Energy 92 (2015) 383–393

Contents lists available at ScienceDirect

Energy

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

Comparison of building energy demand for hotels, hospitals, and offices in Korea

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A R T I C L E I N F O

Article history:
Received 8 November 2014
Received in revised form
14 April 2015
Accepted 15 April 2015
Available online 8 May 2015

Keywords:
Building energy demand model
Hotel
Hospital
Office
Electricity heating cooling hot-water
Korea

A B S T R A C T

Energy demand characteristics were surveyed and measured throughout Korea to establish load models for three types of buildings: hotels, hospitals, and offices. The consumption of electricity and fuel was collected and statistically analysed to establish four types of building loads: electricity, heating, hot water, and cooling energy. The annual, monthly, daily, and hourly patterns of the four load types were derived for the three building types. Key statistical values such as the annual mean, maximum, and minimum values are provided. A procedure is presented to compose building load models as a time series covering the 8760 h of a year by combining daily and hourly patterns. The key features of the load models were compared to better understand the energy consumption characteristics of the three building types. Substantial variations in the magnitudes and patterns were observed among the types of buildings and loads. The load models can be applied to a wide range of problems in building energy system design and planning, including simulations and optimizations of community energy systems.

1. Introduction

Knowledge of building energy demand is an integral part of the smart design of energy supply systems, and a great deal of effort has been devoted to the issue. Generally, buildings require four types of energy: electricity, heating, hot water, and cooling. The combined demand category of heat and hot water is also used, depending on the heat supply methods. Researchers have proposed innovative methods for the estimation of building loads, such as statistical analysis [1–3], spatial regression [4], variable degree days [5], genetic algorithms [6], and climate classification [7,8]. Diverse combinations of load types have been investigated, ranging from the prediction of general demands [9,10] to individual load types of cooling [11,12], lighting [13], electricity [14,15], and heating [16].

Major issues in the development of building energy models include familiar topics of climate change and weather. The impact of climate change has been studied in regard to heating and cooling energy [17,18], energy use [19,20], energy demand [21,22], and electricity needs [23]. The effects of evaporation [24], urban heat islands [25], and dynamic consequences [26,27] have drawn attention throughout the world to cope with energy problems in densely populated regions.

Many studies are available that compare regions such as China [28–30], the UK [31], and Singapore [32] to better understand key variables that control load patterns and characteristics. Numerous energy demand studies have investigated diverse building types, such as residential buildings [33–35], hotels [36], commercial buildings [37], offices [38], free-form buildings [39], and future buildings [40,41]. The use of computers for calculating building loads is increasingly popular, and many powerful tools have been developed, as summarized by Drury et al. [42]. Energy demand forecasting plays an important role in load model development, and there have been numerous studies [43–45].

Much effort is required to develop reliable load models, regardless of the method, because many complex variables are involved. Building energy loads intrinsically depend on local climate and the behavior of the inhabitants, which are difficult factors to model. Acknowledging the importance of reliable building energy demand models, the Korean government is supporting a multi-year research project to collect comprehensive data across a broad range of building types throughout the country.

Residential, commercial, and public buildings consumed about 20% of the total energy used in 2013 (42 out of a total of 210 million TOE) [46]. This amount is below the world average, but for

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http://dx.doi.org/10.1016/j.energy.2015.04.016
0360-5442/

consumption per unit area of buildings, buildings in Korea consume significantly more energy than other developed countries. Obtaining precise numbers is a good starting point for planning future policies. The main purpose of this study is to provide accurate data based on reliable surveys and measurements of real-world buildings. This paper reports the results of an ongoing project. The results for department stores have already been published [46], and models for hospitals, hotels, and offices are presented here.

2. Methodology

2.1. Data collection

As a first step for collecting relevant data, we prepared a survey form and sent it to building owners, who are obligated to maintain energy consumption records under government energy auditing acts. The survey was sent to all audited hotels, hospitals, and offices located in the major cities in Korea (Seoul, Busan, Daegu, Kwangju, and Daejeon). The numbers of buildings that replied are summarized in Table 1. After pre-screening the survey replies, we selected representative buildings with good statistical characteristics and visited them to install measuring devices for on-site real-time data collection. Three hotels, two hospitals, and five offices agreed to install the devices.

