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DECOMPOSING RESIDENTIAL ENERGY USE IN HONG KONG
拆解分析香港住宅組別的能源最終用途

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ABSTRACT (in English, about 300 words)

The Chief Executive pledged at the Asia-Pacific Economic Cooperation Leaders' Declaration in Climate Change, Energy Security and Clean Development held in Sydney, Australia in September 2007 that Hong Kong will reduce energy intensity by at least 25% by 2030 (with 2005 as the base year) in joint effort to tackle climate change.

In response to an increasing actual end-use energy consumption as well as the Government's international commitment to reduce energy intensity and tackle climate change, it is therefore necessary to formulate a mechanism to measure, record and project the trend of energy intensity in Hong Kong with the aim that policy or measures can be timely implemented to mitigate the situation if necessary. As such, the Electrical & Mechanical Services Department engaged a consultant in 2009 to develop and establish an energy supply and demand model and to identify the key drivers of energy intensity on which the Government should focus and take appropriate actions.

Among the tasks to be undertaken by the consultant, one of the tasks is to decompose the historical end-use energy data in order to identify the major socio-economic factors which affect the energy consumption in the territories. Such factors will be used to project the energy demand in the model. In the decomposition analysis, the "Logarithmic Mean Divisa Index (LMDI)" methodology was deployed.

This paper will outline the methodology, elaborate on the decomposition analysis results in the 'Residential sector', which is one of the four sectors in the Hong Kong end-use energy database, and present the findings which may be overlooked in the past.

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摘要

二零零七年九月，特首在悉尼發表的「亞太經合組織領導人關於氣候變化、能源安全和清潔發展的宣言」中，承諾香港會履行在二零三零年前將能源強度，在二零零五年的基礎上，達到至少降低 25%的目標，以認付氣候變化。

為實踐香港政府以上的承諾，機電工程署在二零零九年聘用了顧問工程公司去建立一個能源供應及需求的推算模型，藉以設立機制去量度、紀錄和推算能源強度；作為政府及時去推行針對性政策的參考，來舒緩氣候變化。

在眾多顧問工程公司需要完成的事項中，包括一項分析香港過去能源的使用情況，以便
找出主要影響能源消耗的社會經濟因素，用作模型中來推算將來能源需求的參數。在數據分析中，我們採用了"Logarithmic Mean Divisa Index (LMDI)"方法。

本文將論及該方法，並仔細分析'住宅組別' (四個香港能源最終用途組別之一)能源消耗的結果，其發現可能為人所忽略。

1. INTRODUCTION

The Hong Kong end-use energy is grouped under four sectors, namely, Residential, Commercial, Industrial and Transport. In year 1990 to 2007, the energy end use consumption in the Residential sector is on the rising trend, and accounted for 18% of the total energy and 26% of electricity consumption in the territories.

Given the pursuance of better living standard, the number of appliances was increasing at a fast pace. Through the decomposition analysis, it will be possible for the Government to identify the underlying factors which drive up the energy consumption, and to formulate policy and measures to mitigate the situation in order to tackle climate change.

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2. OVERVIEW OF THE RESIDENTIAL SECTOR

The steady growth in residential energy consumption is caused by a combination of factors, such as steady growth in population, continual rise in per capita income, and a rise in the number of households. C&SD yearly population reports [1] show that the midyear population rose from 5.704 to 6.925 million in 1990 and 2007, respectively, resulting in an average annual growth rate of 1.67% for 1990–2000 and 0.3% for 2001–2007. Expectedly, the slow population growth after 2000 contributed to the deceleration in the growth of residential energy consumption. In addition, it is a common belief that when the per capita income increases, people would tend to consume more energy at home with more electrical appliances and enjoy more luxurious living standard.

Table 2.1 shows that the residential energy end-use and the number of household increased by 62.9% (20,340 TJ) and 45% (692425), respectively, from 1990 to 2007. Specifically, energy intensity increased from 21.16 to 23.72 GJ/household in the period. In addition, Figure 2.1 shows that the energy end-use increased at a faster pace than the number of households in the Residential sector from 1990 to 2007.

