DEVELOPMENT OF A HOUSEHOLD ENERGY CONSUMPTION MODEL FOR MEGACITIES IN ASIA

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Abstract. We develop model of household energy consumption based on in-home and out-home activities. The model has been estimated by using data collected via household survey conducted in four megacities in Asia, Tokyo, Beijing, Jakarta and Dhaka in 2009. A structural equation model was applied to evaluate cause-effect relationships among factors in the determining household energy consumption level. Socio economic, home physics, life-style play significant role in the determining of household energy consumption related to in-home activities. By comparing household energy consumption among cities, seasonal variations observed clearly in Tokyo. In the case of Jakarta, household energy consumption mostly affects by household socio economic conditions. Furthermore, household electronic home appliance ownership and the usage behavior influenced the energy consumption at all cities. Household vehicle fuel consumption mostly dominated by the use of cars in Jakarta city. Model shows positive influence of vehicle fuel consumption on in-home energy consumptions.

Keywords –household energy consumption, structural equation model,

1. Introduction

Understanding household energy usage in-home and out-of-home is vital for the planning of energy consumption and conservation. Household are an important group when addressing energy conservation (R.M.J Benders, 2006). Many researchers pointed out that changing life style is important to reduce the energy consumption (S Kondo, 2007). However, life style has a large variety across nation/region, culture and climate. Domestic energy consumption differs depending on the behaviors after meal, bathing habit, staying or not staying home during daytime etc (Tanaka, 2006). It is important to focusing on the time use and household behavior in home and out home activities.

Common sense and score studies from around the world suggest that a few key factors have dominant impact on the amount of household energy consumption which includes income, residential size, household size, prices of energy and efficiency-use of equipments (leach, 1987). Energy in the home is determined by the technical and architectural characteristics of the house and its heating/cooling system, on one hand and the behavior of the resident, on the other hand (Raaij, 1983). The technical-architectural characteristic will determine in-home energy saving. Other relevant house characteristics are the number of rooms in use, orientation towards sun and wind (ventilation). The other factor, household behavior in purchase-maintenance and usage-related energy behavior determine the energy use in the home (Raaij & Verhallen, 1983). The purchase-related behaviors refer to owning of home appliances which consume energy. Most of researcher neglected maintenance and operational behavior. Usage-related behavior includes the behavior of setting thermostats, frequency and period to use the home appliances etc.

Household energy usage for out-of-home activities closed-related to the vehicle`s fuel/energy consumptions. The annual vehicular fuel consumption of households is clearly the outcome of complex decision that involve the number of vehicles the household own, the makes, model and vintages, allocation of vehicles and activities among drivers, and choice of activity sites, modes of transportation, and the chaining and combining of activities (T.F Golob, 2005). In the city level, urban density is found to affect fuel consumption, mostly through variations in the vehicle stock and in the distances travelled, rather than through fuel consumption per kilometer (vehicle technology) (N Karathodorou, 2010).

Up to now, disaggregate analysis of in-home and out-of-home activity has been mainly used to measure household energy consumption. Portinga (2004) proposed two regression analysis in which home and transport energy used were analyze separately use the same independent variables of household socio-demographic variables. Another study linked between life-styles and energy use as influenced by time use and allocation in-home and out-of-home (Schipper, 1989). However, the approach based on the interdependency of household in-home and out-of-home activities neglected in almost recent studies. To overcome the aforementioned problems, we proposed to measure the cause-effect relationship household activities in-home and out-of-home simultaneously to capture total household energy consumption. This paper attempts to provide additional evidences that further support the idea by using the data collected in Tokyo, Beijing, Jakarta and Dhaka. Furthermore, the second objective of this study is to develop household energy consumption model towards the preservation policies on conservation of energy.

2. Modeling Framework

To realize the above-mentioned in-home and out-of home energy consumptions and its cause-effects relationships, this paper attempts to establish a structural equation model (SEM) to capture the complex cause-effect relationships exiting in the framework of household home-appliance ownership behavior which integrated with household vehicle ownership and its usage behavior (Zhang, 2009) (Figure 1).

