The Simulation of Demand Side Energy Consumption for Households Based on the Agent-Based Modeling

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Keywords： Agent-based modeling, Energy management, Electric consumption simulation

1. INTRODUCTION

After Fukushima crisis, Japan cut down the nuclear energy. As a result, the carbon emission in the 2012 increased by 9% compared with 1990(Ministry of the Environment, 2015). Recently more attention have been gained for the risk of nuclear power because of the nuclear accident, which make solar power energy to play a more and more important role as renewable energy source than before. However, the use of renewable energy in demand side may cause difficult problems in the balance between electricity supply and demand. Therefore, Energy management systems based on different technology and method are constantly being proposed during recent years. The technology for home energy management in the most efficient way with the network is known as Home Energy Management System (HEMS), which allows connecting home appliances to the network for remote management based on the combination of the source network and Internet as saving system in real time. To improve the efficiency of energy use and meanwhile keep the balance between supply and demand side, HEMS is required to be able to well schedule the energy use for households. In this case, the simulation of demand side energy consumption becomes a prerequisite for household energy management.

In this paper, firstly, we attempt to propose a framework of energy management system for different households in one community; and then we explain the necessity of household energy consumption simulation for the framework. Afterwards, we perform a simulation of household energy consumption by a model developed on AnyLogic platform. By analyzing the load trend showed in result, the household pattern is recognized. Finally, according to the analysis of preliminary result, the direction of further revision for the model and the capacity of AnyLogic serving as developing platform for the simulation model of proposed framework will be discussed.

2. FRAMEWORK

2.1. Modeling Considerations for Energy Management Systems of Households

In Recent years, an increment in the research woks about household energy management models has presented. Dittawit K and Aagesen FA presented a project called Power Matching City with 22 households equipped with heating systems and home appliances as dish washers and washing machines. The objective was to observe the electricity supply and demand in the network, based on market mechanisms, as well as time usage of home appliances. Some houses had photovoltaic energy and others wind energy. The software is based on an agent of algorithms called 'Power Matcher' that aims to enable the economically optimum operation of the device within the conditions established by the end user (Dittawit K Aagesen FA, 2013). On the other hand, the Agent-Based Home Energy Management System, integrates smart metering technologies, preferred users configuration and flexibility, use of external signals as the price for residential energy optimization, network loads and changes in the energy market. Energy management in real time is achieved through the interaction of smart meters with the network (via prices or market incentives), and with Home Energy Management Systems (Asare-Bediako B, 2013). Yu Z developed a dynamic optimization model for stochastic thermal conditions in loads of different features, and a predictive model. The optimization is subject to the power, cost and thermal dynamics, and operates on multiple time scales: detection, control and parameter estimation. On and off control units were implemented. Three types of controllable loads: Dynamic load, interruptible load, and non-interruptible load are considered. The possibility of integrating renewable resources such as solar panels is also considered. The System has a control center that receives information through interruption or control signals with sensors. Consumers take control decisions in real-time about

