Energy and Buildings 74 (2014) 120–131

Contents lists available at ScienceDirect

Energy and Buildings

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

A cost-effective method for integration of new and renewable energy systems in public buildings in Korea

Si-Doek Oh[a], Yungpil Yoo[d], Jeonghun Song[b], Seung Jin Song[b], Ha-Na Jang[c], Kangwon Kim[c], Ho-Young Kwak[d,*]

[a] *Blue Economy Strategy Institute Co. Ltd., Kumho Buld. Kuro-Dong, Kuro-Ku, Seoul 152-055, Korea*
[b] *School of Mechanical & Aerospace Engineering, Seoul National University, Seoul 141-742, Korea*
[c] *Korea Energy Management Corporation, Yongin-Si 448-994, Korea*
[d] *Mechanical Engineering Department, Chung-Ang University, Seoul 156-756, Korea*

ARTICLE INFO

Article history:
Received 15 August 2013
Received in revised form
24 November 2013
Accepted 13 January 2014

Keywords:
Cost-effective integration
Energy demand patterns
Public buildings
New and renewable energy sources
Utilization factor

ABSTRACT

Public buildings in Korea have an obligation to supply 10% of the total energy consumption from new and renewable energy sources, which requires proper tools for installation of the energy systems. In this study, a cost-effective method for integration of existing grids with new and renewable energy sources in public buildings in Korea is suggested. A key factor of the method is based on the fact that the unit costs of the products from the energy systems depends on the capacity factor or the utilization factor which is crucially dependent on the interaction between the energy demand pattern for the building and the production time of the specific energy from the new and renewable energy sources. For several public buildings such as two business buildings located at quite different weather conditions, a welfare center and a fire station at different locations, the proper combination of new and renewable energy sources is suggested by detailed numerical calculation based on the hourly energy demand pattern data obtained from field studies for the buildings to minimize the additional cost by installing the energy systems.

1. Introduction

As part of the programs for the dissemination of new and renewable energy sources, public buildings in Korea currently have an obligation to obtain 10% of their total energy consumption from new and renewable energy sources. Public buildings, such as business buildings, police agencies, public prosecutor's offices, fire stations and welfare centers pay a lower electricity fee of 90 KRW/kWh than the system marginal cost (SMP) of electricity of 124 KRW/kWh where KRW is Korean currency Won (1000 KRW are approximately equivalent to 1 US dollar.). However, the unit cost of electricity obtained from new and renewable energy systems is much higher than the system marginal cost (SMP) so that proper installation of such high-cost new and renewable energy systems in public buildings is required. It is not easy task to install the new and renewable energy systems because the production time of the energy from the renewable energy sources is limited and is frequently not matched with the energy demand patterns for the buildings. Such consideration of the interaction between the production time of the energy from the renewable sources and the energy demand patterns for buildings is essential because the interaction determines the unit cost of products from new and renewable energy sources and net metering with the local electric company is not allowed for the buildings in Korea.

In determining the optimal configuration of cogeneration plant in buildings [1–4] and in optimal operation of the energy systems [4–7] based on annual savings and the associated payback periods, energy demand patterns for the buildings have known to be very important factors. The hourly energy demand profiles are also important information for the design and operation of the hybrid system of renewable energy sources [8,9]. For instance, optimum sizing for the installation of a stand-alone hybrid generation of wind turbine (WT) and solar PV was studied by consideration of cost [8–10] and cost and reliability [11] with local meteorological data such as clearness index data and wind speed profiles.

Medrano et al. [12] studied an integration of high-temperature fuel cells, micro-turbines and solar photovoltaic (PV) into four type commercial and public buildings with consideration of economic, energy-efficient and environmental impact. Their results based on annual savings and the associated payback periods indicate that the high-temperature fuel cell unit was best matched with the hospital energy loads, on the other hand, the micro-turbines and

* Corresponding author. Tel.: +82 2 820 5278.
E-mail address: kwakhy@cau.ac.kr (H.-Y. Kwak).

0378-7788/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2014.01.028

Nomenclature

C	Unit cost of fuel or products ($/kJ)
C_i	Initial investment cost ($)
C_o	Unit cost of fuel ($/kJ)
$\dot{C}$	Monetary flow rate ($/h)
$C_{add}(i,J)$	Additional unit cost for i energy system with J unit size.
$CRF(i,n)$	Capital recovery factor
E	Energy
$\dot{E}_x$	Exergy flow rate (kW)
$\dot{E}(i,J)$	Energy production rate for i energy system with J unit size
H	Enthalpy
i	Interest rate
j	Inflation rate
n	Expected life of equipment
PW	Present worth
$PWF(i,n)$	Present worth factor
S_n	Salvage value at the end of nth year ($)
T	Temperature (K)
$\dot{Z}$	Cost flow rate of nonfuel part

Greek symbols

β	Coefficient of performance
β_{cf}	Capacity factor
δ_r	Utilization factor
ΔH	Enthalpy change
ϕ	Maintenance factor
η_e	Exergetic efficiency

Superscripts

BQ	Hot water
CHE	Chemical
W	Work or electricity

Subscripts

FC	PEMFC
k	kth component
P	Purchased electricity
W,w	Work or electricity
x	Exergy

high-temperature fuel cell did not match with the college/school and office buildings.

