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# Energy load superposition and spatial optimization in urban design: A case study

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ABSTRACT

Building energy consumption accounts for a large portion of total energy-use in a city or a regional district. However, energy load spatial distribution has seldom been considered during urban design phase. And energy conservation and energy efficiency measures pay more attention to individual building than buildings in a district or regional space as a whole. If buildings with different functions are mixed together and share same energy system, the savings on system capacity and peak electricity load can be significant. In this paper, a load superposition concept is proposed. The term 'superposition' refers to overlapping of energy demand load curves from different buildings and so that the total peak is smaller than the sum of individual peaks. Three spatial optimization methods of demand side load management and three different schemes of energy systems are proposed in this paper. And economic analysis is recommended to evaluate the different energy systems. The applicability of different approaches and the significance of load superposition was analyzed and elaborated through a case study to offer planners a feasible way for evaluating the potential of load spatial optimization.



## 1. Introduction

With rapid industrialization and urbanization in developing countries, the consumption of fossil fuel increases perpendicularly (Budzianowski, 2011, 2012; Mohr, Wang, Ellem, et al., 2015; Tsinghua University, 2013). According to the statistical analysis, a large portion of energy in cities of many parts of the world is used for building heating and cooling. However, energy used for building heating and cooling fluctuates drastically throughout a whole year compared with other energy demand in buildings. It is urgent to find out a suitable and effective way to ensure the low peak energy value. Thus, district level or regional level urban planning of energy systems inevitably plays an indispensable role in energy conservation management. The original definition of 'region' refers to social communities that dwell in specific areas of any scale (Smith, 2003). In this paper, 'region' is defined as planning land area and normally it is about 1–10 $km^2$. Energy system spatial optimization of heating and cooling is taken into greater consideration. Energy systems in this paper refer to energy, such as gas and electricity, used to provide heating and cooling in the planning area. Usually regional energy infrastructures are built with the construction of a city, and the infrastructure cannot be easily modified or rebuilt once finished. Therefore, during the planning phase, an elaborate energy planning is one of the top priorities.

In traditional design, energy supply is designed to meet energy demand one to one basis. Namely, total energy supply is the sum of all peak load of demand. But actually, electricity peak and valley time occur differently in different types of buildings (Li, Zhang, & Chen, 2010; Zhang & Long, 2010). That is to say, the peak loads of demand do not happen simultaneously, so it does not make sense to design a system with a capacity of providing energy that equals to the sum of all peak load of demand. The load discrepancy between different building types at regional level has been regarded as a virtual resource for a long time, but there are still few examples on how to realize them in district planning.

The methods of regional energy planning are divided into two main categories, top-down approach and bottom-up approach (Chingcuanco & Miller, 2012; Kim, Sting, & Loch, 2014). In this paper, bottom-up approach is adopted to in order to reduce the total and peak energy consumption. We calculate cooling and heating load of each building, and then load superposition is done to get the total peak. According to different values of total peak got by different spatial arrangements, we can make sure which way can get the lowest total peak.

One prospective of district energy planning is DSM (Demand Side Management). DSM includes energy efficiency retrofitting and load management and it is normally used for existing buildings. The prime concern of energy efficiency management is to adopt advanced energy-saving technique and high-efficiency appliances, whereas load management lies in shifting peak load (Finn, Fitzpatrick, Connolly, et al., 2011; Nie, 2006; Wilhite, 2007). For new construction, Liang and Long (2010) developed a model of regional energy. In this model, by comparing different scenarios of energy supplying to demand, an optimal solution can be determined and this solution will lead to increased energy-consuming efficiency and the declined peak power grid load. Long and Liang (2011) pointed out that because electric is hard to store, off-peak electric energy should be stored by means of heat/cool

