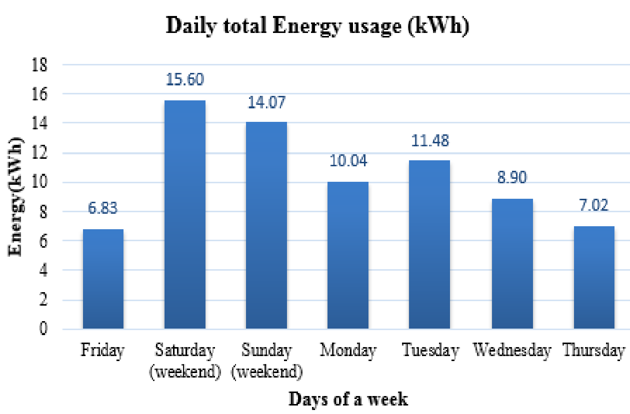

Fig. 6. Comparison of daily energy usage of a week.

The consumption characteristics of the major energy contributor loads on a typical day (e.g. on Tuesday) are presented in Fig. 7 to Fig. 10. The daily power demand of the refrigerator is shown in Fig. 7. The refrigerator has a repetitive consumption behaviour due to the compressor switching cycles to keep the inside temperature within the range. The power demand of the AC for this day is depicted in Fig 8.

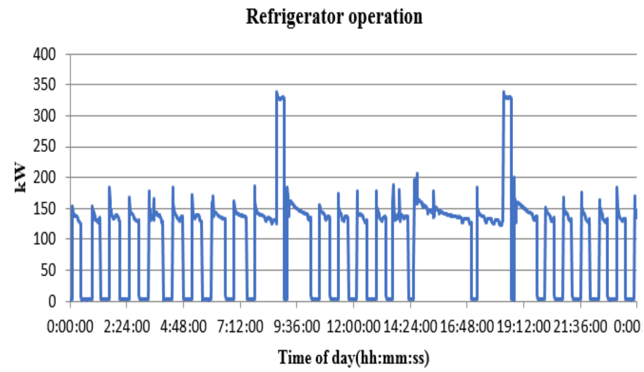

Fig. 7. Characteristics of a refrigerator.

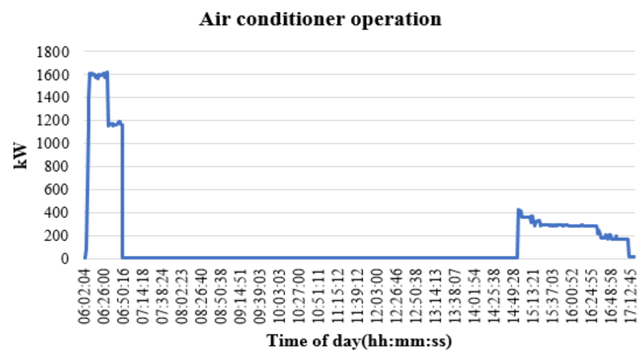

Fig. 8. Air conditioner power demand.

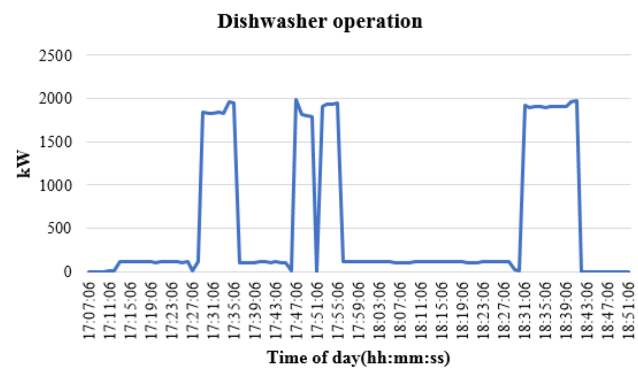

Fig. 9. Dishwasher consumption characteristic.

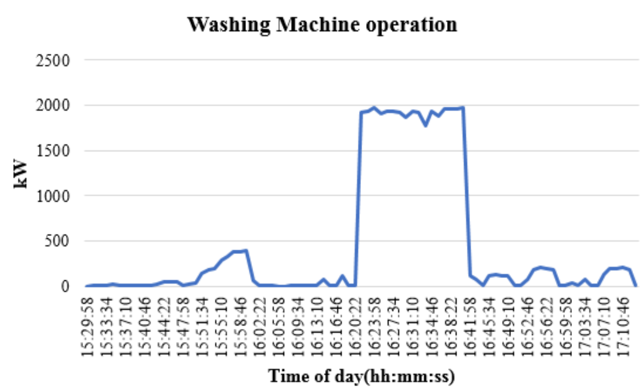

Fig. 10. Washing machine consumption characteristic.

Fig. 8 shows that the AC is being operated two times on Tuesday started at 6.00 and 14.50 respectively. Fig. 9 shows the dishwasher operation cycle (one hour and thirty minutes). It consumed total 0.78 kWh of energy. It is the quickest program for this particular model of dishwasher. The washing machine consumption cycle is around one hour and thirty minutes, and the total consumption is 0.32 kWh, as depicted in Fig. 10. The three case scenarios which are considered in this study are discussed in the next sections.

