CHEMICAL ENGINEERING TRANSACTIONS
VOL. 61, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Petar S Varbanov, Rongxin Su, Hon Loong Lam, Xia Liu, Jiří J Klemeš

**ISBN** 978-88-95608-51-8; **ISSN** 2283-9216
DOI: 10.3303/CET1761184

# Modelling of End-use Electricity Consumption and Saving Potential in Household Sector in Northern Thailand

Kittikun Poolsawat[a], Wongkot Wongsapai[a,*], Watcharapong Tachajapong[a], Sukon Prasitwattanaseree[b]

[a]Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, 239 Suthep, Muang, Chiang Mai 50200, Thailand
[b]Department of Statistics, Faculty of Science, Chiang Mai University, 239 Suthep, Muang, Chiang Mai 50200, Thailand
wongkot@eng.cmu.ac.th

This study presents the actual state of electricity consumption in the household sector in northern region. The characteristics of household electricity consumption was considered to be an essential information for overview estimation of energy usage. The feasibility of energy conservation by improving end-use electricity energy efficiency was investigated. A questionnaire interview survey of 2,500 households concerning 36 kinds of appliances was conducted covering urban and rural areas in northern region in 2016 to identify the characteristics of household electricity consumption.
The survey covers three areas: (i) household characteristics, (ii) dwelling characteristics, and (iii) appliances. The survey results were extrapolating, by using the energy model which implies the majority of household electricity consumption in the area level, to estimate the whole electricity consumption for northern region.
The result overall electricity consumption in the household in northern region will be 5,604.10 GWh in the year 2016 shows with a make-up of refrigerator (32.10 %), air conditioner (18.04 %), light bulb (17.72 %), television (9.36 %), fan (7.63 %), rice cooker (5.19 %), iron (4.57 %), water heater (3.07 %) and washing machine (2.32 %). Around 16.14 % of electricity consumption, 847.24 GWh or 479.96 kt $CO_2$, could be reduced by means of replacement with higher efficiency appliances.
The electricity saving potentials are 65.23 % by changing fluorescent light bulb (FL) to Light Emitting Diode bulb (LED), 44.83 % by changing Cathode Ray Tube television (CRT) to LED television, 1.58 % for rice cooker, 1.53 % for iron, 1.03 % for washing machine, 0.78 % for water heater, 0.70 % for fan, 0.29 % for refrigerator and 0.23 % for air conditioner. The greenhouse gas mitigation from energy reduction potential including the policy recommendation are also raised.

## 1. Introduction

A growing of economic causes a continuous increase in people quality of life and electricity consumption in household sector in Thailand. A diffusion of appliance technologies during the past decade appliance to the increase in electricity usage inevitably. The household electricity consumption constituted 23.45% of total electricity consumption of Thailand (DEDE, 2015). The growth rate of electricity demand was moderate when compared with 10.00 % per year for China (Murata et al., 2008) and 6.70 % per year for Indonesia (Batih et al., 2016). According to the Provincial Electricity Authority (PEA) a growth rate of electricity demand in household in northern region was 6.46% per year increased from 16,844.52 GWh in 2005 to 41,288.71 GWh in 2015 (PEA, 2016).
The household electricity saving is thus important for sustainable development in Thailand. Therefore, survey of household was conducted by regularly to update the actual state of electricity consumption and assessing the trend of electricity demand. The electricity consumption characteristics of end-users was investigated to evaluate the potential for electricity saving by mean of improving the efficiency of the end-use appliances. The survey results revealed end-use appliances that have high electricity consumption and appropriate for introducing the more energy efficient technologies to replace conventional ones.