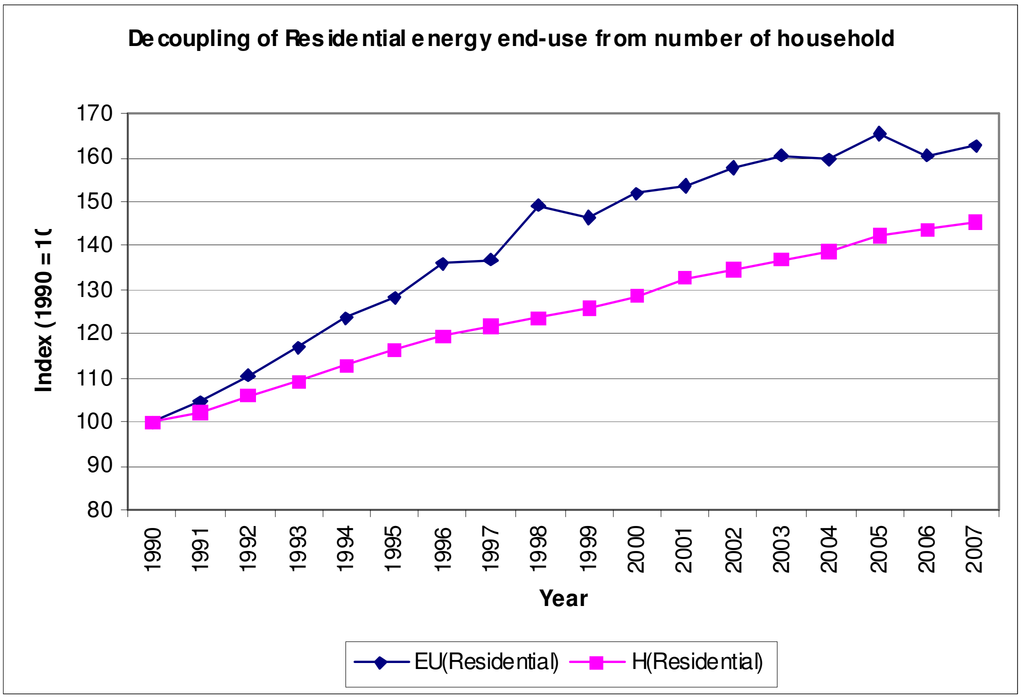
After realizing the increase of the aggregate residential energy intensity, further investigation was conducted to show the degree each residential segment (different type of households) had influenced the energy consumption.

Table 2.1: Residential Sector – Energy End-use (TJ) and Number of Households, 1990 and 2007

Energy Use (E)		Number of Households (H)	
E (1990)	32,327	H (1990)	1527863
E (2007)	52,667	H (2007)	2220288
ΔE	20,340	ΔH	692425
ΔE (%)	62.9%	ΔH (%)	45%

Data source: [1] and [2]

Figure 2.1: Decoupling of Energy End-use from Number of Households, 1990 –2007



Data source: [1] and [2]

According to the characteristics of the property market, the Residential sector is divided into four segments. Each segment exhibits different characteristics resulting in differences in energy consumption among the segments. Apart from the price of the properties, there are other variables [3], such as household income, awareness of energy saving, time spent at home, cooking and washing practices, comfort traditions, equipment penetration, building and appliance standards, and dwelling area. Accordingly, the four segments are as follows:

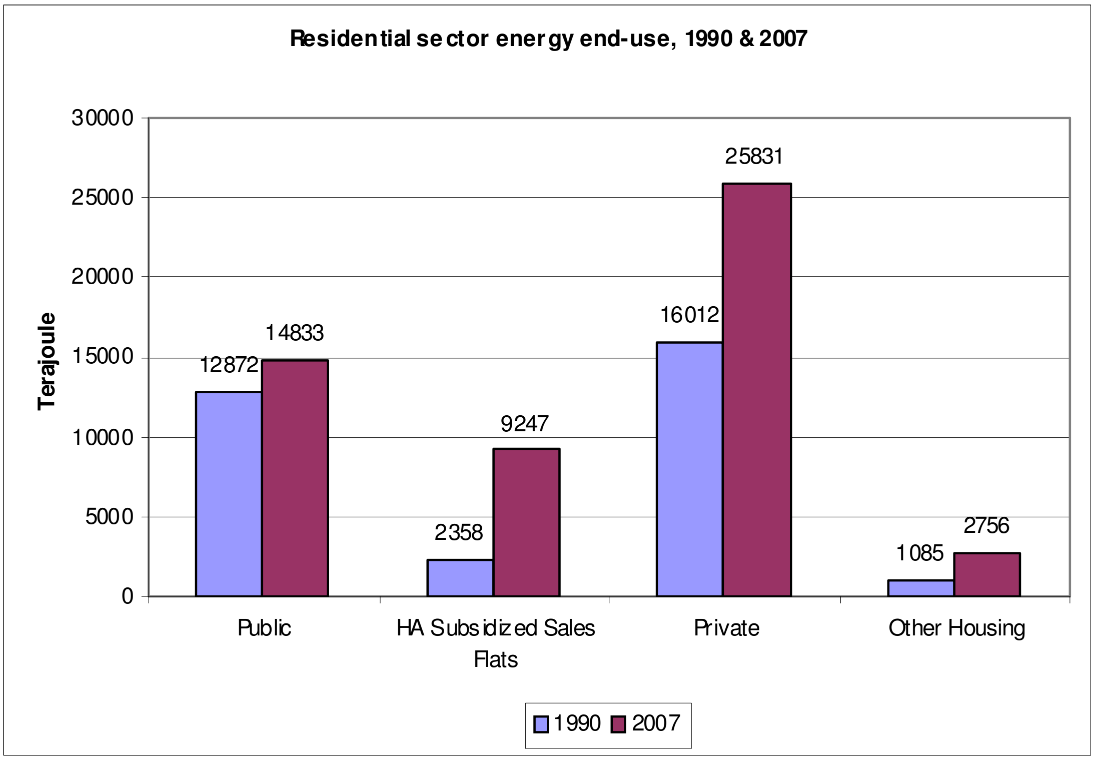
- Public Housing (Public)
- HA Subsidized Sales Flats (HASS)
- Private Housing (Private)
- Other Housing (Others)

Public Housing segment (**Public**) in Hong Kong includes the apartments built under a set of mass housing programs through which the Government of Hong Kong provides affordable rental housing for lower-income residents. HA Subsidized Sales Flats segment (**HASS**) includes building apartments built or supported by the Sandwich Class Housing Scheme, Hong Kong Housing Society for selling to middle-income families (i.e., sandwich class) at concessionary prices. Private Housing segment (**Private**) includes buildings and apartments developed by private builders for open realty market. Other Housing segment (**Others**) includes villas, bungalows, and the like.