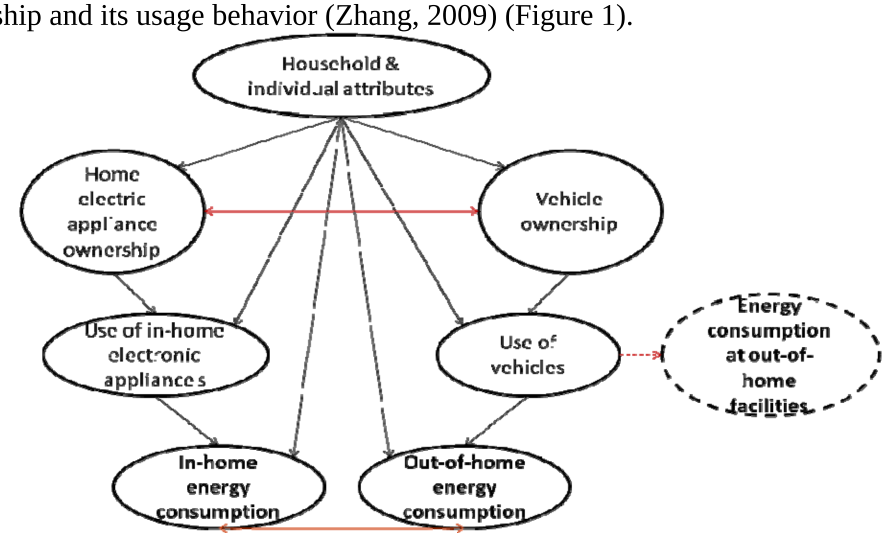

Figure 1. Household Energy Consumption

Methodologically, the SEM plays many roles, including simultaneous equation systems, linear causal analysis, path analysis, structural equation models, dependence analysis, and cross-legged panel correlation technique (Jöreskog and Sörbom, 1989). SEM is used to specify the phenomenon under study in terms of putative cause-effect variables and their indicators. Latent variables will be used to specify the social capacity and its influential factors. The full model structure can be summarized as follows:

Structural Equation Model:

$$\boldsymbol{\eta} = \boldsymbol{B\eta} + \boldsymbol{\Gamma\xi} + \boldsymbol{\zeta} \tag{1}$$

Measurement Model for y:

$$\boldsymbol{y} = \boldsymbol{\Lambda_y \eta} + \boldsymbol{\varepsilon} \tag{2}$$

Measurement Model for x:

$$\boldsymbol{x} = \boldsymbol{\Lambda_x \xi} + \boldsymbol{\delta} \tag{3}$$

Here, $\boldsymbol{\eta'} = (\eta_1, \eta_2, ..., \eta_m)$ and $\boldsymbol{\xi'} = (\xi_1, \xi_2, ..., \xi_m)$ are latent dependent and independent variables, respectively. Vectors η and ξ are not observed, but instead $\boldsymbol{y'} = (y_1, y_2, ..., y_p)$ and $\boldsymbol{x'} = (x_1, x_2, ..., x_q)$ are observed dependent and independent variables. $\boldsymbol{\zeta, \varepsilon, \delta}$ are the vectors of error terms, and $B, \Gamma, \Lambda_x, \Lambda_y$ are the unknown parameters.

In this study, we focus on the household home-appliances ownership and its usage as the influential factors for in-home energy consumption. As for the out-of-home fuel consumption, we focus on the fuel consumed by car and motorcycle owned and used by households. We also consider the household socio-economic factors, household attributes and architecture of household as the other common factors influence on the ownership. Related to the usage behavior of home appliance, we use several parameters such as the frequency of use, thermostat setting, and how long they usually used the appliances. The vehicular fuel consumption of households is hypothetically assumed as the outcome of allocation of vehicles and modes of transportation, and average time for commuting trip.

3. Data

3.1 Study Locations

A questionnaire survey about household energy consumption was conducted in Tokyo through web-survey and a face-to-face interview survey in Beijing, Jakarta and Dhaka metropolitan area in 2009. The questionnaire items include: 1) personal attributes such as age, gender, occupation, academic background, income, household member, type of home, family type, home architecture, living period, the area of the house, commuting behavior and commuting trip time; 2) households ownership of home appliance and the way how to use it every day; 3) vehicle ownership and its usage behavior; and 4) household energy consumption for the electricity, gas, water and other fossil fuels . In some questions we provide the choice sets but the other questionnaires filled with count data. Total valid samples are 1194 households in Tokyo, 1014 samples in Beijing, 1009 samples in Jakarta and 1500 samples in Dhaka.

