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Building energy: a review on consumptions, policies, rating schemes and standards

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Abstract

The building and construction sectors account for more than one third of the global energy consumption. In order to understand the status quo of building energy around the world, a study, as reported here, reviewed the energy consumptions of the major countries/places, their energy policies and rating schemes and standards applicable to building energy use. The review shows that countries with abundant energy resources tend to consume more energy per person than those with less energy resources. Some developing countries have green building rating schemes in place, but many others have not adopted any building energy standard. For those countries who have the standards in place, they may find it difficult to implement the standards in reality. In addition, some new building energy standards have been released lately; studies that make reference to such standards are yet to be seen. Research in future should investigate how the building energy standards could be effectively adopted to reduce building energy use.

Keywords: Building; energy; policy; rating scheme; standard

1. Introduction

The rapid growth of the global energy consumption has caused not only the potential energy crisis but also severe environmental problems such as global warming and air pollution, which endanger people's health and properties. Therefore, intergovernmental organizations and governments around the world have put in place policies to

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encourage energy reduction and carbon mitigation. According to the United Nations Environment Programme (UNEP), the construction and building sectors account for over one-third of the global final energy use, and 230 billion square meters of floor areas are expected to be newly constructed in the world in the next 40 years [1]. For example, the residential and commercial sectors respectively account for 21% and 19% of the total energy use in the U.S. in 2016 [2]. Space heating consumes most of the energy consumption in U.S. homes (42% of total) whereas in commercial buildings, space heating consumes 25% of the total energy in 2012 [3,4]. As far as the commercial sector is concerned, China as a developing country does not consume as much energy as the developed countries, but shares 25% of the total energy use in the global residential sector [5]. Intended to understand the status quo of building energy around the world, this paper provides a review on the energy consumptions and policies of the major countries/places and the rating schemes and standards for assessing building energy use.

2. Methodology

The research method of this study consists of record data analysis and literature review. Energy consumption data of main countries and places (e.g. U.S., Hong Kong) from 2000 to 2015 were collected from the World Bank [6]. Detailed energy consumption data of the building sector were gathered from governments' statistics reports.

Since the energy units used by individual countries are not identical, the conversion factors published by the International Energy Agency (IEA) [7] were applied to standardize all such energy units to kilo tons of oil equivalent (ktoe). Building energy consumption data of the U.S., collected from the Monthly Energy Review of Energy Information Administration (EIA), were in trillion Btu [8], where 1 trillion (short scale) = 1 tera (T); 1 TBtu = 25.1995761 ktoe [7]. The data of the U.K. refer to those in the Energy Consumption in the U.K. (ECUK) report 2017 released by the Department for Business, Energy and Industrial Strategy [9]. The energy unit adopted by the U.K. is ktoe. China's building energy consumption data were downloaded from the official website of the National Bureau of Statistics of China [10]. China's energy unit is 10000 tons of standard coals equivalent (tce), and 1ktce = 0.7 ktoe. Building energy data of Australia were collected from the Australian Energy Statistics; the energy unit is PJ, where 1 PJ = 23.8845897 ktoe [11]. Building energy data of Hong Kong, promulgated by the Electrical and Mechanical Services Department, were in TJ (1 TJ = 0.0238845897 ktoe) [12].

The literature review was proceeded by using keywords (e.g. building, energy, policy, etc.) to search publications from well-known electronic databases: Science Direct and Springer.

3. Energy consumptions

3.1. Main countries/places

Raw energy consumption data of the main countries/places were downloaded from the World Bank's website and then a series of energy consumption trends were plotted. Developed countries such as the U.S. demonstrate a downward trend in energy consumption per capita whereas developing countries such as China tend to consume more energy in recent years [Fig 1]. As bunker fuel oil constitutes over half of Singapore's total oil demand and tankers preferred to fuel in Singapore instead of the Middle East before and during the Iraq war, the total energy consumption of Singapore peaked in 2014 [13]. Countries with abundant energy resources, such as Canada and Australia, tend to consume more energy per person than those with less energy resources, e.g. European Union. These observations correspond with the analyzed findings on energy use per capita by country's income level [Fig 2]. High-income countries consume 5 toe per person, which is about 5 times the level of the middle-income countries.