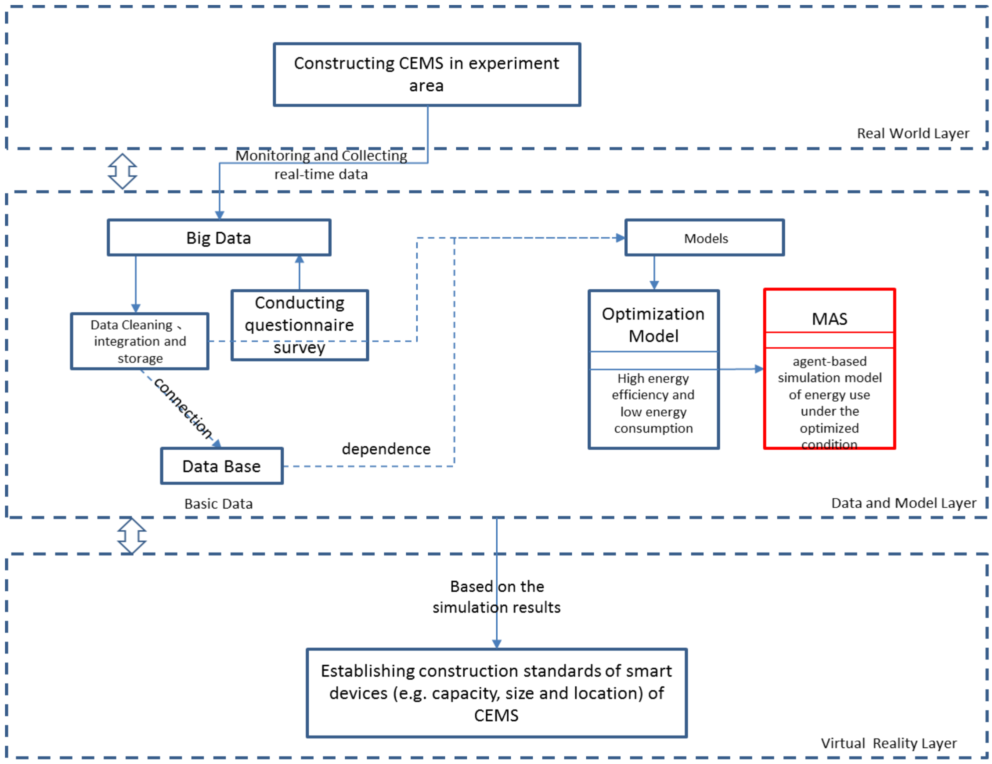

Figure-1. The Framework of Community Energy Management System

energy usage (Yu Z, 2013).

A conclusion can be drawn that the simulation of household energy consumption is a prerequisite of demand side energy management. Further, it's also an indispensable process for the research of residential energy optimization. However, the previous researches rarely consider the difference of household including the member composition, living conditions and lifestyle while simulating the household energy consumption. Besides, the energy management in urban community scale is also barely discussed due to the behavior of households with different types differs obviously which takes a difficulty for the simulation.

2.2. Proposed Framework for Energy Management for Households

The purpose of our framework focuses on not only individual household but also the energy management of different types of household in one community. It's designed for energy saving that contributes to CO_2 reduction of emission in urban area. In a sense, the proposed framework belongs to the concept of community energy management system (CEMS) and it mainly deepens the concept of energy management among the families, while the energy management inside the community is achieved based on the data of individual households' energy consumption. By HEMS, users can know actual energy consumption of each appliance (where), at any time (when) and the corresponding expense (how much) in detail. Thus, control function of all the various household appliances can be integrated in a remote monitoring system.

In this framework, we make an assumption that energy use behaviors of households will change by using HEMS, and this change will help to save energy, reduce carbon emission, and save cost for electricity. A possible way of integrating CEMS and HEMS in experiment communities is also presented in the framework.

Our work involves following technical approaches:

1) Constructing an energy management platform integrated CEMS with HEMS for promoting energy efficiency in both community and household level. Further, platform operation and maintenance programs (including data source, regulatory maintenance department and application guidance) will be proposed.

2) Taking real-time monitoring of smart devices for cleaning, integration, storage management of energy consumption data collected by data management system during a long period at the levels of building and community.

3) Conducting questionnaire survey to households in community for energy use patterns according to residents' behaviors.

4) Optimizing energy use under the conditions of high energy efficiency and low energy consumption in community based on residents' behaviors identified from questionnaires and big data using smart devices, and developing agent-based simulation model of energy use in entire community under optimized condition. (Agent stands for household).

5) Establishing construction standards of smart devices using intelligent hardware (e.g., capacity, size and location) of energy management based on the simulation results. In order to meet the conditions of high energy efficiency and low energy consumption, reasonable allocation for smart devices, and demand based on energy consumption data and

questionnaires can be used to validate the simulation model for verifying construction standards.

3. THE SIMULATION OF DEMAND SIDE ENERGY CONSUMPTION BY ANYLOGIC MODELING

3.1. The simulation of demand side energy consumption

Demand side energy consumption refers to the energy consuming behavior of all the factors in the demand side including industrial, commercial and residential factors. The most important work of energy management system can be simply described as scheduling which kind of electricity (from general grid, generated by PV or discharge from battery) should be use in what time to satisfy the need of demand side. That means the process highly depend on the precise prediction of the value of demand side energy consumption. Thus, it is obvious that the simulation of demand side energy consumption is a prerequisite for realizing the framework. What's more, because the proposed framework in this research is for residential area and the most important factor of residential area is household, the simulation of demand side energy consumption in this paper is focus on the residential households. And the target of the simulation is predicting the value of household energy consumption.

3.2 Agent based modeling of household energy consumption

The traditional method used for the flow calculation of electrical network is based on static power flow calculations. These require the computation of a steady state of the network, and have to be rerun each time a change occurs if a continuous simulation wants to be executed. This can lay to a large number of re-calculations, leading to redundant steps, when only small changes affect small parts of the network. Implementing an agent based approach could try to solve these issues by providing more flexible and dynamic algorithms and through the combination of traditional and agent based modeling techniques.

