DEVEROPMENT OF MODIFIED DIFFUSION MODELS FOR HEAT PUMP SUBSIDY PROGRAMS INTEGRATED WITH EXISTING DSM PROGRAMS

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Abstract: In this paper, modified diffusion models considering subsidy programs for heat pump diffusion are proposed. Although the heat pumps technology is one of the classical fields, which is more than 100 years, it has not substituted conventional boilers and air-conditioners because of the problem of efficiency. However, the technology has been advanced and matured remarkably in recent years. Now there are only two problems which are price and government's willingness-to-pay. Subsidy strategies are very powerful methods to change consumer's behavior, which is proved in various cases. To explain and to forecast this changing, a new concept modifying the very worthy classical model, which is called Bass model, is proposed in this paper.

Key Words: heat pumps, subsidy, DSM (Demand Side Management), diffusion model

1 INTRODUCTION

Nowadays, there is a rising interest on the electrified house technology, which is one of the green growth technologies and is integrated with various areas such as electricity, machinery, architecture, material, etc. and is able to give an effect to customers visibly as like electric vehicles. The electrified houses focused in this paper are not the zero energy houses which could settle all needs of energy among themselves, but are on the pre-phase of the zero energy houses and could cover all energy needs with the electrification. For example, fossil fuel energy is used for heating and hot water supply in the existing conventional houses but electricity is adopted in the new conceptual houses. However, additional methodologies are necessary to enhance the total efficiency of energy usage because electricity is a secondary energy and the efficiency is reduced in the energy conversion process. So some efficient methods using geo thermal energy and air source energy are considered in this paper. To heat and use hot water with the energy, heat pumps are installed, which are activated by electricity, and the adoption of this dynamic loads would change the characteristics of residential loads. However, the heat pump systems are more expensive than existing air-conditioning systems. To compete with them, some subsidy programs should be considered and evaluated the B/C ratio. In this paper, some modified diffusion model are proposed to estimate the penetration of heat pump systems and some optimal strategies of DSM programs are suggested considering the introduction of heat pump system programs, which models are based on the Bass diffusion model that could explain social and natural phenomenon powerfully. The evaluation of B/C ratio will be progressed steadily.

2 STAUTS OF DSM PROGRMS IN KOREA

Various DSM programs have been implemented changing load patterns as some manners which are peak clipping, valley filling, load shifting, strategic energy saving (energy efficiency), strategic load creation, and flexible load. And social and economical environment

of local areas have been additionally considered for these activities. The programs are able to be classified with load management (LM) and energy efficiency (EE), which are easy and reasonable classification to explain the differences.

2.1 Load Management Programs (LMs) [1]

KEPCO (Korea Electric Power Corporation) classifies load management programs into three types which are load reduction, load shifting, and contingency programs as shown in Table 1.

Table 1: Load Management Programs Operated by KEPCO

Category	Program
Load Reduction	Demand adjustment program of advance notice Demand adjustment program of designated period Demand Controller
Load Shifting	Cool storage system Ice storage A/C TOU(Time-of-use) tariffs
Contingency Programs	Average Load Reduction upon Request Direct Load interruption

2.2 Energy Efficiency Programs (EEs) [2]

In Korea, the Ministry of Knowledge and Economy (MKE) and Korea Energy Management Corporation (KEMCO) are operating three energy efficiency programs which are the energy efficiency standards & labeling, the e-standby program, and the high-efficiency appliance certification program as shown in Table 2. KEPCO is operating some EEs of these programs.

