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Improvements to the customer baseline load (CBL) using standard energy consumption considering energy efficiency and demand response

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ABSTRACT

Electricity demands are steadily increasing every year because of continued improvements to the quality of life and extreme hot and cold weather conditions. Therefore, the electric demand response management (DRM) system was introduced to prevent unstable electricity supply both domestically and globally. Unlike power generation in power plants, DRM regulates the demand and supply by reducing building energy consumption. Demand management is divided into energy efficiency and demand response. Energy efficiency reduces normal energy consumption by replacing older equipment and materials with high-efficiency models, remodeling the building envelope, and efficient system operation. Demand response reduces the electric consumption of pre-contracted electrical consumers at certain times, especially at peak load times. To determine the energy savings of buildings, the customer baseline load (CBL) is used. However, the CBL cannot evaluate the energy savings due to the energy efficiency improvements because it only assesses savings based on normal energy consumption. Therefore, DRM has a high incentive for buildings with high-energy consumption, while buildings with implemented energy efficiencies have low incentives, even though electricity demand is reduced. In this paper, we present the standard energy consumption to reflect both energy efficiency and demand response which can help stabilize power supply in the nation.

1. Introduction

Energy consumption is steadily increasing due to population growth and improvements to the comforts of life [1,2]. Therefore, rather than the domestic and foreign governments increasing the electrical supply to manage the power demand of the country, it implements demand management systems that regulates the supply and demand of electric power by reducing the consumption, which in turn benefits the society [3–5]. Companies can voluntarily participate in DR to reduce peak energy consumption and contribute to stable power supplies, which can reduce the enormous expense of power plant construction. In addition, since the price of electricity is high at peak periods when the reserve margin is low, and is inexpensive at off-peak periods when the reserve margin is high, there have been efforts to lower the power price when the consumer reduces the power consumption at peak periods. Consumers receive energy saving incentives from peak load energy cost reductions based on DRM [6–8]. In South Korea, DRM was first implemented in 2014 and has increased by an order of three times in participating electric power plants over three years, to a level of 4352 MW, and it is increasing every year [9].

DRM is divided into energy efficiency and DR [10]. Energy efficiency reduces normal electricity consumption by replacing equipment with high-efficiency models, remodeling the building envelope, and operating efficiently. Yuan et al. [11] reviewed bionic technologies for building functions, structure, and materials for energy efficiency. Ahn et al. [12] studied the heating properties of LED lighting and established a management strategy to exploit these properties and reduce the amount of energy required for heating and cooling buildings. DR change customer's normal electric consumption patterns in response to alterations in the price of electricity over time, or by incentive payments designed to induce lower electricity use at times of high wholesale market prices, or when system reliability is jeopardized [13]. Albadi and El-Saadany

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Nomenclature

a-f	coefficients for the curve equation [-]
A	surface area [m^2]
al(d,h)	actual load for day d and hour h [kWh]
C	heat capacity [kJ/m^3 K]
C_p	zone air specific heat [kJ/kg K]
h	solar altitude [deg]
h_i	internal heat transfer coefficients [W/m^2 K]
I	solar radiation [W/m^2]
I_0	solar constant, 1367 [W/m2]
K_{DS}	regression equation [-]
K_T	clearness index [-]
K_{TC}	boundary point of K_T [-]
$\dot{m}$	air mass flow rate [m^3/s]
N	each elements [-]
n	number of measure data points [-]
pl(d,h)	predicted load for day d and hour h [kWh]
$\dot{Q}$	convective load [W]
T	air temperature [K]
T_z^t	zone air temperature at the time step t [K]
$T_z^{t-\delta t}$	zone air temperature at the previous time step t [K]
t	time [h]
$\tilde{y}$	model predicted results of building energy consumption [kWh]
y_i	measured data of building energy consumption [kWh]
$\bar{y}$	average value of y_i [kWh]

Abbreviations

BEMS	building energy management system
CBL	customer baseline load
COP	coefficient of performance
CAPFT	cooling capacity ratio modifier function of temperature
Cv(RMSE)	coefficient of variation of root mean square error
DR	demand response
DRM	demand response management
EHP	electric heat pump
EIRFT	cooling energy input ratio modifier function of temperature
EIRFPLR	cooling energy input ratio correction factor function of part-load ratio
EPW	energyplus weather
ESS	energy storage system
Frac	fraction
HPRTF	heat pump runtime fraction
KMA	Korea meteorological administration
KPX	Korea power exchange
MBE	mean bias error
PLR	part-load ratio
SAA	symmetric additive adjustment
SHGC	solar heat gain coefficient

Subscripts

b	direct (beam)
c	outdoor dry-bulb
d	diffuse
g	global
i	internal
inf	infiltration
load	energy demand
min	minimum
ref	reference
si	internal surface
sl	latent and sensible
supply	supply air
sys	system
wb,avg	indoor average wet-bulb
z	zone
zi	interzone
∞	outdoor

[14] studied DR's potential benefits when customers intentionally reduce their electricity usage during peak period. Finn et al. [15] developed a method for participating in DR using wind-generated electricity. Lee et al. [16] created a platform to reduce peak energy consumption using real-time weather forecast data.

In the case of power plants, electricity is produced and settled based on the metered data. However, since the demand response is difficult to assess for savings in electricity consumption, a CBL is used to assess the energy savings [17–19]. CBL predicts the amount of electricity that would normally be used if electricity consumption had not been reduced by the KPX directive. Additionally, as outdoor temperatures could be very high or low on event days, the SAA option corrects the CBL to align with energy patterns on proxy event days. This aids the CBL to predict as close to an actual energy consumption as possible [20]. However, in cases where DR estimates the energy savings based on normal energy consumption, the energy savings by energy efficiencies such as envelope remodeling, system control, system efficiency improvement, and renewable energy use cannot be accurately evaluated. In addition, buildings with lower energy consumption due to energy efficiency have a lower CBL and saving effect resulting in reduced energy savings. Therefore, DRM only concentrates on reducing peak loads rather than energy efficiency [21].

There is a three-tier approach to reduce building energy. Tier 1 is basic building design, Tier 2 is passive systems, and Tier 3 is mechanical equipment. Tier 1 and 2 reduce the energy consumption of buildings by as much as 80% [22]. Under these descriptions, Tier 1 and 2 are energy efficiency, and the DR is a component of Tier 3. Therefore, not only demand response but also efficiency improvement should be applied in order to significantly lower the national electricity demand. In addition, improved energy efficiency in buildings can assist to lower the peak load as well as the off-peak load, helping to manage national electricity demand. Electric consumers can participate in DRM in a variety of levels, including building, system, and renewable energy [23–26]. Therefore, it is necessary to improve the CBL by incorporating the incentives based on the energy efficiency savings through new standards that can reflect both energy efficiency and demand response.

There are international standards for assessing building energy consumption including DIN 18,599 [27] and ISO 13,790 [28]. In South Korea, to facilitate the use of international standards, an ECO2 software develop by the Korea Institute of Civil Engineering and Building Technology and the Korea Institute of Energy Research provides a national accredited certification tool that can quantitatively assess building energy consumption [29]. The software is based on the international standard ISO 13,790, and is used to evaluate energy efficiency ratings of buildings. Only national license holders can use ECO2 software to assess building energy