Please cite this article as: Poolsawat K., Wongsapai W., Tachajapong W., Prasitwattanaseree S., 2017, Modelling of end-use electricity consumption and saving potential in household sector in northern thailand, Chemical Engineering Transactions, 61, 1117-1122 DOI:10.3303/CET1761184

## 2. Methodology

### 2.1 Data collection

Northern region is the third most household in Thailand. It is covering 17 provinces have Chiang Mai, Lamphun, Lampang, Uttaradit, Phrae, Nan, Phayao, Chiang Rai, Mea Hong Son, Nakhon Sawan, Uthai Thani, Kamphaeng Phet, Tak, Sukhothai, Phitsanulok, Phichit and Phetchabun. As official statistics registration system in the 2016 conducted by Department of Provincial Administration (DOPA), the household of northern region was 4.46 million 31.65 % of households are in urban areas and 68.35 % in rural areas (DOPA, 2016). Since an energy conservation scheme in household sector needs the detailed data of electricity consumption characteristics, a survey was conducted to collect the data on characteristics of household electricity consumption. The details of the survey method were described below.

### 2.2 Selection of survey sites and the sample size

The method of stratified random sampling was used by classifying all samples into four stages with two stratums as follows: 1st stage including urban and rural area, 2nd stage - province with high and low levels of ratio household, 3rd stage - district with high and low levels of ratio household, and the last stage - local area with high and low levels of ratio household. In stratified random sampling, all members of population in each stratum are categorized into a homogenous group based on their similar characteristics defined by the purpose of samplings. Then the sample units were selected randomly with the proportional allocation in each stratum. There is certain parameter that need to be considered for the determination of sample size; i.e. type of variables to be measured, error estimation and estimation of variance. Cochran addressed two factors for error estimation: level of precision and level of confidence (Cochran, 1977). In this study, 5 % level of precision of estimated values was used, and a level of confidence of 95 % was selected for samples sizes determination in this study. Cochran (1977) showed that sampling size for discrete random variables can be represented by

$$n = \frac{z^2_{1-\frac{\alpha}{2}} \cdot (\sum_{h=1}^{L} W_h (P_h Q_h))}{e^2} \quad (1)$$

Where $z_{1-\frac{\alpha}{2}}$ is a standard normalized value which corresponds to the selected confidence level, $W_h$ is a weight of stratum $h$, $P_h$ is a proportion of interested outcome in stratum $h$ and $Q_h = 1 - P_h$, $e$ is a specified level of precision of the estimated true mean value which is normally specified as a percentage of the true mean of a population. The appropriate sample size was determined about 2,500 households, by using the proportion of gas consumption for cooking in urban and rural areas with 0.72 and 0.58 (NSO, 2010). The household sample were proportionally allocated into both stratums in each stage as shown in Table 1.

*Table 1: Sampling frame in this study by area of northern Thailand*

| Stratum area | $W_h$ | Households | Stratum province | $W_h'$ | Households | Provinces | $W_h''$ | Households |
|---|---|---|---|---|---|---|---|---|
| Urban | 0.32 | 800 | I | 0.66 | 526 | 01-Chiang Mai | 0.85 | 448 |
| | | | | | | 02-Uttaradit | 0.15 | 78 |
| | | | II | 0.34 | 274 | 03-Nan | 0.15 | 41 |
| | | | | | | 04-Phitsanulok | 0.44 | 120 |
| | | | | | | 05-Phetchabun | 0.41 | 113 |
| Rural | 0.68 | 1,700 | I | 0.50 | 850 | 01-Chiang Mai | 0.80 | 673 |
| | | | | | | 02-Uttaradit | 0.20 | 177 |
| | | | II | 0.50 | 850 | 03-Nan | 0.27 | 175 |
| | | | | | | 04-Phitsanulok | 0.36 | 328 |
| | | | | | | 05-Phetchabun | 0.38 | 347 |

### 2.3 Attribution of questionnaire and survey

The questionnaire was designed following the Northern Thailand Residential Energy Consumption Survey 2003. It covers three areas; i.e. household characteristics, dwelling characteristics, and energy consumption in electricity appliances. The survey was conducted by interviewing 2,500 respondents between May 2016 and August 2016. None of questionnaires was rejected.