Energy end-use of residential segments, 1990 –2007

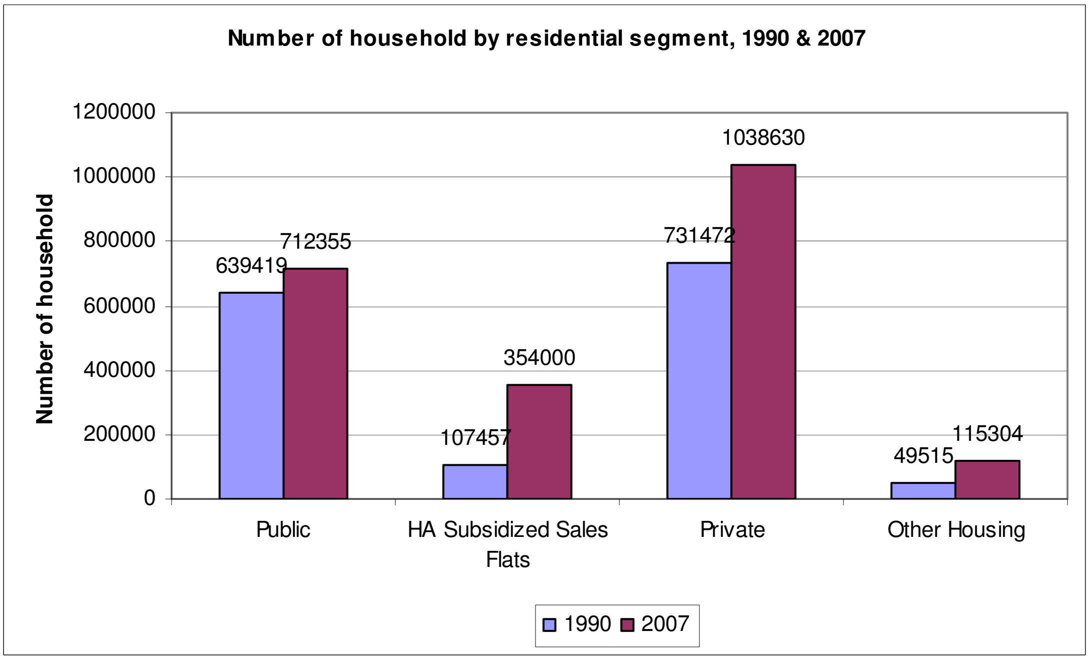
Figure 2.2 shows the energy end-use of the Residential sector in 1990 and 2007, broken down into segment levels. Obviously, the Private segment was the key energy-consuming segment, followed by the Public segment. It should be noted that while the energy end-use of all segments increases over the period, there is a two-fold increase in energy consumption for the HASS segment. Similar pattern can be identified in the number of households of the Residential sector as shown in Figure 2.3. Figure 2.4 presents the energy intensities by segment with the HASS and Public segment having the highest and lowest energy intensity value, respectively.

Figure 2.2: Residential Sector – Energy End-use by Segment (TJ), 1990 and 2007



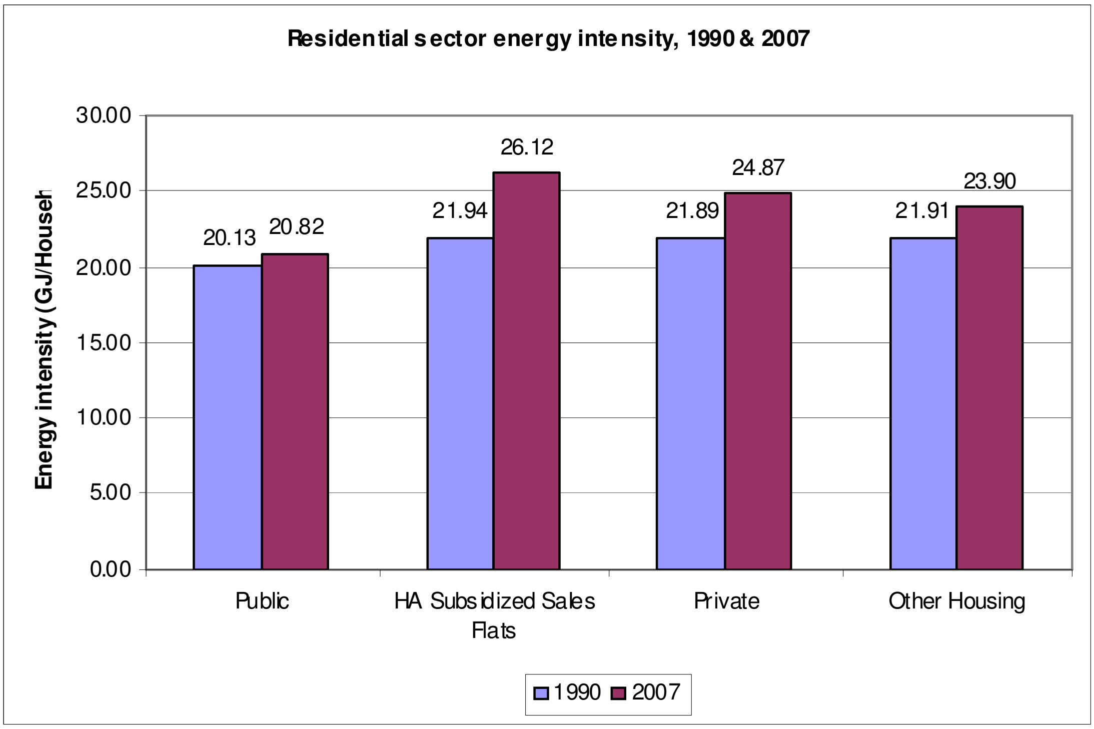
Data source: [2]

