Energy and Buildings 133 (2016) 810–822

Contents lists available at ScienceDirect

Energy and Buildings

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

A study on the energy performance of school buildings in Taiwan

Jen Chun Wang

Department of Industrial Technology Education, National Kaohsiung Normal University, No.62 Shenjhong Rd., Yanchao District, Kaohsiung 82446, Taiwan

ARTICLE INFO

Article history:
Received 22 July 2016
Received in revised form 15 October 2016
Accepted 21 October 2016
Available online 24 October 2016

Keywords:
Energy consumption
Energy consumption intensity
Energy audit
School buildings
Educational buildings

ABSTRACT

The energy consumption (EC) conditions of 51 universities, 7 high schools, 11 middle schools, and 5 elementary schools were examined in the present study. The energy use intensity (EUI) values of the universities, high schools, middle schools, and elementary schools were 79, 26, 16, and 17 kWh/m^2/year, respectively. The average energy use per person (EUP) values of the universities, high schools, middle schools, and elementary schools were 1855, 734, 310, and 289 kWh/person/year, respectively. Universities serve complex functions; they contain various teaching, research, and testing equipment and rely heavily on air-conditioning to create comfortable indoor spaces. Therefore, universities consume far more energy than middle and elementary schools. The average EC structure of the schools consisted of 93% electricity and 7% fuel and gas. Therefore, electricity should be the principal concern for schools in energy conservation. A considerable difference was observed in the EC conditions of different universities. Particularly, universities centered on academic research and development exhibited a higher EC than did those focused on teaching solely. The average EC of public universities was also higher than that of private universities, and the characteristics of the colleges in the universities significantly influenced EC. A regression model was established to determine the EC of school buildings and observe the correlations between EC-related variables. The results indicated that air-conditioning and lighting were the key factors influencing school building EC. In conclusion, several feasible energy conservation techniques are proposed in the present study. The current findings can guide school authorities in evaluating their EC and determining optimal energy saving conditions.

1. Introduction

School buildings or educational institutions are primary drivers of energy consumption (EC) in many countries. In the United States, school buildings account for 13% of the total energy consumption (TEC) of commercial buildings, ranking fourth behind retail buildings (32%), offices (18%), and hotels and restaurants (14%) [1]. School buildings account for 10.8% of the total electricity consumption of buildings in the United States, ranking third behind offices (20.4%) and retail buildings and malls (20.4%) [2]. Moreover, school buildings are also the third most energy-consuming buildings in the United Kingdom, behind only commercial buildings and offices [3]. Although Taiwan has yet to collect precise data on the EC of building types, the *Energy Audit Annual Report for Non-Productive Industries* published by the Bureau of Energy, Ministry of Economic Affairs, in 2015 reported that the EC of school buildings accounted for 14.4% of the energy consumed by high-voltage customers, ranking second behind hospital buildings (14.9%) [4]. These statistics confirm the immense EC of school buildings.

2. Literature review

International and domestic studies concerning school building EC are presented in Table 1. In these studies, energy use intensity (EUI) is a standard factor used for evaluating and comparing the annual consumption of fuel, gas, electricity, and other forms of energy in school buildings. EC is measured in kWh divided by the gross floor area (GFA) of a school building to obtain the annual EC per unit GFA. Most studies have adopted kWh/m^2/yr as the measure for EUI, and only one study adopted MJ/m^2/yr. The observation of this study was converted to kWh/m^2/yr to achieve a consistent measure for all of the studies. Accordingly, the average EUI for school buildings worldwide was determined to be 55–405 kWh/m^2/yr. In the present study, the unit of kWh/m^2/yr was used to describe EUI.

Previous literature has confirmed the association between EUI and climate. Excluding the findings of studies in South Korea [5], those obtained in the European studies indicated that EUI was typically higher in regions with harsh climatic conditions than in those with pleasant climatic conditions. For example, cold inland regions of Slovenia exhibited an average EUI of 192 [6], high-latitude regions of Finland exhibited an average EUI of 214 for elementary and middle schools and 229 for universities [7], and computer-

E-mail addresses: jcwang@nknucc.nknu.edu.tw, jck4928@ms39.hinet.net

http://dx.doi.org/10.1016/j.enbuild.2016.10.036
0378-7788/

Table 1
Literature review of energy consumption and energy use intensity of school buildings worldwide.