### 2.4 Estimation electricity consumption

Electrical energy is generally used in household sector for lighting, cooking, entertainment, and other purposes. An annual electricity consumption for each appliance, E was estimated based on input power and average usage period per unit as (Meng, 2016)

$$E = \sum_{i=1}^{n} P_i \cdot N_i \cdot U_i \cdot F_i \quad (2)$$

where $P_i$ is a rated power of appliance (kW), $N_i$ is a number of appliances (unit), $U_i$ is a length of time in using an appliance (h/year), $F_i$ is a factor of appliance.
Since appliances are used for different purpose, such as air conditioner, fan, refrigerator, water heater and washing machine. The significant difference in electricity demand characteristics was observed so the factors; i.e. load factor, seasonal factor, and utilization factor were used to improve the accuracy of prediction according to usage behavior as follow;

### 2.5 Load factor

The load factor refers to a ratio of the actual power consumption to a nominal rated power consumption of an appliance due to the on/off cycle behavior of operations. It was used to estimate the actual electricity consumption for air conditioner, fan, refrigerator, water heater and washing machine in which the actual power consumptions are less than it is rated power consumption due to them on/off cycle operations. The load factors for air conditioner, fan, refrigerator, water heater and washing machine were assumed to be 0.75, 0.70, 0.45, 0.60 and 0.55 (Meng, 2016).

#### 2.4.1 Seasonal factor

The seasonal factor refers to a ratio of the actual power consumption to a nominal rated power consumption of an appliance due to non-usage in particular season. It was used to estimate the actual electricity consumption for water heaters and air conditioners because they are inactive during winter and summer. The seasonal factors were average value from survey to be 0.83 for air conditioners and water heaters.

#### 2.4.2 Utilization factor

The utilization factor refers to a ratio of the actual power consumption to a nominal rated power consumption of an appliance due to hanging out, business trip, and weekend excursion. It was used to estimate the actual electricity consumption for all appliances and average value from survey was 0.70 for all appliances.

## 3. Result

### 3.1 Household characteristics

There were 4.46 million households in the northern region. Average size of household was 3.64 persons per 1 household which was more than the average size of the previous census round in the year 2010 in which the average size was 3.00 persons per 1 household. Most household heads, which was 60.25 % of total household heads (NSO, 2010), were males as shown in Table 2.

*Table 2: Number and size of household, percentage of household head by area*

| Household characteristics | Total | Area | |
|---|---|---|---|
| | | Urban | Rural |
| Number of households | 4,467,077 | 1,413,774 | 3,053,303 |
| Average size of household | 3.64 | 3.56 | 3.68 |
| Household with female household head (%) | 39.75 | 43.61 | 37.93 |

### 3.2 Dwelling characteristics

About 93.67 % of households in the northern region are detached houses, followed by 3.5 % of row house, and 1.89 % of town house duplex and town home. There is row house in urban area more than those in rural area 6.80 % and 1.72 %. And town house duplex and town home in urban area is higher proportion than rural area 4.49 % and 0.67 %. And condominium apartment and flat in urban area more than those in rural area 2.11 % and 0.62 %. Data is shown in Table 3. Considering the electricity consumption, it was found that in the Northern, detached house is the most average electricity consumption per household of about 1,212

kWh/household-year or 101 kWh/household-month. Average electricity consumption per household is shown in Figure 1.

*Table 3: Number and percentage of dwelling characteristics by area*

| Dwelling characteristics | Total | | Area | |
|---|---|---|---|---|
| | Number | % | Urban | Rural |
| Type of living quarters | 4,467,077 | 100.00 | 100.00 | 100.00 |
| Detached house | 4,184,159 | 93.67 | 86.60 | 96.99 |
| Town house, duplex, and town home | 84,524 | 1.89 | 4.49 | 0.67 |
| Condominium, apartment, and flat | 48,888 | 1.09 | 2.11 | 0.62 |
| Row house | 149,506 | 3.35 | 6.80 | 1.72 |