For most of the countries studied, fossil fuel accounts for more than 70% of their total energy use [Fig 3]. Among those countries, Singapore shows the highest ratio (98%) [Fig 3]. As a country with no oil or natural gas production, Singapore imported energy resources mainly from its neighboring countries [14]. With the Clean Energy policy, Singapore's energy use mainly relies on natural gas, which is a kind of fossil fuel. This causes the extremely high fossil fuel share of Singapore [Fig 3]. Ranked just behind Singapore, Hong Kong also has a high fossil fuel proportion – about 95%. The reason for this is that the Hong Kong Government insists in free market economy, focusing mainly on public safety and environmental protection while imposing little intervention on energy mix

[15]. Probably because of the reliance on nuclear electricity, the fossil fuel consumption of Japan was not high until 2011 when the Fukushima Nuclear Leakage occurred. As a result, nuclear electricity was substituted by fossil fuel electricity and the fossil fuel's share surged in the ensuing two years: rose from about 80% to 95% [Fig 3].

Renewable energy used to be characterized by advanced technology and high investment. However, low-income countries has a low proportion of fossil fuel energy consumption [Fig 4], which implies their heavy reliance on renewable energy. Conversely, the proportion of fossil fuel energy consumption of high- and middle- income countries was high, at around 80%. Before 2010, the high-income countries had a slightly higher proportion of fossil fuel than the middle-income countries [Fig 4].

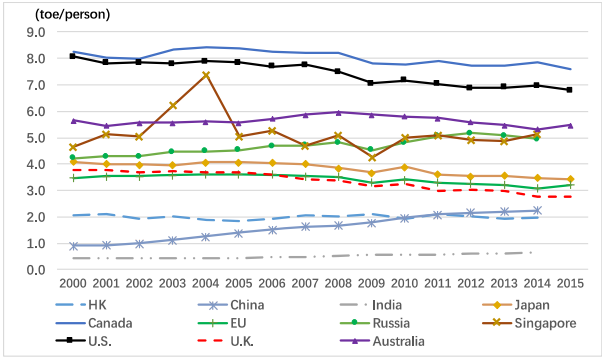

Fig 1. Energy use per capita of major places

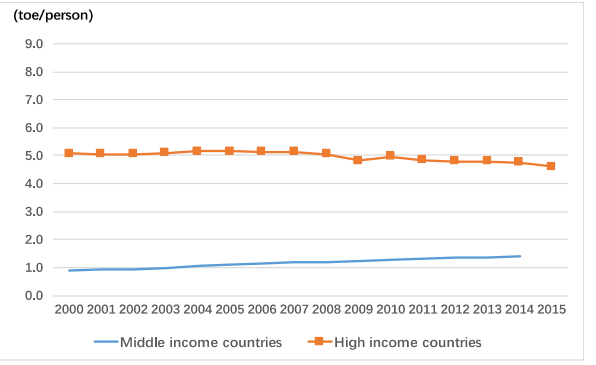

Fig 2. Energy use per capita by countries' income level

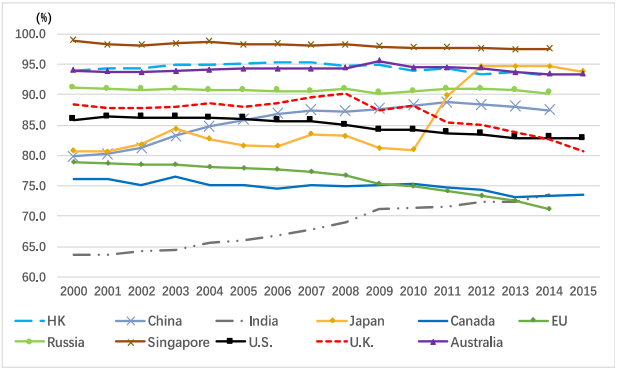

Fig 3. Fossil fuel energy consumption (% of total energy consumption) of major places