Figure 2.3: Residential Sector – Number of Households (H) by Segment, 1990 and 2007



Data source: [1]

Figure 2.4: Residential Sector – Energy Intensity (GJ/H) by Segment, 1990 and 2007



As the segments are heterogeneous in the pattern of energy consumption, the aggregated energy intensity clearly cannot adequately reflect the real situation by segment level and support any meaningful conclusion. Particularly, the aggregate energy intensity would change over time with structural changes. Decomposition study was employed to obtain "disaggregate" energy intensity that is unaffected by structural change. In this paper, the Divisia decomposition approach is adopted and presented in the next section.

3. METHODOLOGY

In this study, the logarithmic mean Divisia index (LMDI) method was employed, a decomposition technique originally conceived in the late 1970s to study the effects of structural changes on energy use by industry. Since then, the method has been widely used to analyze energy consumption and carbon dioxide emissions in OECD countries [4]. According to [5], the following multiplicative decomposition ratio of energy consumption at the end of the period (2007) to the beginning (1990) was derived,

$$D_{Tot,2007} = \frac{E_{2007}}{E_{1990}} = D_{act,2007} \times D_{str,2007} \times D_{\text{int},2007} \times D_{Wea,2007}$$, where

$$D_{act,2007} = \exp\left[\sum_j w^*_{j,2007} * \ln\left(\frac{H_{2007}}{H_{1990}}\right)\right]$$ representing the activity effect (A),

$$D_{str,2007} = \exp\left[\sum_j w^*_{j,2007} * \ln\left(\frac{H_{j,2007}/H_{2007}}{H_{j,1990}/H_{1990}}\right)\right]$$ representing the structural effect (S),

$$D_{\text{int},2007} = \exp\left[\sum_j w^*_{j,2007} * \ln\left(\frac{\tilde{E}_{j,2007} / H_{j,2007}}{\tilde{E}_{j,1990} / H_{j,1990}}\right)\right]$$ representing the intensity effect (*I*),

$$D_{Wea,2007} = \exp\left[\sum_j w^*_{j,2007} * \ln\left(\frac{E_{j,2007} / \tilde{E}_{j,2007}}{E_{j,1990} / \tilde{E}_{j,1990}}\right)\right]$$ representing the weather effect (*Wea*),

where

H_t = number of households at time *t*;

$H_{j,t}$ = number of households of segment *j* at time *t*, and $H_t = \sum_j H_{j,t}$;

$\tilde{E}_{j,t}$ = the weather adjusted energy consumption of segment *j* at time *t* by means of cooling degree days.

Hence, total energy used by the residential sector at time *t*, $E_t = \sum_j E_{j,t}$;

j = {*Public, HASS, Private, Others*};

$$w^*_{j,2007} = \frac{\mathrm{L}[E_{j,2007}, E_{j,1990}]}{\mathrm{L}[E_{2007}, E_{1990}]}; \text{ and } \mathrm{L}[a,b] = \frac{a\text{-}b}{\ln(a)\text{-}\ln(b)}.$$

Note that

$E_{2007} = D_{act,2007} * D_{str,2007} * D_{int,2007} * D_{Wea,2007} * E_{1990}$, and

$$\Delta E_{x,T} = \left(\frac{E_T - E_0}{\ln E_T - \ln E_0}\right) \ln D_{x,T}$$ where *x* = {*act, str, int, Wea*}.

The number of households (*H*) was used as the activity factor in conducting the decomposition analysis because it is found that the residential energy consumption highly correlates with the number of households.