In the authors' opinion, agent based modeling is especially well suited to cope with all difficulties one finds trying to obtain a dynamic model of the energy consumption. The proposed model use the three central ideas of this paradigm: agents to represent households, the environment object to represent in space and time the geographic area where the power lines are wired, and then single rules are bring up to each agent in order to induce the necessary complexity to the model. Then, emergent properties of the model will represent the energy consumption behavior.

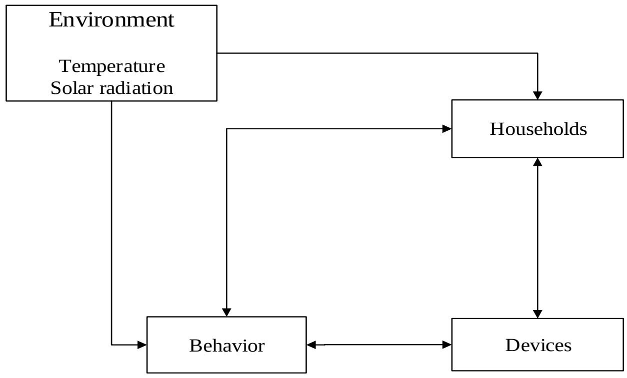

Figure-2.Interactions between environment, households and devices

3.3 The simulation of energy consumption for household

In this research, the authors use a model developed based on computational hybrid method and agent-based simulation approach to make a primary simulation of household energy consumption. The model is developed on the AnyLogic platform, although the model is just an initial one, the authors conducted a simple simulation of household energy consumption and tried to make an exposition to the preliminary result. Further, according to the result, the further revision for the model and the capability of AnyLogic platform for developing simulating model of demand side energy management will be discussed.

The interface of the model consists of 2 parts: main dash board and household interior. The number of households should be set in the beginning of the simulation. Then, the corresponding icon of households will generate in the main dashboard. During the simulation, the state of total energy consumption in whole community is monitored, and the system capacity which is the controlling condition of energy consumption can be adjusted at any time in the main dashboard. The electric consumption level of each household is presented by different colors in the main dashboard while the current load is shown simultaneously. By clicking the icons, users can get into the interior of household where the detail of household energy consumption is presented. For instance, users can understand the layout while also observe the operating status of appliances inside the house. Besides, the energy consumption of the selected household is also presented in the household interior as showed in figure-3. For each individual household, the interior layout can be preset and generally consist of several parts including bedroom, bathroom living area, kitchen and common room. What's more, the number and location of appliances can be also set manually according to the different conditions.

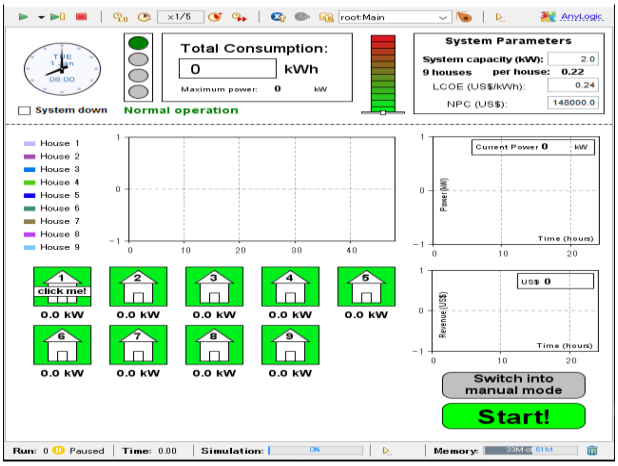

Figure-3. Main dashboard interface

1) Load modeling: The modeling of loads can be a quite complex issue. The behavior of a load mainly relies on the electrical energy consumption created by an appliance. Considering a load in the traditional, electrical engineering sense, a single impedance with some fixed characteristics is meant. But regarding energy consumption, the connected loads normally will be households or some other complex consumers that consist of a large number of appliances that create an aggregated energy demand. In present version of the model, the following appliances are considered: lighting bulb (LED bulb, CFL bulb and Incandescent bulb), radio, TV, Computer, Fridge, washing machine, and phone charger. The model will simulate the operation of the appliances based on the possible behavior and position of the household members at that time point.