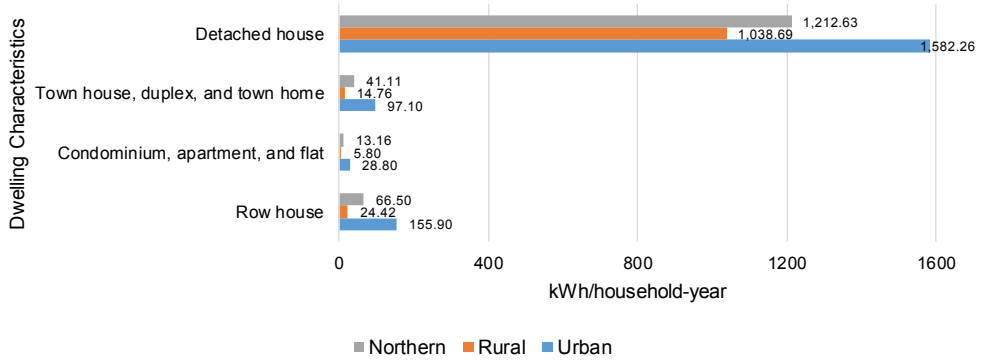


*Figure 1: Average electricity consumption by dwelling characteristics in northern Thailand*

### 3.3 Electricity consumption

By extrapolating the survey results from 2,500 households to estimate the whole 4.46 million households in the year 2016, it was found that electricity consumption in northern region was 5,604.10 GWh, which was higher than 5,542.34 GWh of PEA (PEA, 2016). To determine the potential of saving, we investigated the appliances which consumed electricity more than 2 % of total electricity consumption in northern. The total of 9 appliances were found to consume energy substantially; i.e. refrigerator, air conditioner, light bulb, television, fan, rice cooker, iron, water heater and washing machine. They consumed energy 1,684.47 GWh, 947.00 GWh, 930.27 GWh, 491.10 GWh, 400.61 GWh, 272.56 GWh, 239.79 GWh, 160.97 GWh, and 121.59 GWh, consumption of appliances is shown in Figure 2. And proportion of average electricity consumption on appliances per household is shown in Figure 3.

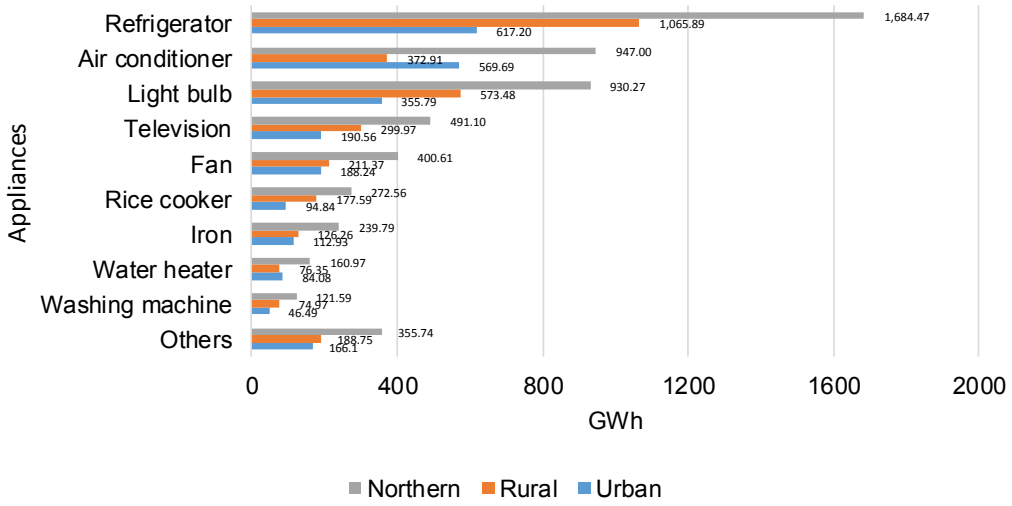


*Figure 2: Profile of electricity consumption in appliances in northern Thailand*

