Sustainable Cities and Society 43 (2018) 451–461

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

# Energy consumption of subway stations in China: Data and influencing factors

Bowen Guan, Xiaohua Liu, Tao Zhang*, Jianjun Xia

*Department of Building Science, Tsinghua University, Beijing 100084, China*

ARTICLE INFO

*Keywords:*
Energy consumption
Statistic analysis
Influencing factors
Subway stations

ABSTRACT

Subway transportation systems are in rapid development and energy consumption in subway stations is becoming more and more significant. The present paper aims to reveal the electricity consumption of subway stations for non-traction purpose, and data from 341 subway stations in 5 cities in different climate zones in China have been statistically integrated and analyzed. The results demonstrate that the average annual electricity consumption ranges 1.8–2.3 million kWh in underground non-transfer stations. Electricity consumption per unit floor area is taken as the benchmark to evaluate the energy performance with an annual average value of 131–144 kWh/m$^2$ in each city. The VAC (ventilation and air conditioning) system and lighting system are found in dominant positions of the total electricity consumption, accounting for about 46% and 27% respectively in City A. Influencing factors of the energy consumption are also analyzed, including floor area, annual passengers, CDD (cooling degree days), service year, PSD (platform screen door) system, platform type and number of entrances. These factors are compared and classified into three categories according to the degree of influence on energy consumption. The current information provides references for understanding the energy consumption level and establishing energy consumption standards for subway stations.

## 1. Introduction

As the backboneof urban public transportation, subway system provides convenient and efficient transit in modern cities. The subway network is a complex system and a huge energy consumer. For example, the London Underground, the most long-standing subway system, is the single biggest consumer of electricity in London and one of the top 10 electricity consumers in the United Kingdom (Transport for London, 2011). Chinese Urban Rail Transit, with a route length of more than 4000 km, is reported to consume an electricity power of 11.1 billion kWh, accounting for 1.88‰ of the total Chinese electricity consumption in 2016 (China Association of Subways, 2017; National Energy Administration, 2017). It is urgent and significant to reduce the energy consumption of the subway system.

As for the subway system, abundant studies have paid close attention to the energy consumption of rolling stock and corresponding measures for its energy saving (Ghoseiri, Szidarovszky, & Asgharpour, 2004; Lin, Li, Zhao, & Yang, 2016; Ye & Liu, 2016). Energy consumption for non-traction purpose is usually responsible for 30%–50% of the total energy consumption (Li, 2011; Transport for London, 2009). Despite its importance, there have been scarce studies on energy consumption of subway stations for non-traction purpose in comparison to those on rolling stock.

In the subsystem stage, previous research on energy conservation can be divided into two aspects, i.e. performance of key subsystems and different operation strategies. Main subsystems in subway stations include VAC system, lighting system, vertical transportation system and others. The VAC subsystem in subway station accounts for about 30% of the total energy cost in North China, and nearly 50% in South China (Li, 2011; Lu, He, Pei, & Chen, 2011). Lighting subsystem has been revealed a significant energy consumer in a subway station, responsible for 37% of the total in Barcelona (Casals, Gangolells, Forcada, Macarulla, & Giretti, 2014), and it has been declared that LED lighting will save energy by a considerable scale and reduce maintenance requirements in subway stations (Anderson, Maxwell, & Harris, 2009; Zhao, 2017). Platform screen door (PSD) installed has been demonstrated to contribute to energy saving with different significances in different regions (Han, Lee, & Jang, 2015; Zhang, Gong, Kang, & Han, 2011; Zhu et al., 2016). As for vertical transportation, Kuutti and Sepponen have analyzed the energy consumption of escalators in a subway station and have offered energy saving suggestions based on the periodical pedestrian patterns (Kuutti, Sepponen, & Saarikko, 2013). With respect to operation strategies, VAC strategies will directly influence the energy consumption in subway stations (Le, Hwangbo, Kim, & Yoo, 2017).

* Corresponding author.
*E-mail address:* zt2015@mail.tsinghua.edu.cn (T. Zhang).

https://doi.org/10.1016/j.scs.2018.09.018
Received 23 December 2017; Received in revised form 7 September 2018; Accepted 14 September 2018
Available online 17 September 2018

**Nomenclature**

| | |
|---|---|
| A | Floor area ($10^3$ $m^2$) |
| $A_{service}$ | Floor area per entrance ($10^3$ $m^2$) |
| $C$ | Regression coefficient |
| $C_0$ | Constant |
| $CDD$ | Cooling degree days |
| $EC_a$ | Additional energy consumption in cooling months (kWh/$m^2$) |
| $EC_b$ | Basic energy consumption (kWh/$m^2$) |
| $EC_i$ | Energy consumption in month i (kWh/$m^2$) |
| $EC_t$ | Total energy consumption (kWh/$m^2$) |
| $EC_u$ | Energy consumption of underground non-transfer stations (kWh/$m^2$) |
| $m$ | Number of moths without cooling supplied |
| $n$ | Number of days in the year |
| $N$ | Number of entrances |
| $P$ | Number of annual passengers (million) |
| $PT$ | Platform type |
| $T_j$ | Daily mean temperature for day j (°C) |
| $T_r$ | Reference temperature (°C) |
| $y$ | The year of the station starting to use |

*Greek symbols*

| | |
|---|---|
| $\varepsilon$ | Random error |

Yang has compared different VAC operation strategies to determine the best for energy saving with similar environmental performances (Yang, Zhang, & Xia, 2018). Some studies have provided a solution for using the piston wind to reduce the air-conditioning consumption (Li, Chen, Yan, Pan, & Zhang, 2014; Shen, Wu, & Dong, 2005). Researches using artificial intelligence and automatic control systems have also been conducted to minimize the energy consumption of VAC subsystem (Shi, Xu, Zheng, & Zhu, 2014; Wang, Feng, & Xi, 2017; Zhang & Wei, 2012).