Country or region	Source	Energy use intensity (EUI)(kWh/m^2/yr)	Description
Cyprus	Katafygiotou and Serghides [13]	62.75–116.22	Energy consumption survey 24 secondary schools Discussion of the EUI, gross floor area, number of staffs and students 107.99 kWh/m^2/yr in mountainous areas, 55.67 kWh/m^2/yr in inland areas, 48.44 kWh/m^2/yr in coastal areas
Slovenia	Butala and Novak [6]	192	Energy audit 24 school buildings Energy consumption survey 100 kWh/m^2/yr for heating and the average total energy consumption is 192 kWh/m^2/yr
Ireland	Hernandez et al. [15]	55–235	Energy consumption survey In Irish primary schools electricity is between 5 and 35 kWh/m^2/yr and for heating is between 50 and 200 kWh/m^2/yr with an average consumption for heating at 96 kWh/m^2/yr
Stuttgart (Germany)	Beusker et al. [14]	93 (31–205) heating energy consumption only	Energy consumption survey 105 school buildings Discussion of the relation of energy consumption with population parameters and the other factors
Greece	Centre for Renewable Energy Sources [9]	92	Energy consumption statistics in schools
Greece	Santamouris et al. [10]	95	Energy consumption survey 320 school buildings 68 kWh/m^2/yr for heating and 27 kWh/m^2/yr for electricity consumption
Euros (Greece)	Vagi and Dimoudi [11]	79.82	Energy audit 10 elementary schools 71.18 kWh/m^2/yr is required for heating and 8.64 kWh/m^2/yr for electricity
Luxembourg	Thewes et al. [19]	93 (24–197)	Energy consumption survey 68 school buildings 77 kWh/m^2/yr in using a district heating system and 66 kWh/m^2/yr in using a pellet boiler for thermal end energy All schools which were constructed after 2005 consume less than 100 kWh/m^2/yr and less than 50 kWh/m^2/yr of thermal energy
Espoo (southern Finland)	Sekki et al. [7]	214 (schools) 229 (Universities)	Energy consumption audit 74 school buildings and 13 university buildings In schools, 383 kWh/m^2/yr to 31 kWh/m^2/yr for heating, and 212 kWh/m^2/yr to 10 kWh/m^2/yr for electricity In universities, 178 kWh/m^2/yr to 6 kWh/m^2/yr for heating, and 450 kWh/m^2/yr to 89 kWh/m^2/yr for electricity Newer schools consume less heating energy
Portugal	Lourenço et al. [12]	67	Energy audit 8 secondary schools 16 kWh/m^2/yr referred to gas use and 51 kWh/m^2/yr referred to electricity use Discussion in the schools was 41 kWh/m^2/yr before the refurbishment and 67 kWh/m^2/yr after the refurbishment
South Korea	Kim et al. [5]	405 Study area only	Energy audit 10 elementary schools 289 kWh/m^2/yr y for electricity, 26 kWh/m^2/yr for oil, and 90 kWh/m^2/yr for gas 42–112 kWh/student·monthly
UK	Bull et al. [8]	173 (132–210) heating energy consumption only	Energy consumption simulation 4 school archetypes
Taiwan (This study)	Wang (2016)	16–79	Energy consumption statistics in schools 74 school buildings 79 kWh/m^2/yr in universities, 26 kWh/m^2/yr in senior high schools, 16 kWh/m^2/yr in junior high schools and 17 kWh/m^2/yr in elementary schools Discussion of the relation of energy consumption with various factors

simulated building samples for the United Kingdom exhibited a peak EUI of 173 [8]. However, the EUI data of temperate southern Europe were comparatively lower. For example, a series of tests in Greece, whose climate is regulated by the warm Mediterranean Sea, exhibited an EUI ranging between 80 and 95 at different times of the year [9–11]. Portugal, a seaside country with a latitude similar to that of Greece, exhibited an EUI of only 67 [12], whereas Cyprus, also a Mediterranean country with warm winters, exhibited an EUI