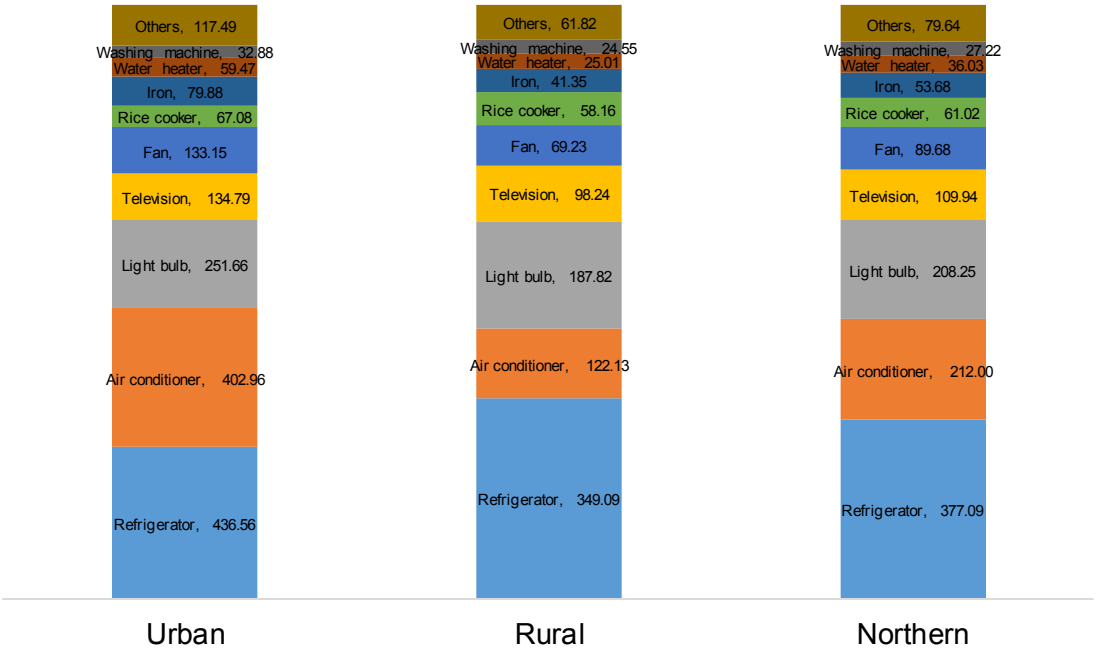


*Figure 3: Proportion of average electricity consumption per household in appliances by area in northern Thailand*

### 3.4 Saving potential

The result shows that refrigerators, air conditioning unit, light bulb, television, fan, rice cooker, iron, water heater, and washing machine are appliances that have the highest potentials for electrical energy saving. The overall energy consumption will be 5,604.10 GWh in the year 2016. Around 16.14 % of energy reduction potential or 847.24 GWh could be achieved by means of replacement with higher efficiency for these four end-use appliances as shown in Table 4. The energy saving potential for changing CFL lamps to LED, CRT to LED television, low to high energy efficiency rice cooker, and low to high efficiency iron were 65.23 %, 44.83 %, 1.58%, and 1.53%.

*Table 4: Electricity consumption and saving potential by appliances*

| Appliances | Electricity Consumption | | Policy | Saving Potential | | | |
|---|---|---|---|---|---|---|---|
| | | | | Total | | Urban | Rural |
| | GWh | % | | GWh | % (reduction) | % | % |
| Total | 5,248.36 | 100.00 | | 847.24 | 16.14 | 46.12 | 53.88 |
| Refrigerator | 1,684.47 | 32.10 | Energy label | 4.82 | 0.29 | 38.13 | 61.87 |
| Air conditioner | 947.00 | 18.04 | Energy label | 2.18 | 0.23 | 74.65 | 25.35 |
| Light bulb | 930.27 | 17.72 | FL to LED | 606.79 | 65.23 | 37.71 | 62.29 |
| Television | 491.10 | 9.36 | CRT to LED | 220.16 | 44.83 | 37.36 | 62.64 |
| Fan | 400.61 | 7.63 | Energy label | 2.81 | 0.70 | 50.36 | 49.64 |
| Rice cooker | 272.56 | 5.19 | Energy label | 4.32 | 1.58 | 33.95 | 66.05 |
| Iron | 239.79 | 4.57 | Energy label | 3.66 | 1.53 | 48.49 | 51.51 |
| Water heater | 160.97 | 3.07 | Energy label | 1.25 | 0.78 | 50.40 | 49.60 |
| Washing machine | 121.59 | 2.32 | Energy label | 1.25 | 1.03 | 44.00 | 56.00 |