Table 2: Energy Efficiency Programs Operated by KEPCO

Category	Program (Appliances)
Energy Efficiency Standards & Labeling	Refrigerators, Air Conditioners/Refrigerator-Freezers, Washing Machines, Incandescent Bulbs, Fluorescent Lamps, Ballasts for Fluorescent Lamps, Compact Fluorescent Lamps, Domestic Gas Boilers, Dish Washers, Hot and Cold Water Dispensers, Rice Cookers, Automobiles, Kimchi Refrigerators, Vacuum Cleaners and Freezers
E-Standby Program	Computers, Monitors, Printers, Fax Machines, Copiers, Scanners, Multi-function Devices, Energy Saving & Controlling Devices, Televisions, Video Cassette Recorders, Home Audio Products, DVD Players, Microwave Ovens, Battery Chargers, Set-top Boxes, DC Power Supplies, Door Phones
High-Efficiency Appliance Certification Program	Induction Motors, 26mm 32W Fluorescent Lamps, Ballasts for 26mm 32W Fluorescent Lamps, Self-ballasted Lamps, Reflectors for Fluorescent Lamps, Sensor Lighting Equipments, Heat Recovery Ventilators, Windows, Water Coolers, Pumps, Uninterruptible Power Systems, Industrial Gas Boilers, Domestic Gas Boilers, Transformers, Vending Machines, T-5 Fluorescent Lamps, Electronic Ballast for Metal Halide Lamps, Electronic Ballast for Natrium Lamps, Inverters, Auto Thermostatic Valves For Heating, LED Traffic Lights, Multi-function Type Switchgear Systems, Direct-fired Absorption Chillers-heaters, Single Phase Motors, Ventilation Fans, Centrifugal Blowers, Ballasts for 16mm Fluorescent Lamps, Metal-halide Lamps, - Reflectors for HID Lamps, - Motor Pumps for Aeration, - Ballasts for FPL 32W Compact Fluorescent Lamps, - FPL 32W Compact Fluorescent Lamps, - Oil Burning Water Boilers

3 DIFFUSION MODELS

3.1 Why Diffusion Models?

Various diffusion models have been designed or developed and modified with some variables to describe in detail by many researchers. Because these models are so powerful to explain social and natural phenomenon or tendency, a lot of applications exist in various fields. In general, these models have been used to analyze the penetration of commercial products. Market forecasting is possible using these models additionally. Bass' diffusion model is well-known among various diffusion models and we have studies various fields using Bass model. Figure 1 shows the basic concept of Bass model [3][4][5].

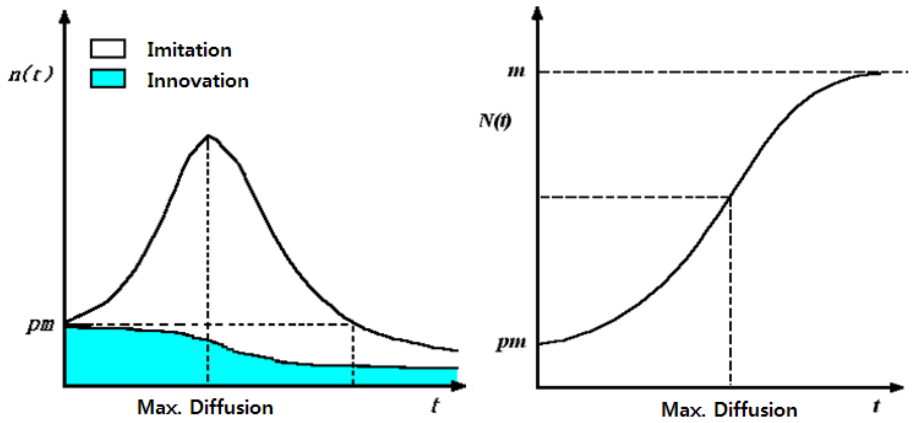

Figure 1: Basic Concept of Bass Model [3][4][5]

3.2 Bass Model

Bass model is derived from the hazard function expressed in equation (1), the probability that an adoption will occur at time t given that it has not occurred [3].

$$\frac{f(t)}{1-F(t)} = p + qF(t) \tag{1}$$

Equation (1) means the conditional probability of adoption and it is the basic premise underlying the diffusion process of end-uses such as high efficient appliances.

$$mf(t) = n(t),\ mF(t) = N(t) \tag{2}$$

$$n(t) = \frac{dN(t)}{dt} = p[m - n(t)] + \frac{q}{m}N(t)[m - N(t)] \tag{3}$$

Diffusion capacity in season [s, s+1] can be represented as the cumulative adoption function N(s) expressed in eq.(4), and the integral denotes the adoption probability in season s.

$$N(s) = m\int_{s}^{s+1} \frac{p(p+q)^2 e^{(p+q)t}}{(p + qe^{-(p+q)t})^2}\,dt \tag{4}$$

where m : the potential market size
p : coefficient of innovation
q : coefficient of imitation .

4 REQUIREMENT OF SUBSIDY PROGRAMS FOR THE HEAT PUMP DIFFUSION

4.1 Status of Midnight Electricity Rate

Various types of subsidy program have been implemented for DSM programs, green building programs, new & renewable programs, etc. which are funded by the government according to the diffusion strategies. For example, the one million green home program that was launched by KEMCO in 2009 supports to facilitate installing NRE facilities in residential areas such as private houses, multi-family houses and public rental houses [6].