2) Energy consumption control condition: In the present version, the main control condition of energy consumption for the model is electricity peak. In beginning of the simulation, the tolerable total load of all households should be set as the limitation factor. Thus, during the simulation, if the total load is close to or exceed the set value, the system will determine there is high risk that Electric Peak happens and start a countdown to stop the simulation. The controlling process is shown in figure-4.

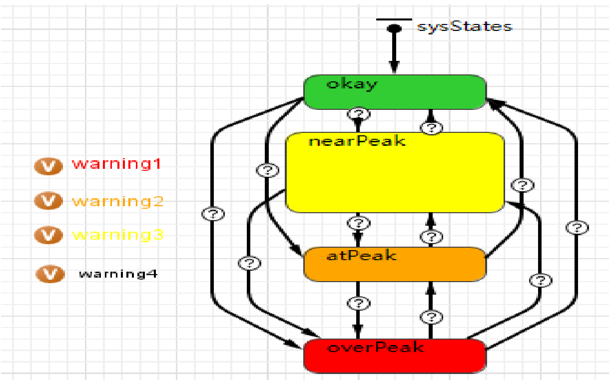

Figure-4. Controlling process for energy consumption

4.PRELIMINARY SIMULATION RESULT OF HOUSEHOLD ENERGY CONSUMPTION

In present version of the model, we focus on the electric consumption inside individual household, thus we set up 1 household and operate a round of simulation to generate the result. According to the general case, the house is set as the typical form of Japanese apartment house, the layout including a kitchen, a living area, a bathroom (with toilet), and 2 bedrooms. The number and locations of the appliances is set based on the life experience by the Japanese style, the details are as figure-5 shows.

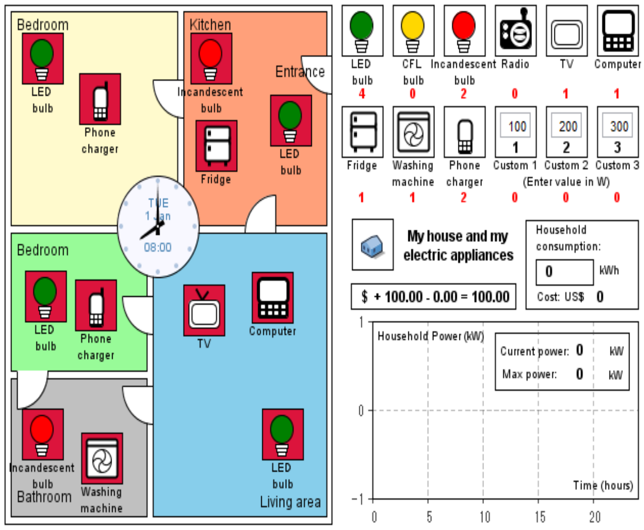

Figure-5.Household interface

As for the simulating time, it is assumed to be an ordinary workday, the electric consumption of household for a whole day from 0:00 a.m. to 24:00 p.m. will be simulated. During the whole simulation, the Fridge kept operating because it is the only appliance that demands uninterruptible electric supply in the present version of the model. The hourly usage conditions of other appliances is listed in table 1.

Table-1. Hourly usage conditions of appliances except Fridge

Time	Appliances under operation
0:00~6:00	2 phone chargers
6:00~7:00	2 incandescent bulbs
7:00~8:30	incandescent bulb, TV
8:30~18:00	None
18:00~19:00	incandescent bulb, LED bulb
19:00~20:00	incandescent bulb, LED bulb, TV, washing machine
20:00~22:00	LED bulb, TV, PC,
22:00~24:00	2 phone chargers

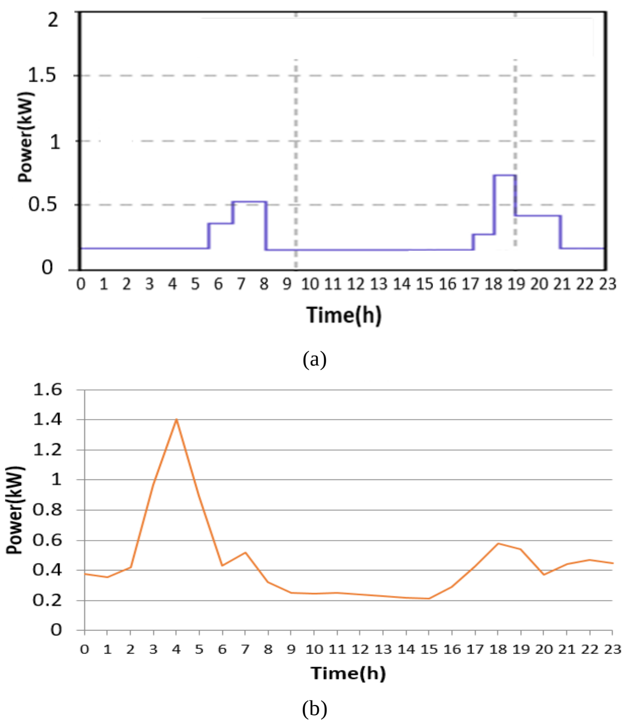

Figure-6. The trend of electric consumption in simulation result (a) and actual measured data (b)