## 4. Discussion

### 4.1 Environmental impact

Saving of potential is 847.24 GWh of energy reduction potential and greenhouse gas mitigation of 479.96 $ktCO_2$ by using the grid emission factor of 0.5665 $tCO_2$/MWh (EGAT, 2016) as shown in Table 5. This target of Thailand NAMAs based on Energy Efficiency Development Plan (EEDP) need Carbon dioxide ($CO_2$) reduction

5,909 kt $CO_2$ in 2020 (Wongsapai, 2017). Reduction potential in study can be decrease target on plan around 12.31 %.

*Table 5: Energy reduction potential greenhouse gas mitigation by appliances*

| Appliances | Saving potential GWh | Reduction Potential t $CO_2$ |
|---|---|---|
| Total | 847.24 | 479,961.46 |
| Refrigerator | 4.82 | 2,730.53 |
| Air conditioner | 2.18 | 1,234.97 |
| Light bulb | 606.79 | 343,746.54 |
| Television | 220.16 | 124,720.64 |
| Fan | 2.81 | 1,591.87 |
| Rice cooker | 4.32 | 2,447.28 |
| Iron | 3.66 | 2,073.39 |
| Water heater | 1.25 | 708.13 |
| Washing machine | 1.25 | 3.13 |

## 5. Conclusions

Priority to improve the efficiency of lighting bulb, television, refrigerator and rice cooker have to be considered, because of their high rated electricity consumption and in the long term. In the short term, the government should focus on the implementation of LED lighting as the first priority for rural area, as their investment cost is the most effective and due to a large amount of deployment among poor peoples.

**Acknowledgments**

The authors would like to thank the Energy Conservation Promotion Fund and Energy Policy and Planning Office (EPPO) for all funding and support. We remain culpable for any remaining errors.

**References**

Batih H., Sorapipatana C., 2016, Characteristics of urban household's electrical energy consumption in Indonesia and its saving Potentials, Renewable and Sustainable Energy Reviews 57, 1160-1173.

Cochran W.G., 1977, Sampling Techniques 3rd edition, John Wiley & Sons, New York.

DEDE, 2015, Energy Balance of Thailand 2015, Department of Alternative Energy Development and Efficiency,Bangkok.<www.dede.go.th/download/state_59/Energy%20Balance%20of%20Thailand2015.pd> accessed 10.02.2016.

DOPA, 2016, Official Statistics Registration System, Department of Provincial Administration, Bangkok. <stat.dopa.go.th/stat/statnew/upstat_age.php> accessed 05.02.2016.

EGAT, 2016, Grid Emission Factor from Power Sector 2016, Electricity Generating Authority of Thailand, Bangkok.

Meng L.S., 2016, Meeting on Household Energy Consumption Survey in Northern Area, Economic Research Institute for ASEAN, Jakarta, Indonesia.

Murata A., Kondou Y., Hailin M., Weisheng Z., 2008, Electricity demand in the Chinese urban household sector, Applied Energy 85, 1113-1125.

NSO, 2010, The 2010 Population and Housing Census in Northern Region, National Statistical Office, Bangkok. <popcensus.nso.go.th/report/Northern_T.pdf> accessed 07.02.2016.

PEA, 2016, Electricity Consumption 2005-2015 Monthly Data, Confidential Report, Personal Communication.

Wongsapai W., Bunchuaidee R., Wayuparb N., Ritkrerkkrai C., 2017, Policy-basd Greenhouse Gas Mitigation Tracking and Institutional Framework Development under Thailand's NAMAs in Energy Sector, Chemical Engineering Transactions 56, 295-300.