Heat pumps have been installed in commercial and industrial areas in Korea and most of these heat pumps are air-source heat pumps. However, there are many types of heat pump and the residential area is another blue ocean in this field. Recently, the diffusion of heat pumps is motivated by the revision of midnight electricity rate. The rate had set and kept at a ridiculously low rate under the production cost for about 20 years. This unreasonable price has caused peak load in the midnight period of winter season. The installation cost of midnight appliances has been subsidized for operating from 23:00 to 09:00 or from 22:00 to 08:00. This change of load pattern has imposed a heavy burden on power system operation and planning. That is, new construction and operation of power plants are required for the only a few hours and this is very inefficient.

4.2 Contribution of Subsidy Programs for Heat Pumps

The COP of currently heat pump system is evaluated over 3.0 and this means that heat pump systems contribute to efficient energy usage in viewpoints of government, utilities, and customers. Figure 2 shows that electrification with heat pump systems is able to reduce the use of fossil fuel energy for thermal fields such as heating.

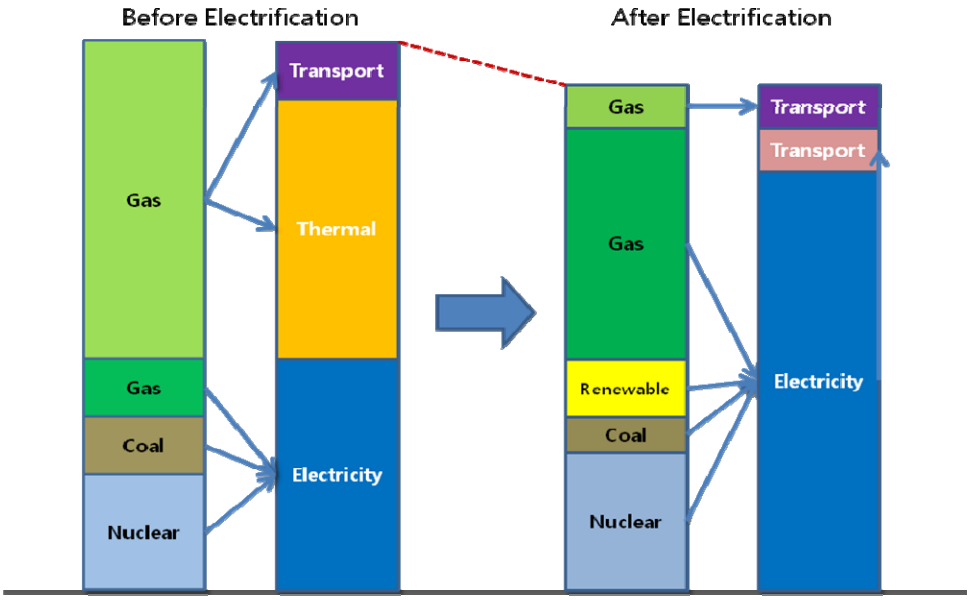

Figure 2: Concept of Energy Consumption Change by Electrification

However, hat pump systems are much expensive than conventional boilers or multi air-conditioners so that it is difficult to penetrate into the market substituting those existing systems. This is the reason that subsidy programs are required to support the installation costs. The effects by heat pump subsidies appear not only in the customer side but also in the supplier side which means electric power utilities in general. Figure 3 shows that DSM and electrification with heat pump systems contribute to power systems operation by means

of load shifting and load curtailment. This is able to avoid the additional construction of electricity supply facilities such as power plants, transmission lines, substations, distribution equipments.