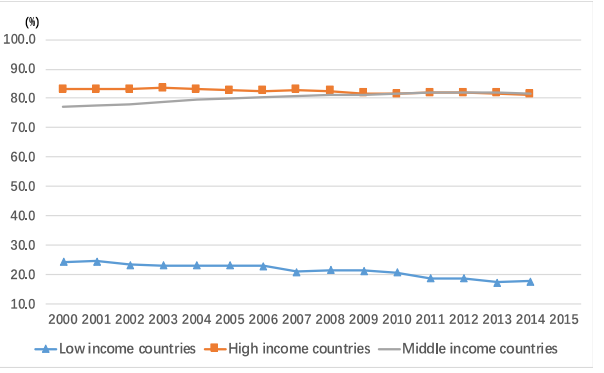

Fig 4. Fossil fuel energy consumption (% of total energy consumption) by countries' income level

3.2. Building sector

In the U.S., both the residential and commercial sectors consume about 500000 ktoe of energy per year [Fig 5]. With slight fluctuations over the years, the total energy consumption of the two sectors was close to 1000000 ktoe.

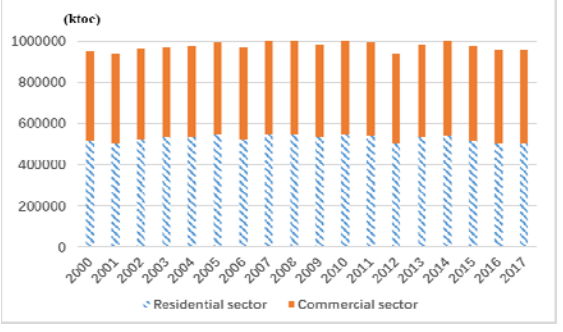

Fig 5. Building energy consumption in the U.S.

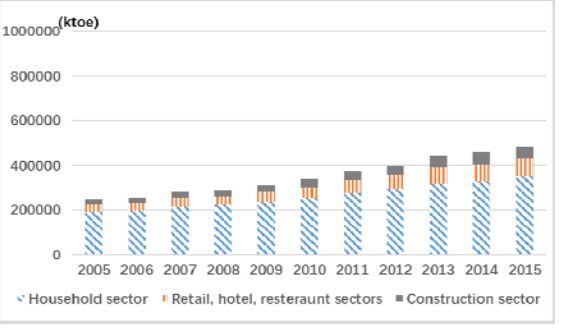

Fig 6. Building energy consumption in China

On the other side, the household sector, construction sector, and the retail, hotel, and restaurant sectors in China, for example in 2015, collectively consume about half of the energy used by the commercial and residential sectors in the U.S. [Fig 6]. In the U.K., the domestic sector consumes about 4 times the energy used by the commercial sector. With mild dips in some years, the annual total energy uses of the two sectors stood at around 60000 ktoe [Fig 7]. In Australia, the energy consumptions of the residential and commercial sectors have gradually increased since 2000, with their total amount approaching 20000 ktoe in 2015 [Fig 8].

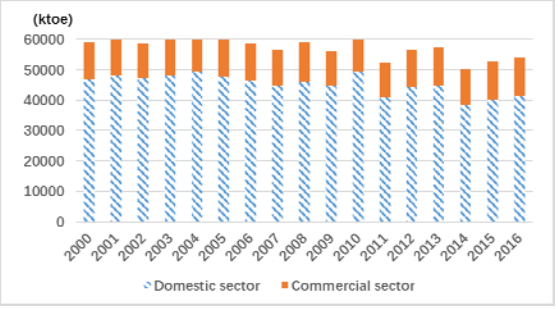

Fig 7. Building energy consumption in the U.K.

Fig 8. Building energy consumption in Australia

4. Energy policies

Building energy policy is a critical factor affecting the achievement of building energy efficiency [16]. Countries with limited natural resources tend to be more active in promoting green buildings or zero-carbon buildings. For instance, in Japan, the Act on the Rational Use of Energy was launched in 1979 and revised several times later on until 2008 [17]. Besides mandatory regulations, economic incentive measures are also adopted by the Japanese government in promoting green buildings and energy-efficient residential buildings [18]. In Singapore, The Green Building Masterplan, which is also known as the Green Mark Incentive Scheme for New Buildings, was first released by Building and Construction Authority (BCA) in 2006 and the latest release was in 2014 [19]. Each time, the incentive scheme allocates millions of dollars to encourage building owners to make their new buildings achieve at least the Green Mark Gold rating [19]. In 2005, the HK ***3030*** Campaign was promulgated by the Hong Kong Green Building Council with the aim of cutting ***30***% of the electricity consumption by 20***30*** (referencing the 2005 baseline) [20].