Figure-6 shows the simulation result of electric consumption trend comparing with the actual measured data. The curve represents an active power demand (almost no reactive power is consumed by households). As figure-6(a) shows, the value keeps stable and relatively low in most of the time, 2 peaks of energy consumption happened during the simulation. The peaks happened in the morning and evening as they coincide with the usage time of high power devices. Figure-6(b) shows the average electric consumption value of weekdays in Oct., 2015 of an ordinary office-worker household living in Osaka. A consumption peak happens from 2:00 to 6:00 because this household charge the storage battery with a cheaper price in midnight. Beside this, the trend of electric consumption in actual measured data is generally agreeable with the simulation result, which means that the result totally reflect the realities of ordinary Japanese office-worker households. All the members go to work or go to school in the morning and stay outside during daytime. After work, they go back home and start a series of complex activities inside house.

5. CONCLUSION

In the present version of the model, the results are promising, but still needs further revision. During the simulating process, the model worked smoothly, and did not occur apparent error. Although the result is crude and remains inconclusive at this stage, the model allows for simulation of household energy consumption, and it is a good foundation for further developing.

The system still needs some improvements as well as an enhanced validation in order to deliver more realistic results. The life style of ordinary office-worker households is generally reflected by the simulation result. However, in some real case such as households with elderly people or housewife, members may stay in the house in most of time instead of going to work. Thus, the energy consuming rule for different types of households should be designed. What's more, some appliances such as air conditioner, heater, and rice cookers are not considered in the present version as their energy consuming process is more complex than other appliances. That result in the difference between simulation results and actual measured data and will be revised in future.

AnyLogic serves stably as platform of the model. Some of the existing components provide a convenient for development of the model. Although it is just in a primary stage, the AnyLogic expected to be able to achieve the functions we proposed in the framework of energy management for households. The household energy consumption differs significantly in different seasons and under different weather conditions. So, the future version of the model should allow more settings of environmental parameters in order to simulate under different scenarios. Meanwhile, as for the simulation of energy management with HEMS and CEMS, the more related components should be added in the model such as battery, PV panel and so on.

ACKNOWLEDGEMENT

The authors are grateful to JSPS (C) for providing fund through Urban Planning Laboratory (project no. 15K06354), Kanazawa University to support this research.

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エージェントベースモデルに基づく需要側における家庭エネルギー消費量のシミュレーションに関する研究

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ｷｰﾜｰﾄﾞ：エージェントベースモデル、エネルギー管理、電力消費シミュレーション

概要:

日本はエネルギーの大量消費国であり、原子力を除いたエネルギー自給率がわずか 5%と低く、エネルギー資源のほとんどを海外からの輸入に頼っている。しかし経済成長と人口増加により、今後、世界のエネルギー消費量も大幅な増加が見込まれているため、限りある資源をめぐって世界で資源獲得競争が激化することが懸念されている。エネルギー需要が急増し、それにともなう化石燃料の消費の増大が見込まれているなか､地球温暖化の主な原因である CO2 排出量の削減も地球規模で実施すべき急務となっている。これらの問題を踏まえると、効率的なエネルギー管理システムの開発は、エネルギーを節約するためのキーポイントの一つである。

本研究では、コミュニティレベルでの家庭用エネルギー管理システムの枠組みを提案した。更に、需要側のエネルギー消費にシミュレーションを行う必要性及び提案した枠組みとの関係を説明した。その後「AnyLogic」プラットフォームで開発されたエージェントベースモデルを使用して、需要側としての世帯のエネルギー消費量をシミュレーションした。シミュレーションを行った結果、一日電力消費量の変化はサラリーマン世帯の実態と一致した。結論としては､「AnyLogic」プラットフォームとエージェントベースモデルは提案された枠組みを実現するための良い基盤であり、さらなる開発の必要がある。

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