4. DECOMPOSITION RESULTS AND DISCUSSIONS

Table 4.1 presents the summary of decomposition results of the Residential sector by segment. Overall, the energy end-use of the Residential sector increased by 20,340 TJ from 1990 to 2007 (62.92% of energy end-use of the sector in 1990, equivalent to an annual increase of 2.91% in the period), contributed mainly by the Private segment (9,819 TJ or 48.3% of the total increase) and followed by the HASS segment (6,889 TJ or 33.9% of total increase).

Table 4.1: Decomposition Results by Segment, 1990 and 2007

Residential Segment	Activity effect (ΔE_{act})	Structural effect (ΔE_{str})	Intensity effect (ΔE_{int})	Weather effect (ΔE_{Wea})	Total effect (ΔE_{tot})
Public	5,169	-3,675	-327	795	1,961
HASS	1,884	4,126	589	290	6,889
Private	7,674	-476	1,440	1,180	9,819
Others	670	845	53	103	1,671
All	15,397	820	1,754	2,369	20,340

Activity effect

The activity effect was the major contributing factor to the energy end-use increase from 1990 to 2007. It accounts for 15,397 TJ or 75.7% of the total increase. In particular, the increase in the energy consumption in the period was highly dependent upon the activity level of the Residential sector and accounts for about 75.7% of the end-use increase. The activity level of the Residential sector is represented by the number of households of the sector, which suggests further an increase in household number bringing forth 15,397 TJ additional energy consumption from 1990 to 2007.

From the column "Activity effect" in Table 4.1, the Private segment shows the largest energy end-use increase contribution (7,674 TJ or 37.7% of the total energy increase of the sector). This finding implies that the Private segment consumed more energy than other segments due to the increase in the number of households of the Private segment. This was followed by the Public segment at 5,169 TJ or 25.4% of the total energy increase. Overall, the activity effect of all segments positively contributed to the energy end-use in the Residential sector.

Structural effect

Structural effect at segment level measures how the relative changes of the number of households in a segment (household number in the segment vs. household number in the sector) contribute to the energy end-use in the sector.

The column "Structural effect" in Table 4.1 indicates that the HASS segment provided the largest positive structural effect (an increase of 4,126 TJ or 20.3% of the total energy increase of the sector), while the Public segment had the largest negative structural effect (a decrease of 3,675 TJ or -18.1% of the total energy change in the opposite sign). Figure 2.3 shows a corresponding structural shift of households from the Public to HASS segment with the relative share of the household of the Public segment declined from 42% to 32%, while that of HASS increased from 7% to 16%.

Intensity effect

Compared with activity and structural effects, the intensity effect is a better representation of the energy efficiency of the Residential sector. Although the structural effect of the Private segment was negative, its intensity effect contributed positively to the largest energy end-use change (an increase of 1,440 TJ or 7.1% of the total energy increase of the sector). The worsening of the energy intensity of the Private segment is probably caused by more energy (electricity) consuming devices (air-conditioners, computers, audio-video equipment, etc.) being used/installed in private households as such cannot be adequately compensated by the improvement of the energy efficiency of the appliances. The increase of 1,440 TJ is one of the key reasons the residential energy consumption did not decline during the period.

According to the definition of "Hong Kong Property Review" [6], Private Domestic units (Private segment) are defined as independent dwellings with separate cooking facilities and bathroom (and/or lavatory). They are sub-divided by reference to floor area as follows:

Class A - saleable area less than 40 m^2
Class B - saleable area of 40 m^2 to 69.9 m^2
Class C - saleable area of 70 m^2 to 99.9 m^2
Class D - saleable area of 100 m^2 to 159.9 m^2
Class E - saleable area of 160 m^2 or above

The cumulative percentages of Class D & E dwellings continually increase throughout the years (Table 4.2). It is a common belief that households with bigger size (over 100 m^2) would consume more energy compared with the smaller households (a sign of prosperity). This may explain the energy increase observed in the Private segment over the period. However, this is only a hypothesis and the significance of the relationship between the flat size and energy end-use needs to be further investigated and confirmed through survey.