Referring to the four categories of building energy policy instruments defined by the UNEP [21], most building energy policies launched in China can be classified as control and regulatory policy instruments (e.g. Management Rules on Residential Building Energy Efficiency), and the other policy instruments include tax, energy label and carbon trading [21]. In India, the Energy Conservation Building Code (ECBC) was issued in 2007 as its first building energy code [22]. Newly revised in 2017, the ECBC focuses on large commercial buildings and specifies minimum requirements for energy performance on mechanical and HVAC systems, renewable energy, etc. [22].

5. Rating schemes

According to the World Green Building Council, there are more than 40 green building rating tools applied worldwide, including BREEAM, LEED, BEAM Plus, etc. [23]. Developed in 1990 by the U.K. Building Research Establishment Ltd., BREEAM is believed to be the first building environmental performance rating system in the world and it is now employed by 77 countries covering all building, infrastructure and master-planning projects [24]. Released by the U.S. Green Building Council in 1994, LEED devoted to promote energy-efficient, cost-effective building designs that are healthy for occupants [25].

In Hong Kong, the commonly used green building assessment tool is BEAM Plus, which was upgraded from BEAM – the previous version issued by the Hong Kong Green Building Council in 1996. BEAM Plus is tailored for the Hong Kong's high-rise, high-density built environment [26]. The India Green Building Council also provides specific rating systems for different types of buildings [27]. Other eminent building rating schemes include Green Star of Australia, BCA Green Mark Scheme of Singapore, ASGB of China, and CASBEE of Japan [28].

Recently, a study compared the evaluation criteria of 15 renowned green building rating systems and the results demonstrate that water and material aspects are evaluated by all the 15 schemes, whereas energy, indoor environment, site, land and outdoor environment, innovation, waste, construction project management are key criteria evaluated by most of the rating systems [28].

6. Standards

Building energy codes and standards, by setting up minimum requirements for energy-efficient building design, construction, operation and management, play an important role in achieving building energy efficiency. However, a survey result of building energy regulations reveals that 42% of the surveyed countries, most of which being developing countries, do not have building energy standards at all [29].

International and national organizations such as ISO and ASHRAE have published standards on building energy efficiency and building energy audit. So far, there are over 155 ISO standards concerning energy efficiency (e.g. ISO 50000 serial standards) [30]. For instance, ISO 50001 illustrates energy management system requirements for organizations to achieve energy reduction and save cost while ISO 50002 introduces energy audit procedures to general organizations [31,32]. Issued in 2017, ISO 52016 focuses on energy performance of buildings and specifies calculation methods for building energy assessment [33]. Previous studies on building carbon emissions (e.g. [34,35]) were commonly conducted with reference to the Greenhouse Gas Protocol. Newly published ISO 16745, focused on carbon audit for buildings [36], has not yet attracted much attention from researchers. In contrast, ISO 50001 or ISO 50002 has been frequently studied [37,38]. The literature search completed so far could hardly find any published studies on ISO 16745 and only a few papers mentioned ISO 52016 [39]. As regards ASHRAE, Standard 90.1 is a popular building energy standard cited by reviewed papers, especially those focused on commercial buildings and computer simulations [40].

7. Conclusions

In developed countries with sufficient natural resources, the consumption of fossil fuel is significantly higher than that in developing countries. In order to curb the global warming resultant from the massive use of fossil fuel, those developed countries should demonstrate more determination on energy reduction and introduce more measures to encourage the use of renewable energy. As developing countries are likely to consume more energy in parallel to the expansion of their commercial sector, the policy-makers of such countries should formulate measures for minimizing the energy consumptions of commercial buildings.

Some developing countries have green building rating schemes in place, but a wider adoption of such schemes necessitates more promotion to, and acceptance by, the industries, building owners and end-users.

Many developing countries have not adopted any building energy standard and those who have the standards in place may find it difficult to implement the standards in reality. Moreover, even newly published papers on building energy do not refer to the newest building energy standards. Research in future should investigate how the building energy standards could be effectively adopted to reduce building energy use.

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