ARTICLE IN PRESS

Applied Thermal Engineering xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Residential energy end-use model as evaluation tool for residential micro-generation

Yoshiyuki Shimoda [a,b,*], Ayako Taniguchi-Matsuoka [a,b], Takuya Inoue [a], Masaya Otsuki [a], Yohei Yamaguchi [a,b]

[a] Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan
[b] CREST, Japan Science and Technology Agency, Japan

HIGHLIGHTS

- Energy end-use model is developed to evaluate residential micro-generation.
- This model calculates electricity and heat demand profile for various households.
- Optimal system for each household type is selected from MGE, PEFC, SOFC.
- City-level replacement cost for CO_2 optimum micro-generation is estimated.
- Electricity load curve change by introduction of micro-generation is assessed.

ARTICLE INFO

Article history:
Received 7 April 2016
Revised 22 August 2016
Accepted 13 September 2016
Available online xxxx

Keywords:
Residential sector
Urban-scale energy end-use simulation
Micro-generation
Electricity load curve

ABSTRACT

It is expected that dissemination of micro-generation in the residential sector will have various kinds of impacts on urban- and grid-scale energy systems. To evaluate these impacts quantitatively, it is necessary to use an urban-scale energy end-use simulation model. The authors have been developing a city-scale residential energy end-use simulation model in a bottom-up manner. This model has three features. First, the model estimates all of the energy demand profiles for each household category. Second, the demand profile is estimated at 5-min intervals to simulate the realistic operation of a cogeneration system. Third, all households in a target region are classified into detailed household categories according to household type and building properties. Therefore, this model can evaluate the potential contribution of residential cogeneration systems to energy conservation and global warming mitigation on a city scale.

In this paper, the energy, economic, and environmental performances of micro-generation systems (SOFC, PEFC, gas engines) are evaluated for each household category by this model. From these results, the CO_2 reduction potential by disseminating micro-generation on a city scale is estimated in relation to cost. The change of the electricity load curve by dissemination of micro-generation into the residential sector is also evaluated.

1. Introduction

After the Great East Japan Earthquake and following the Fukushima Nuclear Power Plant Accident, the Japanese government discussed a new long-term plan for an “energy mix” in Japan. From the report of the government committee [1], approximately 119 billion kWh, which is equivalent to 11% of the total electricity generation (1,065 billion kWh), is expected to be generated by cogeneration systems by 2030. To generate such a huge amount of electricity from cogeneration systems, not only the industrial and the commercial sectors, but also the residential sector must introduce a substantial amount of micro-generation systems such as gas engines and fuel cells. In Japan, a residential gas-engine cogeneration system, a residential polymer electrolyte fuel cell (PEFC) cogeneration system, and a residential solid oxide fuel cell (SOFC) cogeneration system were put on the market in 2003, 2009, and 2012, respectively. In the energy mix, it is expected that 5.3 million units of fuel cells will spread into the residential sector by 2030; this number of fuel cells is equivalent to approximately 10% of households in Japan.

The electricity and heat demand profiles of residential buildings differ by household type and building properties. The energy

* Corresponding author at: Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan.
E-mail address: shimoda@see.eng.osaka-u.ac.jp (Y. Shimoda).

http://dx.doi.org/10.1016/j.applthermaleng.2016.09.066
1359-4311/

Please cite this article in press as: Y. Shimoda et al., Residential energy end-use model as evaluation tool for residential micro-generation, Appl. Therm. Eng. (2016), http://dx.doi.org/10.1016/j.applthermaleng.2016.09.066

efficiency of micro-generation and the energy performance of various kinds of micro-generation systems for specific households are greatly affected by these profiles. Therefore, an evaluation tool that calculates economic and environmental performances by introducing residential micro-generation systems under various household conditions is desired.

Especially, from the viewpoint of energy policy, the following questions need to be answered.

- How much effect on energy saving and greenhouse gas emission reduction can be expected by dissemination of micro-generation in the residential sector at the city or grid level?
- How much financial support is required to provide these environmental effects?

These kinds of information can be calculated quantitatively by considering the composition of households and the building characteristics in the target region.

In addition, the electricity load curve in an electric power system will vary considerably by the large-scale installation of micro-generation systems. Because this variation will affect the composition of electric power sources on the power generation side and greenhouse gas emissions, the function of an electricity load curve prediction is also important.

To fulfill these requirements, the authors have been developing a city- or grid-scale residential energy end-use simulation model in a bottom-up manner. This model evaluates the energy conservation policy on a city scale [2] and new hot water heater systems that include residential micro-generation systems and heat pump water heaters [3].