Fig. 1 shows the arrangement of the measurement devices. Electricity consumption, fuel consumption, and important physical quantities such as temperatures and flow rates were measured. The results are transmitted through communication lines to a lab located at the KIER (Korea Institute of Energy Research) for processing.

The physical quantities were measured with the devices listed in Table 2. The measuring time interval was 4 min, and the span was 12–15 months, depending on the local situations.

2.2. Data processing and load model development

We used the following notations for systematic organization of the data and consistent presentation of the results.

- Capital letters represent the load types: *E* - electricity, *H* - heating, *C* - cooling, *W* - hot water
- Superscripts represent the day of the year
- Subscripts represent the hour of the day

Accordingly, E_h^d represents the hourly electricity demand for the *h*-th hour of the *d*-th day of the year.

A preliminary analysis of the data revealed the following features:

- There are conspicuous weekly periodic patterns in all of the energy consumption profiles. These patterns were conveyed in the 365-day variations when load models were derived (see Figs. 7–10.)
- The daily sums vary significantly throughout the year.
- The hourly patterns for a day depend weakly on the month and the day of the week.

Table 1
Number of buildings surveyed and measured.

Building types	Hotel	Hospital	Office
Sent Survey	58	52	121
Replied	16	14	13
Measured	3	2	5

Based on these observations, load models for electricity, cooling, hot water, and heating were developed as follows.

2.2.1. Electricity load

Electricity demand for a building consists of different components:

- General power demand for lighting, elevators, ventilation fans, and supply and discharge pumps. These components vary regularly around a steady mean value throughout the year.
- Power demand for the operation of refrigerators and cooling systems such as cooling water pumps, cooling tower fans, cold water pumps, etc. These components are needed during the cooling season only.
- Power demand for the operation of heat pumps and heating devices such as boiler pumps, heat exchanger pumps, hot water supply pumps, etc. These components are needed for the heating season only.

To develop independent models for each type of load, separating the electricity used for cooling and heating is important to prevent double counting. In principle, the separation should be done by separately counting the amount of electricity consumed by refrigerators, heat pumps, and ancillary devices. However, this separation was impossible because only collective sums were available in most of the data. Consumers and utility companies seldom separate electricity consumption by device. Fortunately, we were able to circumvent the problem by exploiting climate patterns. There are two spans of time during the year when neither cooling nor heating is needed (from mid-September to early November and from April to May). We will call these spans *the neutral seasons*. We investigated both survey data and on-site data before deciding the span for these periods. The buildings kept precise records for the start and end dates of heating and cooling. We used those dates to separate the heating, cooling, and neutral seasons. This means that we used different neutral periods for hotels, hospitals, and offices. We assumed that the pattern of the general electricity component (consumption other than that from refrigerators, heat pumps, and ancillary devices) changes less profoundly throughout the year.

The general components of a non-neutral month are assumed to have the same patterns as the nearest neutral month. The main purpose of the models is system analysis for energy planning or feasibility studies, so we do not consider detailed system dynamics or control strategies. Based on this assumption, we derived the electricity load model as follows. The effects of daylight on the electricity are reflected in the model by providing hour-by-hour patterns throughout the year.

1. Electricity load models for only the neutral seasons were developed by statistical treatment of the data for those periods.
2. The general components of the nearest non-neutral month were used for non-neutral months.
3. The excess electricity was estimated for the months of the non-neutral seasons.
4. The excess electricity was converted to heat energy for the heating season and to cooling energy for the cooling season.
5. The final heating and cooling load models were adjusted while accounting for the energy found in step 4.

2.2.2. Cooling load

Estimation of the cooling load depends on the type of refrigeration system. For an electrical refrigeration system (vapor compression), electricity consumption for cooling is the difference