Figure 2 Study Locations

Household size in Tokyo was observed less than 4 members in households, and in case of Bejing, the number of member in households less than 3 persons. We found various households members from 2 – 6 persons in both Jakarta and Dhaka cities (Figure 3a). Most of house in Jakarta are private owned house (nearly 80%). In contrast with Dhaka, more than 60 % are rental house/apartment. Various type of house observed in Tokyo and Beijing. In Tokyo we found an almost equal composition of private owned house, private apartment and rental house/apartment. On the other hand, private-owned house is very small in Beijing but company-owned apartment give a big share (Figure 3b). Reinforce concrete type of architecture is dominant in Tokyo (55.3%) follows by wooden (32.7%) and still frame (11.5%) houses. Reinforce concrete and brick were dominant in Beijing (60% and 37.7%). Most of house in Jakarta was made by Brick (59.8%) and reinforce concrete (38.1%). In Dhaka, most of house was made from reinforced concrete (42.0%), bricks (42.6%) and other (42.6%) respectively. People in Tokyo used train or walking for their commuting trips. Dhaka's people walk to their office/school and ride a bus. In Beijing, people went to their office/school by bicycle, car and bus. Motorcycle and car was carried out almost 54% of commuters in Jakarta city follows by taxi car (18.8%) and bus (16.6%) (figure 3d).

There are various situations observed for household home-appliance and vehicle ownership in those cities. Refrigerator, air conditioning and washing machine are owned by almost all respondents in Tokyo. In contrast, respondents in Dhaka only owned electric fan in their household. Electric fan was also popular among respondents in Jakarta due to the weather conditions and lower operational cost (Figure 4a). The highest car ownership observed in Tokyo (> 50%) follows by Beijing and Jakarta. More than 60% of respondent has motorcycle in Jakarta city. The ownership of car, motorcycle and bicycle in Dhaka was very low compare to other three cities (Figure 4b).

The seasonal variations of household electricity consumption consumptions observed clearly in Tokyo. Electricity consumption will increase drastically in winter and summer due to the weather condition. But, we couldn't find similar situation in Beijing although people in Beijing may face the similar weather conditions. Gas consumption also similar whole year in Beijing although highest gas stove ownership found in Beijing. Seasonal variation of household energy consumption couldn’t observe in Jakarta and Dhaka (Figure 5a and 5b).

