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Drivers of moderate increase in cooling energy use in residential buildings in Hong Kong

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ABSTRACT

Increase in cooling energy usage of the residential sector in Hong Kong has been moderate in the most recent ten years (2004–2013). Factors and drivers responsible for this are of interest to policy makers in search of performance improvement but such information is not available in extant literature. This paper reviews the policy instruments introduced in Hong Kong during this period of time and examines the different engineering factors contributing to improvements in cooling energy efficiency. Whether the policy instruments have been instrumental in bringing about changes in engineering design and thus improvement in cooling energy efficiency is evaluated on the basis of the equipment and building envelope characteristics of 64 residential developments in Hong Kong. Different statistical analyses reveal that the use of more energy efficient room air-conditioning units (COP), smaller window-to-wall ratios (WWR) and walls with higher U-values are the engineering factors (WallU) that have contributed to moderation of growth of energy consumption; these were driven by policies introduced by the Hong Kong Government. Regarding the sensitivity of the three engineering factors, it was found that COP was the highest amounting to 0.455, followed in descending order by WallU and WWR. Their sensitivities were 0.289 and 0.006, respectively.

1. Introduction

Cooling energy usage in the residential sector is affected by physical, social and engineering factors [1]. Physical factors relate to population, climatic conditions and number of households [2]. Social factors relate to human behaviour and habit of using air-conditioners [3]. While engineering factors relate mainly to energy performance of room air-conditioners and heat gains through the building envelopes [4].

For physical factors, energy statistics in Hong Kong show that in the most recent ten years (2004–2013), annual cooling energy use of the residential sector increased by 11% [5] while population growth was 6% [6,7]. This rate of increase was quite moderate compared to the preceding ten years (1994–2003) when energy use increased by 42% [8] and the population growth was only 12% [6]. If compared to a prediction by Wong et al. indicating that the heat gain through building envelopes of high-rise residential buildings in Hong Kong could substantially increase due to the continuously changing climatic conditions [9], the rate of increase in cooling energy use in the recent ten years is considered highly acceptable.

The moderate increase in cooling energy use in recent years can therefore be attributed to social and engineering factors.

Literature on human energy usage behaviour and habits can broadly be divided between economics, where demand is calculated using income and price elasticity and social-psychological, where demand is determined by habits, social norms and moral behaviour [3]. With a continuous increase in the standard of living in Hong Kong (Human Development Index ranked 15th in the world [10]), Hong Kong people are economically and psychologically demanding a higher level of comfort, leading to wider use of air-conditioners in the residential sector [11]. Thus social factors are playing a negative role in reducing cooling energy use. The central role therefore is played by the engineering factors.

In the context of energy performance of RACs (room air-conditioners), new models being introduced are often with higher coefficient of performance (COP) because they are equipped with capacity control mechanism for the compressor [12]. However, other new technologies such as making use of the condenser waste heat for water heating (e.g. heat pump technology, air-water condenser, storage-enhanced heat recovery unit) [13–15] and reducing the space cooling volume by floor-based system [16] are still in very early stages of development.

Heat gains through the building envelope have been examined extensively and many research works have revealed the impact of

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thermal performance of building envelope on the amount of heat gain and heat loss in buildings [17–19]. Recent works have investigated the proper selection of phase change materials (PCMs) to form part of the building envelope based on thermo-physical properties and the climatic conditions of the locations of use [20–22]. On PCMs, recent works are focused on investigating the incorporation of different proportions of expanded graphite into construction materials for enhancing the overall thermo-physical properties of building envelopes [23,24]. There have also been studies that have investigated envelope designs to optimize cooling, heating and lighting energy usage [25]. To enable prediction of thermal performance of building envelopes, different mathematical models have been developed [26,27].

A relevant question in this context is whether policy instruments have resulted in changes in engineering design and thus improvements in cooling energy efficiency in the recent ten years? If yes, what are the engineering factors and their relative sensitivities? However, relevant information is not available in extant literature.

In this study, the cooling energy use, RAC units' performance and building envelope designs of high-rise residential buildings in Hong Kong constructed in the recent ten years, together with the relevant policy instruments are reviewed and analysed. Through the analysis and review, it is ascertained whether policy instruments have been the drivers for the better engineering designs and thus improvements in cooling energy efficiency. The relative sensitivity of various engineering designs is also evaluated. The results are expected to be useful for decision making by policy makers in search of performance improvement in building energy usage in Hong Kong and elsewhere in the world.