In this study, a cost-effective method for installing new and renewable energy systems such as solar PV, solar thermal unit, ground-source heat pump (GSHP) and proton exchange membrane fuel-cell (PEMFC) in public buildings was developed based on the additional unit costs to produce energy from the new and renewable energy systems with a continuous energy mixing strategy [13]. The proper size and mix of a new and renewable energy system for a specific building were determined by comparing the additional unit costs of products of the various new and renewable energy systems. The additional unit costs were obtained using thermoeconomics or exergy costing methods [14–17] based on the hourly energy demand patterns obtained from field studies for the buildings.

2. Methodology

Brief description of the energy demand patterns for several selected public buildings are presented is this section. A cost-effective method developed for installing appropriate new and renewable energy systems fitted to the energy demand patterns for the public buildings in Korea based on the thermoeconomic approach is discussed below.

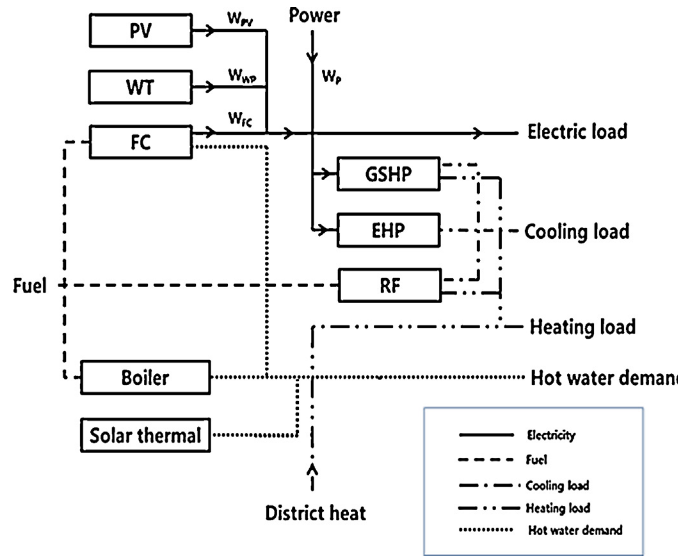

Fig. 1. Schematic diagram of possible energy systems for public buildings.

2.1. Energy demand patterns for public buildings

It is well known that the energy demand patterns for building are vital tool in energy planning and management so that various methods to obtain reasonable energy demand patterns for the buildings were tried [18–23]. In this study, the energy demand patterns were obtained from field studies for 24 public buildings located in various cities in Korea. The electricity demands were obtained from the hourly consumed electricity recorded in smart meters. The cooling and heating loads were obtained using the operating hours of the electric heat pump (EHP) and other heat pump units, which depend on daily temperatures. The hot water demand was estimated based on the operating hours and the type and capacity of the boiler used in particular buildings. The estimated energy demand patterns were checked by comparing the paid electricity and gas fees with the calculated prices based on the assumed energy demand profiles. The public buildings addressed in this study are two business buildings located in different cities, a welfare center and a fire station. The cooling/heating areas for the public buildings range from 3400 to 11,300 m^2.

The cooling/heating areas, operating energy systems, average electricity and gas consumed per month and the renewable energy systems already installed in the buildings are shown in Table 1. As shown in Table 1, EHPs, GSHPs and gas direct-fired systems (RFs) are installed for heating and cooling in public buildings in Korea. Hot water demand can be usually supplied by gas-fired boilers. Renewable energy systems, such as solar PV and solar thermal units, were installed in the public buildings in Korea. No public buildings were found to use WT or PEMFC units.

Fig. 1 shows the general structure of the energy systems, including fuel cell (FC) units and WT for public buildings. The GSHPs and EHPs are operated by the power generated from PV, WT, FC and/or purchased electricity (w_p). The solar thermal unit only can supply hot water (heat) demand in Korea. In Fig. 1, the solid line, dashed line, dot-dashed line, two-dot-dashed line and dotted line indicate the flow of electricity, fuel, cooling load, heating load and hot water demand, respectively.

The energy demand patterns for public buildings, which are displayed in Figs. 2–5, can be demarcated by the base load, which is