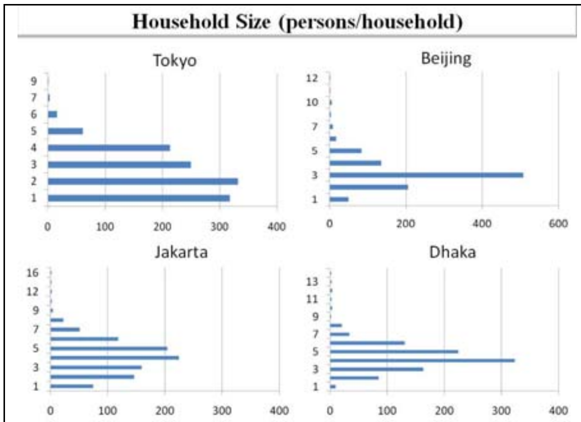

Figure 3a Household Size

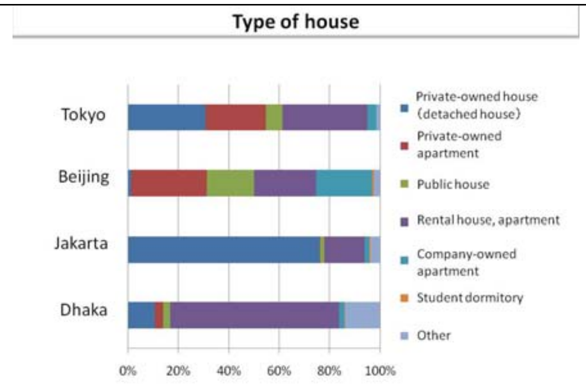

Figure 3b Type of house

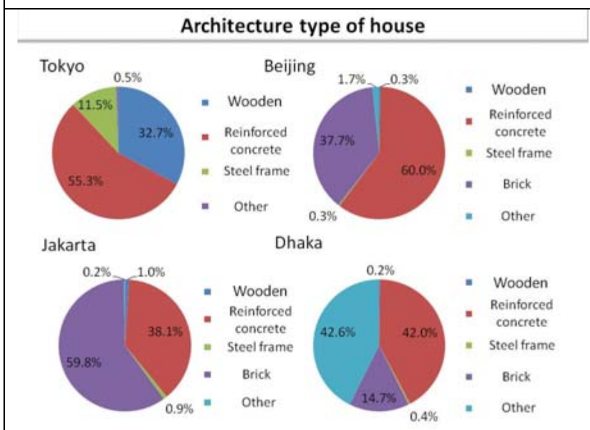

Figure 3c Architecture type of house

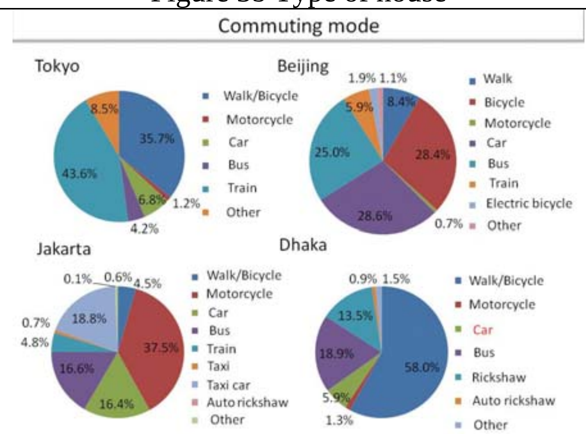

Figure 3d Commuting mode

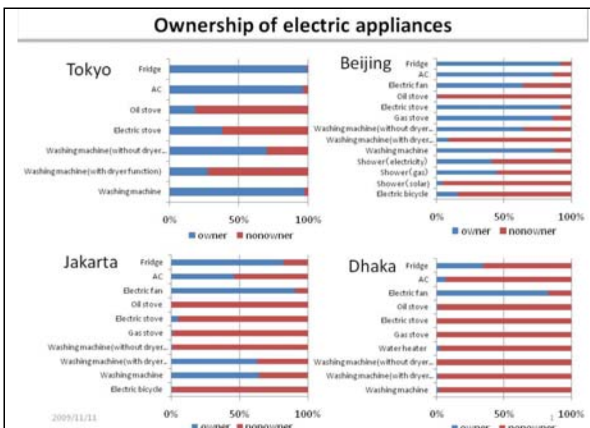

Figure 4a Ownership of home-appliances

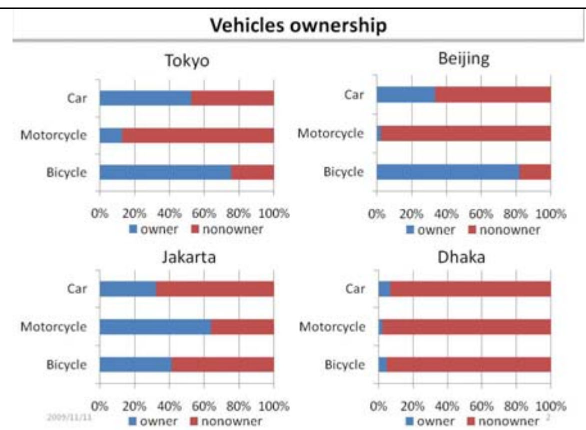

Figure 4b Ownership of vehicles

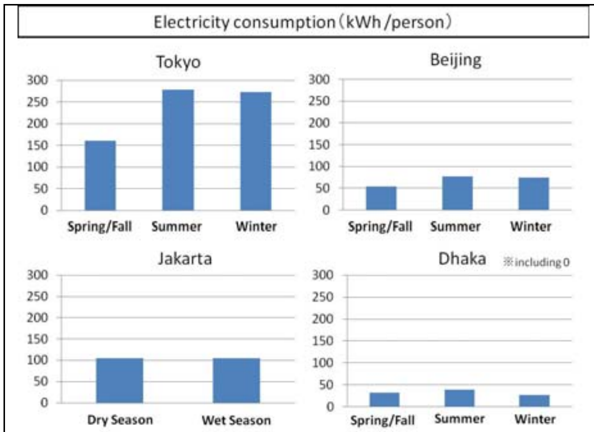

Figure 5a Household Electricity Consumption

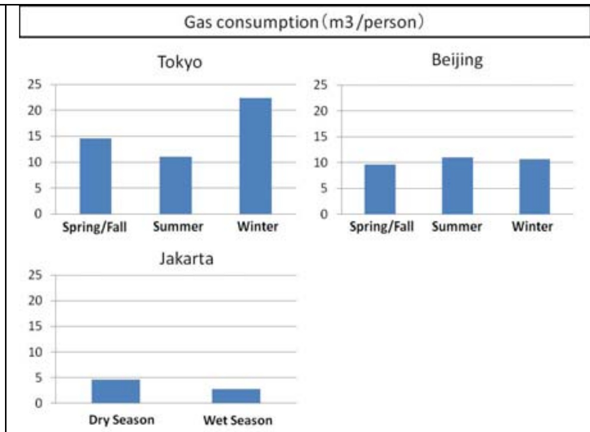

Figure 5b Gas Consumption

4. Model Estimation and Evaluation of Household Energy Consumption

To observed cause-effect relationships between in-home and out-of-home energy consumption, we propose a structural equation model which consist the following ten latent variables “household socio-economic”, “home-physics”, “household attributes”, “vehicle ownership”, “vehicle usage”, “refrigerator ownership”, “ownership of air condition”, “AC usage”, “in-home energy” and “out-of-home energy” in our model. Latent variable household socio-economic consist of parameter household income, household member and household family type. Household area, architecture type and housing types used to build the latent variables of home physics. Respondent’s age and education level used to represent the latent variables of household attributes. Number of car and motor cycle owned by household, car and motorcycle age (model year) includes the latent variables of vehicle ownership. Latent variables refrigerator consist of number of refrigerator owned, model year and its capacity. To build the latent variables of AC ownership, we use air conditioner density (total number of ac owned multiply with its capacity divided by housing area) and model year of AC. Related to AC use behavior, we use the total hour of air condition usage in a day and thermostat setting refers to average ambient temperature. Frequency use of motorcycle and car in one month and also average travel time parameter used to develop latent variable vehicle usage. In this paper, we only used data observed in Jakarta city and estimated the model by using AMOS for dry and wet season.