Napoli et al. [4] evaluated energy and economic performances of residential PEFC and SOFC systems by using a measured load profile in a detailed model of fuel cell cogeneration. Dorer et al. [5] evaluated SOFC and PEFC systems for two types of houses and two different numbers of household members by IEA-Annex 42 model for CHP system and TRANSYS for building energy use. Rosato et al. [6] examined the dynamic performance of a micro engine CHP system combined with a three-story multi-family house by a model similar to that of Dorer et al. Rosato et al. [7] also evaluated the energetic, economic, and environmental feasibility of a micro engine CHP system.

Our micro-generation system model is simpler than these models to enable us to evaluate many types of households, and the authors focus on the city-level impact of dissemination of micro-generation systems. The purpose of this paper is to demonstrate that our improved version of this model is available for evaluation tool of residential micro-generation systems through (1) quantitative evaluation of energy saving effect by introducing a micro gas engine cogeneration system, PEFC cogeneration system, and SOFC cogeneration system under various types of electricity/hot water demand profile generated by our model, (2) city-level evaluation of CO_2 emission reduction and additional cost requirement effect by disseminating these micro-generations, and (3) evaluation of impact on power system by disseminating micro-generations.

2. City-level residential energy end-use model

Fig. 1 shows a flowchart of the city-level residential energy end-use simulation model developed by the authors [2]. In this simulation, the annual energy consumption of one household is calculated iteratively for 19 family compositions, and 12 building categories (six categories for detached houses and six categories for apartments set depending on the floor area). In addition, four types of building insulation levels are assumed. Each occupant's time allocation for living activities, amount and temperature of the hot water supply, weather data, and energy efficiency properties of appliances are provided as input data. The simulation of

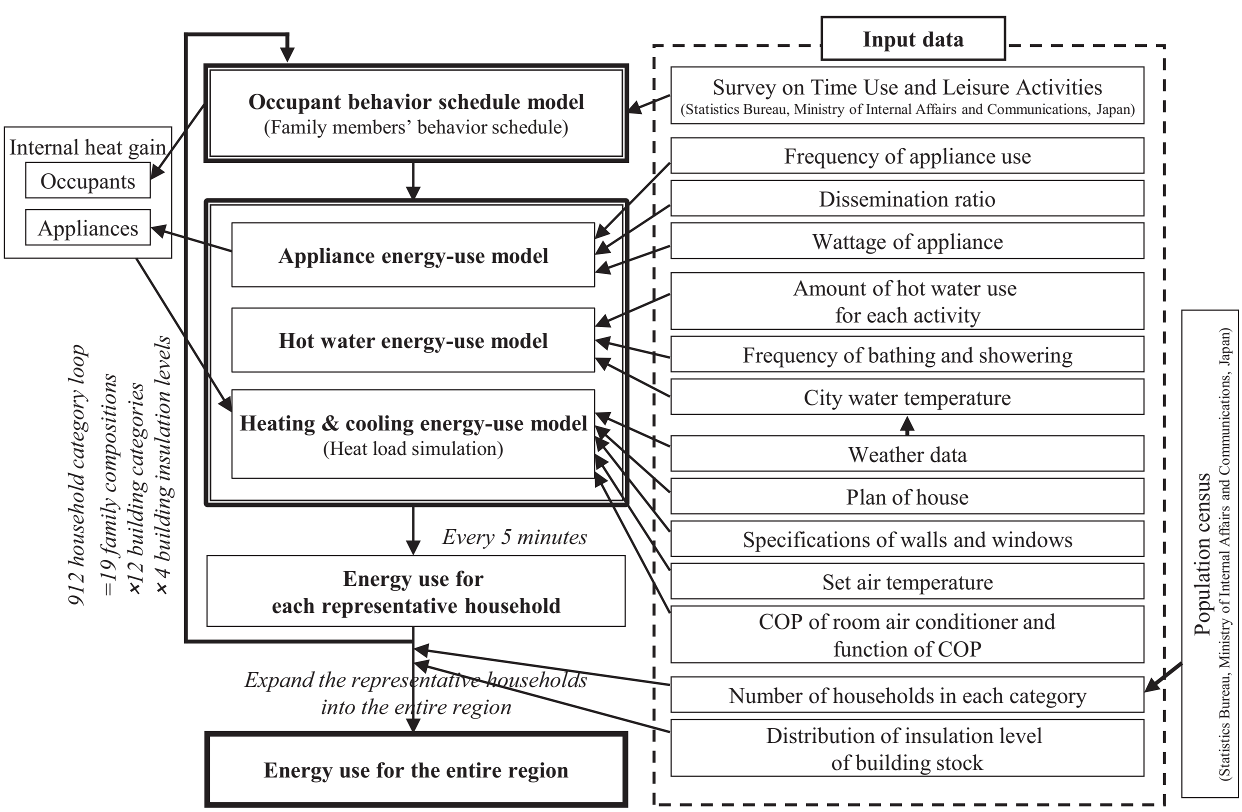

Fig. 1. Flowchart of the model.