IV. CASE SCENARIO ANALYSIS

A. *Scenario 1: Estimate weekly and monthly energy bill without changing consumption behaviour*

The total energy consumption recorded over the seven-day period is equal to 73.94 kWh. The household is currently on the standard Home Plan (HP1) tariff, which is considered here as a base plan for comparison with two TOU DR tariffs (PS1 and SM1). The weekly and monthly electricity costs with both PS1 and SM1 are compared with the base plan considering without load shifting. From Table II it has seen that the consumer monthly bill is increased by 8.8% and 2.1% with the SM1 and the PS1 plan respectively.

TABLE II. *WEEKLY AND MONTHLY ENERGY COST WITHOUT LOAD SHIFTING*

	Power Shift (PS1)	Smart Home (SM1)	Home Plan (HP1/ base plan)
Weekly bill	$ 20.49	$ 21.83	$ 20.06
Monthly bill	$ 87.82	$ 93.54	$ 85.97
Monthly bill savings	-2.1%	-8.8%	0

B. *Scenario 2: Estimate weekly and monthly energy bill with changing consumption behaviour*

A family can't change their behaviour much when it comes to the refrigerator, AC or kettle. However, they can achieve savings by shifting washing machine, dishwasher, or dryer to off-peak periods without affecting their comfort levels. For the representative household, washing machine and dishwasher are considered as shiftable loads. The consumption times of these two loads are shifted to off-peak and shoulder periods to realize the cost impact from the three tariffs on consumer weekly and monthly energy bills. From the Table III, it can be seen that with the PS1 the household saves energy bill by shifting the two loads into both the off-peak and shoulder periods. Interestingly, with the SM1, the household achieve saving on energy bill only when the usages of the appliances occur in off-peak periods. Energy bill increases when consumption shifts to shoulder periods.

TABLE III. WEEKLY AND MONTHLY ENERGY COST WITH LOAD SHIFTING

	Power Shift (PS1)		Smart Home (SM1)		Home Plan (HP1/base plan)
	off peak	shoulder[a]	off-peak	shoulder	
Weekly bill	$ 18.48	$ 19.37	$ 19.59	$ 20.53	$ 20.06
Monthly bill	$ 79.19	$ 83.03	$ 83.96	$ 88.00	$ 85.97
Monthly bill savings	+7.9%	+3.4%	+2.3%	-2.4%	0

[a] shoulder periods represent the peak periods of PS1 plan

C. *Scenario 3: Estimate weekly and monthly energy cost with both changing behaviour and avoiding standby power loss*

Standby power loss contributes a substantial increase of consumer energy cost. Consumer can save money by avoiding standby power loss of the appliances. The measured standby energy losses over a week from the appliances include: 1.04 kWh for AC, 0.26 kWh for dishwasher, 0.11 kWh for TV, 0.1 kWh for washing machine and 0.04 kWh for lights. The calculated total weekly and monthly energy costs with the pricing plans considering both standby loss reduction and load shifting to off-peak hours are presented in Table IV. Finally, the percentages of monthly bill savings are calculated by comparing with base bill presented in Table III. Table IV shows that consumer can obtain maximum monthly cost saving with PS1 plan compare to other pricing plans.

TABLE IV. WEEKLY AND MONTHLY ENERGY COST WITH LOAD SHIFTING AND AVOIDING STANDBY LOSS

	Power Shift (PS1)		Smart Home (SM1)		Home Plan (HP1/base plan)	
	standby	off-peak	standby	off-peak	standby	Total
Weekly bill	$ 0.35	$ 18.13	$ 0.37	$ 19.22	$ 0.40	$19.7
Monthly bill	$ 1.48	$ 77.70	$ 1.60	$ 82.36	$ 1.73	$84.2
Monthly savings		+9.6%		+4.2%		+2.0%

V. CONCLUSION

In this study three electricity tariffs provided by Synergy in Western Australia have been evaluated on a typical residential consumer. Power Tracker smart load monitoring devices were installed across the household appliances to obtain daily and weekly consumption patterns. The results from the case study showed that the particular household is a high-energy user (73.94 kWh per week) and has high usage profiles during peak and shoulder periods compared to off-peak periods.

The calculated monthly electricity costs have been increased with both the TOU tariffs (PS1 and SM1) without load shifting, particularly with the SM1, the cost increased by 8.8% compared with the base tariff (Home Plan). While shifting washing machine and dishwasher to off-peak periods, the monthly electricity costs have been reduced by 7.9% and 2.3% with the PS1 and SM1 respectively.

The cost of energy increased by 2.4% with SM1, and decreased by 3.4% with PS1, when the loads are shifted in the shoulder periods. Finally, monthly cost savings increased significantly with PS1 (9.6%) and SM1 (4.2%) tariffs when both load shifting and standby power loss reduction were considered.

It can be recommended that the particular household is better off with the PS1 tariff due to achieved convincing costs savings on electricity bills. However, the PS1 tariff is currently no longer provided by Synergy for the residential sector. SM1 is the only TOU pricing option, currently provided by Synergy. The household also can achieve substantial cost savings with SM1 tariff by reducing peak electricity usages and standby power losses.

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