Observing the model accuracy indices (i.e., GFI and AGFI), the model for the Dry season shows GFI (AGFI) value is around 0.669 (0.593) and 0.666 (0.588) for Wet season. Due to minor seasonal variation of household in-home energy consumption observed in Jakarta, this estimation results was acceptable. Based on the calculated GFI and AGFI values, the established model cannot statistically be rejected. Comparing the models, it is clear that the model for Dry season better than Wet season. All estimated parameters are significant for both models. Household socio-economic and home physics gave negative influence for all latent variables of ownership (refrigerator, AC and Vehicle). In contrast, household attributes (age and education level) positively influence on the vehicle usage and ownership of refrigerator. It becomes negative on the influence to the usage behavior of air conditioner. Elder people and well educated respondents less to use Air Conditioner in the house and also set the thermostat nearly to the atmospheric temperature. In-home energy consumption positively affected by the usage of air conditioner. It was similar to the total fuel consumption which mostly affected by frequency to use car, motorcycle and average travel time. Out-of-home energy consumption also gave positive influence on in-home energy consumption.

Looking at the standardized total effects, household socio-economic gives more influence on car fuel consumption per week, electricity and liquid/natural gas consumption higher compare to the estimation results for motorcycle fuel consumption per week and kerosene consumption. Home physics also mostly influenced on in-home energy consumption rather than gas or kerosene consumption. We also found, the frequency use of car strongly affected by household socio-economic.