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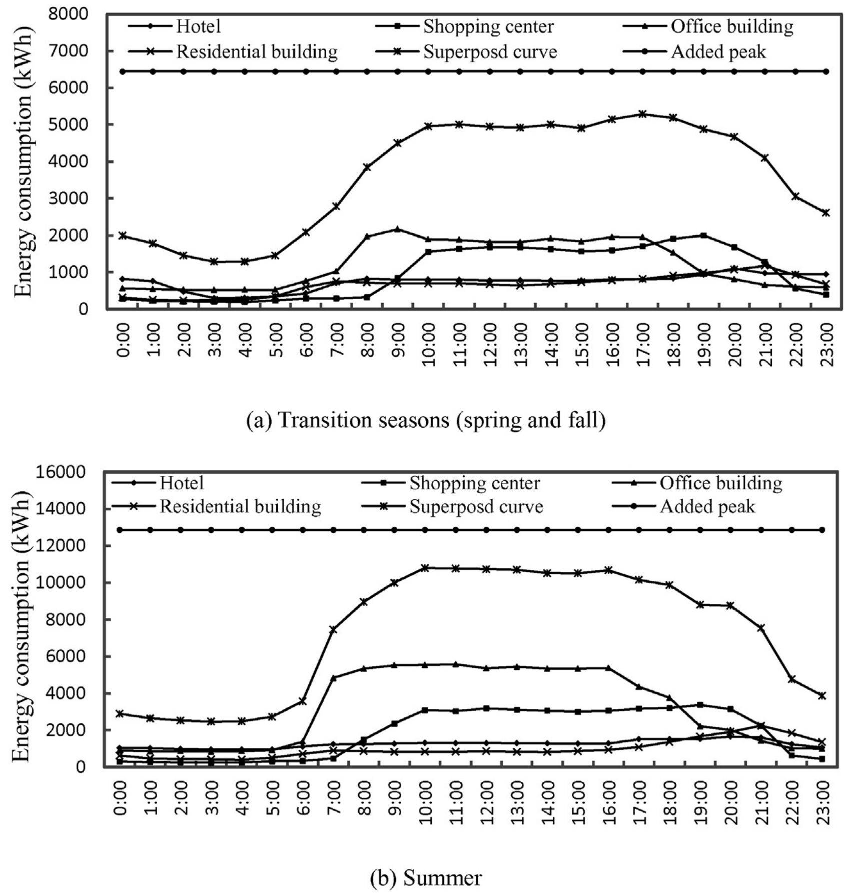


**Fig. 1.** Energy demand curve of measured data from four buildings.

storage and then released during peak times. In this way load shifting can be attained, while less total energy is used by avoiding two conversion processes in conventional electric storage, the charge and discharge. Nikonowicz and Milewski (2012) addressed that DER (Distributed Energy Resource) system has great development potential. One of the most important reasons is that DER system can compensate load from different buildings at different time, and so the overall total peak load can be shifted. In the paper, different system schemes have been compared, and DER system is taken into consideration.

Energy storage is not always the most effective way to minimize peak load. Instead, it is more important to optimize energy demand, in particular the spatial distribution in district planning phase. Energy load superposition refers to overlapping energy demand curves from different buildings. The superposition can not only reduce the peak demand and installed utility capacity in a region, but also improve the overall grid security and economics with an overall flat energy demand curve. Undoubtedly, this type of load arrangement at regional level can treated as one type of passive demand side management methods. Energy load superposition and load spatial optimization can be utilized to reduce peak energy consumption to some extent in a region with diversified building functions. In addition, previous researchers have found that peak load shifting through demand-side load spatial optimization can not only ease pressures of the grid but also bring considerable economic benefits to energy users (Ashok & Banerjee, 2000; Gang, Wang, Gao, et al., 2015; Kurz, 2002; Middelberg, Zhang, & Xia, 2009; Van Staden, Zhang, & Xia, 2011; Wilhite, Shove, Lutzenhiser, & Kempton, 2000).

Fig. 1 is an example of energy system superposition. Four lines at the bottom are measured energy demand curve of four real buildings, a shopping center (40,000 m$^2$), an office building (98,830 m$^2$), a residential building (63,000 m$^2$), and a hotel (19,991 m$^2$). The added peak of three buildings is much higher than the superposition load curve. Therefore by mixing buildings of different functions together, the overall installed capacity of energy system can be much lower. Although the concept is simple, it is seldom a practice during urban design, because normally location and function of buildings were set first before engineers start to design energy system.

In this paper, a method of energy load superposition is proposed at the regional level. This paper focuses on the load superposition in the regional energy system planning and three specific spatial load optimization methods of calculation are provided, 1) simultaneity factor method, 2) site survey method and 3) simulation method. An actual regional energy planning case study was performed to illustrate the effect and significance of load spatial optimization and peak shifting.

## 2. Methodology

### *2.1. Method of load spatial superposition*

#### *2.1.1. Simultaneity factor method*

In this method, load intensity index, formulated in national or local codes, refers to the cooling and heating load density of different types

**Table 1**
Introduction of the three types of energy systems.

| No. | System | Description |
|---|---|---|
| 1 | Distributed system | Household air-conditioner or VRV system is used in each building |
| 2 | Small-scale central system | A small-scale central system is chosen in each function zone. Chiller and gas boiler are used to supply cooling and heating. |
| 3 | Regional central system | Four regional central energy plants are built in the whole region. Chiller and gas boiler are used for space cooling and heating, |