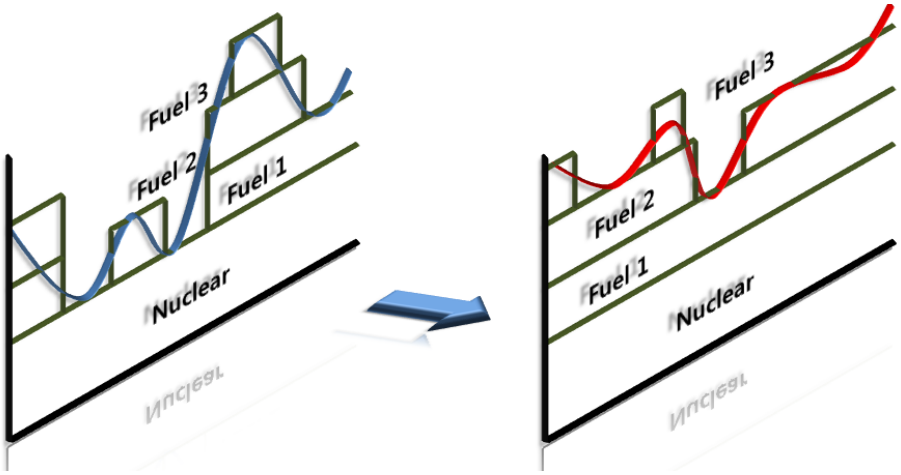

Figure 3: Concept of Load Shifting and Curtailment by DSM and Electrification

5 MODIFIED DIFFUSION MODELS FOR HEAT PUMPS

5.1 Background of Modified Models

The concept of modified diffusion models proposed in this paper is very easy. Heat pump systems are not optional elements but compulsory elements in buildings. If we do not use heat pump systems, we must use others heating and cooling systems such as boilers with fossil fuel or electricity and air-conditioners. Furthermore, the production and purchase of heat pump systems are affected by the construction market. That is to say, the heat pump systems' diffusion depends on construction boom because heat pumps are included with others facilities in the construction. In this sense, it is necessary to modify coefficients of diffusion models. This paper develops this modification of coefficients such as market potential and innovation coefficient.

5.2 Development of Modified Models

Construction business index functions (CBI) are applied to the existing diffusion model as shown eq. (5) and (6). These index functions are derived from historical construction statistics data and estimated by some numerical analysis such as least square method. These equations mean market potential and innovation by construction business environments in time series, respectively. Essential difference with existing models is that modified models have time-varying coefficients. This could bring some difficulties to estimate diffusion states and so some assumptions are needed. Eq. (3) is changed into eq. (7) using (5) and (6).

$$m(t) = f(CBI(t)) \tag{5}$$

$$p(t) = g(CBI(t)) \tag{6}$$

$$n(t) = \frac{dN(t)}{dt} = p(t)[m(t) - n(t)] + \frac{q}{m(t)} N(t)[m - N(t)] \tag{7}$$

A concept of this change is shown in Figure 4. That is, construction business environments affect on the heat pump penetration.

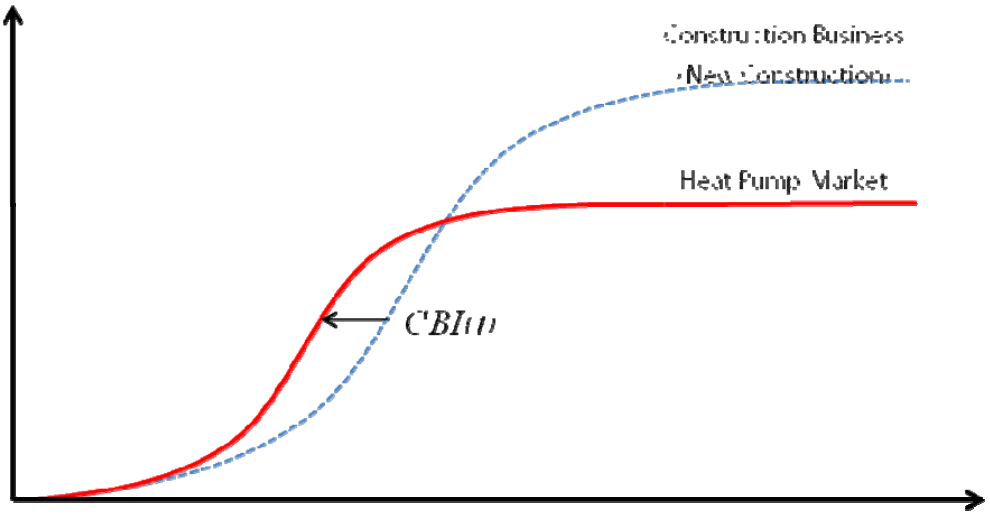

Figure 4: Heat Pump Diffusion by Construction Business

6 CONCLUSIONS

Modified diffusion models considering subsidy programs for heat pump diffusion are proposed. Essential difference with existing models is that modified models have time-varying coefficients and these are derived from historical construction environments data and estimated by some numerical methods. This estimation will be progressed in future studies.

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