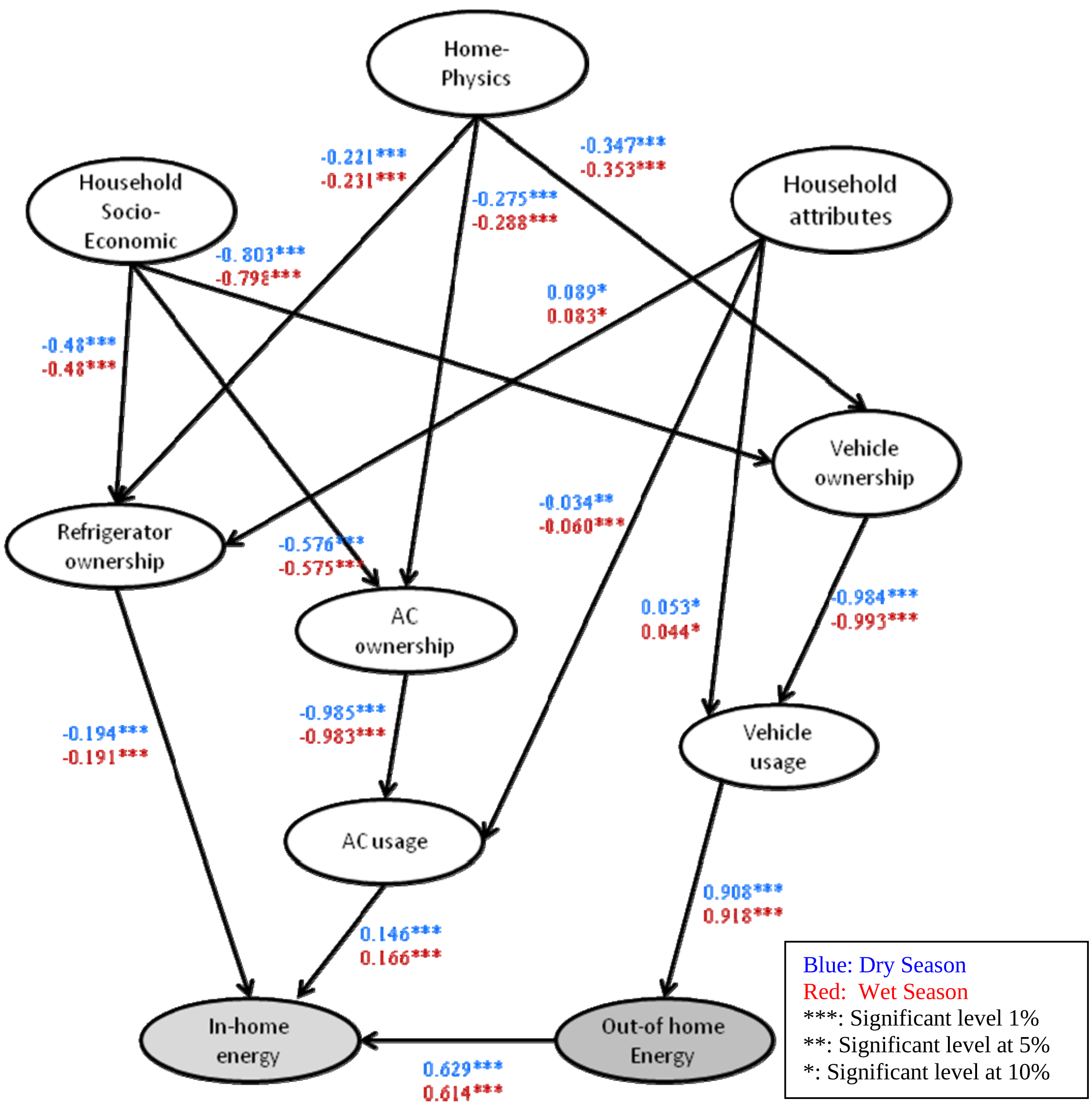

Figure 4. Model for Household Energy Consumption in Jakarta City

5. Conclusion

Using data collected from survey in Tokyo, Beijing, Jakarta and Dhaka metropolitan area, we successful capture the household energy consumption patterns. Seasonal variations of in-home energy consumption observed clearly in Tokyo. In contrast, we couldn't observe in Beijing, Jakarta and Dhaka. Variability of home appliance ownerships and home physics conditions across cities. It is found in Jakarta city, household socio-economic conditions have dominant impact on in-home energy consumption follows by home physics. But, we couldn't neglect the usage behavior especially for air conditioner in Jakarta city. It was proven in our model, period to use air conditioner in a day and thermostat setting positively influence on the household electricity consumption. Household socio-economic conditions also have dominant impact on frequency use of car and then it will influence on total car's fuel consumption. In this model, we found positively influence of vehicle fuel consumption on in-home energy consumption. However, we couldn't found seasonal variation of the estimation results in Jakarta city. It is also necessary to apply this model to other cities to get more evidence on the estimation results and also spatial and temporal variability.

6. Acknowledgements

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