2. Influential factors for cooling energy use

2.1. Physical factors

Residential buildings in Hong Kong are classified into different segments, including public housing, private housing, subsidised sale flats and other housing. Other housing includes villas, bungalows and the like. The annual cooling energy usage for all segments in the two ten-year periods (1994–2003 and 2004–2013), according to the government database [5–7], are summarized in Table 1. It can be seen that the rate of increase in cooling energy usage in the two periods has been 42% and 11%, respectively while population growth has been 12% and 6%, respectively. To better reflect the rate of increase in cooling energy use over the two ten-year periods, the energy use and the increase over the two periods are normalized by the population number into kJ/person, which are shown in Table 1.

Fig. 1 shows the correlation between cooling energy usage and population growth. It can be seen that as compared to the recent ten-year period, annual cooling energy use in the earlier ten-year period correlates closer with population ($R^2 = 0.8599$ as compared to $R^2 = 0.6854$) and the slope is steeper (5.6 as compared to 4.2). The results indicate that rate of increase in cooling energy usage in the recent ten-year has dropped and deviates slightly from the population growth. But as the correlation result (R^2) is still greater than 0.5, it can be concluded that population is an influential physical factor affecting cooling energy use [28].

Table 2 summarizes the climatic conditions of Hong Kong between 1993 and 2013. The climatic conditions are represented by the yearly mean daily maximum, mean monthly mean and mean daily minimum dry bulb temperatures between the months of April and November when use of air-conditioning is most widespread [34], and the cooling degree days.

The cooling degree days were determined based on the monthly mean air temperature recorded at Hong Kong Observatory's Headquarters for the period from 1Jan2004 to 31Dec2013 [29,30], and a balance air temperature of 20.5 °C. The balance air temperature is the average of the maximum and minimum outdoor air temperatures of Hong Kong, which are 33 °C and 8 °C respectively.

Table 1
Population and annual cooling energy use in the two ten-year periods.

Period	Year	Population	Annual Cooling Energy Use	
		(1000 persons)	(TJ)	kJ/person
Last 10-year	1994	6035.4	8854	1467.0
	1995	6156.1	9622	1563.0
	1996	6435.5	10830	1682.9
	1997	6489.3	10665	1643.5
	1998	6543.7	12761	1950.1
	1999	6606.5	11264	1705.0
	2000	6665	11997	1800.0
	2001	6724.9	12879	1915.1
	2002	6744.1	13297	1971.6
	2003	6730	12530	1861.8
Increase over the period		12%	42%	21.2%
Recent 10-year	2004	6783	12135	1789.0
	2005	6813	12393	1819.0
	2006	6857	11919	1738.2
	2007	6916	11904	1721.2
	2008	6957	11774	1692.4
	2009	6972	12729	1825.7
	2010	7024	13116	1867.3
	2011	7071	13423	1898.3
	2012	7185	13846	1927.1
	2013	7221	13426	1859.3
Increase over the period		6%	11%	3.8%

It is noted from Table 2 that the average air temperatures and cooling degree days of the past 10-yesr period are slightly higher than that of the recent 10-year period, which are 0.4–1%, and 2.7%, respectively. However, the small difference is not sufficient to explain the drop in the rate of increase in cooling energy use.

Table 3 shows the figures for the total number of households in the recent ten years, collected from various government databases [31–33].

To determine if the deviation of annual cooling energy use from population is attributed to the other physical factors (air temperatures, cooling degree days and number of households), bivariate correlation analysis for determining their empirical correlations was conducted. The Pearson correlation coefficients indicate that correlations are not significant (R^2 between −0.316 and +0.716) enough at the 0.05 significance level (2-tailed) to conclude that except population, other physical factors exert very little influence on cooling energy use.

2.2. Engineering factors

The trends of changes in performance of RAC units and in building envelope designs of residential buildings in Hong Kong in the recent ten years were reviewed. The review aims to identify the engineering factors that exhibit a clear trending series possibly contributing to the reduction in cooling energy usage in recent years.

Design packages for new residential developments submitted for BEAM assessment (details are discussed in Section 4) which were completed within the recent ten years were used for collecting details of equipment and construction characteristics. The equipment and construction characteristics are extracted from drawings and technical specifications while the completion year is determined by the date of occupation permit as in government records [35].

Based on the collected information, Monte Carlo analysis [36], whereby it is often used for evaluating the influence a set of vari-