In the overall energy consumption stage, investigation on energy consumption for non-traction use can be divided according to the sample scale. On single station scale, Casals et al. (2014) focused in particular on a breakdown of the energy consumption by major subsystems in an underground station in Barcelona. Fu and Deng (2009) investigated the energy cost of main parts in Guangzhou railway station. On multiple-station scale, energy consumption of all subsystems in Kobe subway stations has been broken down and analyzed in different seasons (Kobe Traffic Bureau, 2004). Leung and Lee (2013) have gathered the energy consumption data of 19 subway stations in Hong Kong and tried to estimate the consumption. Hong and Kim (2004) have revealed the energy consumption level of subway stations in four Korean cities and the climatic effect on energy consumption has been briefed, however, energy consumption of main subsystems in these stations hasn't been separated and discussed. Zhang et al. (2017) have proposed operation models for stations in different cities with energy conservation performance given. Consequently, there are still limited studies or data to compare and analyze the energy consumption performance in multiple stations in different regions.

Power demands in subway stations are likely to increase continually in China and more attention should be paid on its energy consumption analysis and conservation strategies (Liang, Liu, Cao, Zhong, & Liao, 2008). The limited knowledge of energy consumption level of subway stations in China has challenged the energy consumption evaluation, leading to the lack of unified benchmark or standard. Energy consumption data for non-traction purpose in subway stations in different climate zones will be revealed in the present research. The consumption levels of different stations and the breakdown of the overall energy cost will be emphasized. Influencing factors will also be explored to help in understanding the discrepancy of energy consumption in stations in different cities.

## 2. Background information

### 2.1. Basic information

In the present research, 341 subway stations in different climate zones in China are selected to investigate the energy consumption and influencing factors, referring to 12 subway lines in five cities. The data is provided by the local subway companies. Annual passengers and energy consumption data in 2015 are collected in Cities A, B, D, E according to the station record system, whereas data in 2016 is collected in City C.

The detailed information of these subway lines is shown in Fig. 1

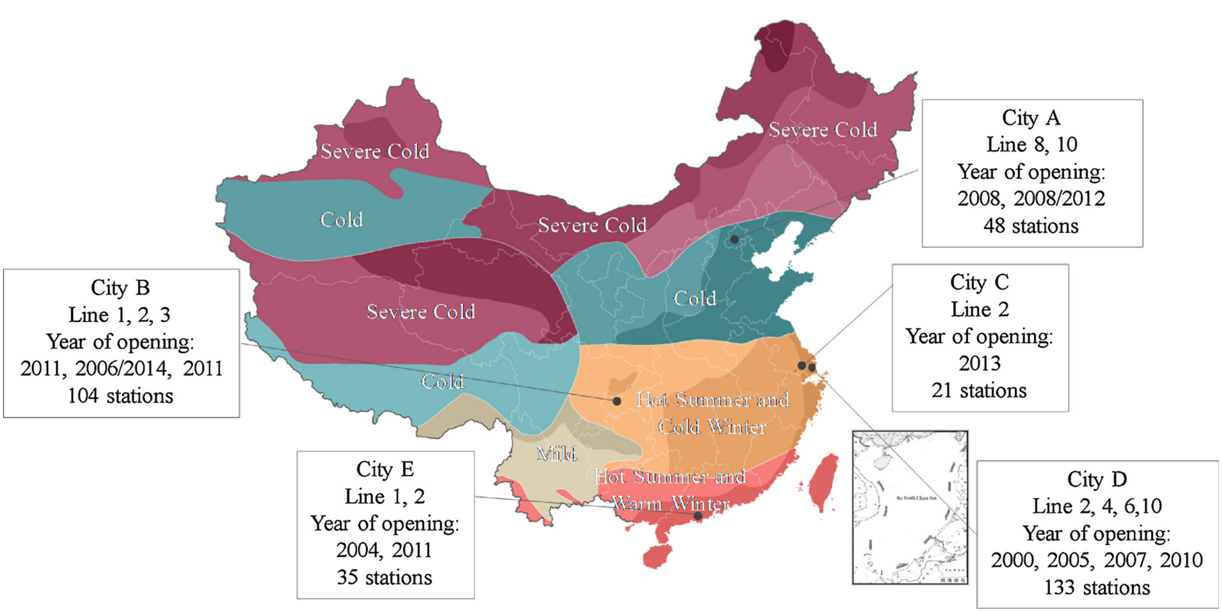


**Fig. 1.** Locations and climate zones of subway stations surveyed in this paper.