Table 4.2: Cumulative Percentage of Completions by Class

Year	A & B	C	D & E
1997	82.24%	13.45%	4.30%
1998	79.56%	13.55%	6.89%
1999	79.76%	14.43%	5.81%
2000	76.67%	16.70%	6.63%
2001	76.36%	16.65%	7.00%
2002	75.17%	17.93%	6.90%
2003	76.68%	16.64%	6.68%
2004	76.87%	16.06%	7.07%
2005	76.80%	16.20%	7.00%
2006	76.61%	16.27%	7.12%
2007	76.68%	16.20%	7.12%

Data source: [6]

The intensity effect of the HASS segment was also positive (an increase of 589 TJ or 2.9% of the total energy increase). This shows that the segment was also consuming more energy per household over the years.

It is interesting to note that the intensity effect of the Public segment was negative (a decrease of -327 TJ). It may be due to the decrease of the household income in the Public segment. As shown in Table 4.3, the number of low-income household was increasing and leaning towards the lowest income classes. Furthermore, as the utility tariff cost was increasing over the years, the low-income households used less utility facilities and/or more actively adopt energy saving measures to meet a reduced utility budget.

Table 4.3 Domestic Households by Monthly Domestic Household Income, 1996, 2001, and 2006

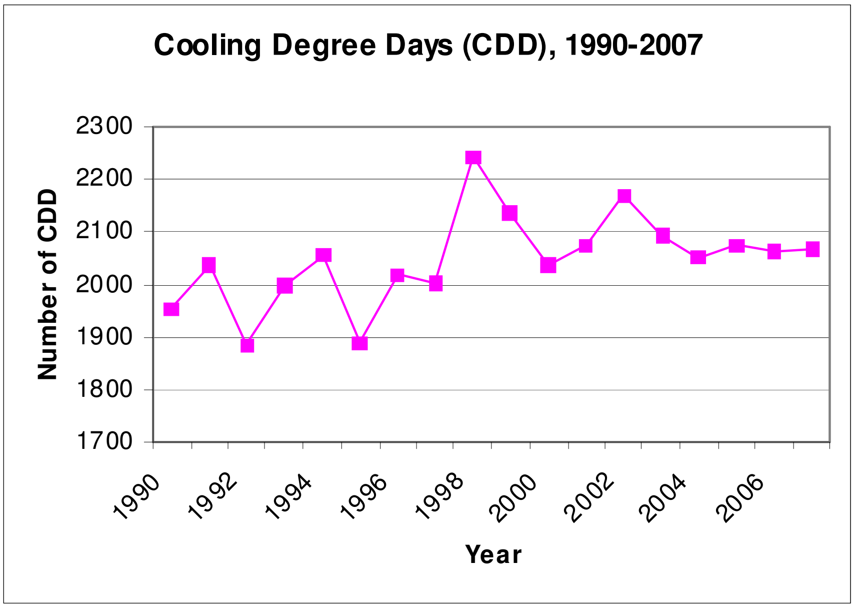
	1996		2001		2006	
Monthly Domestic Household Income (HK$)	Number	% of total (1996)	Number	% of total (2001)	Number	% of total (2006)
< 2,000	55 597	3.0	65 855	3.2	86 736	3.9
2,000 - 3,999	68 272	3.7	97 568	4.8	118 779	5.3
4,000 - 5,999	75 595	4.1	93 018	4.5	121 605	5.5
6,000 - 7,999	105 639	5.7	116 340	5.7	146 010	6.6
8,000 - 9,999	136 577	7.4	120 721	5.9	147 081	6.6
10,000 - 14,999	324 001	17.5	318 623	15.5	339 469	15.2
15,000 - 19,999	269 694	14.5	262 086	12.8	279 217	12.5
20,000 - 24,999	210 926	11.4	223 708	10.9	225 292	10.1
25,000 - 29,999	147 295	7.9	159 470	7.8	162 783	7.3

Source: [1]

Weather effect

The weather effect contributed positively to the energy use change of the sector (increase by 2,369 TJ or 11.6% of the total energy change of the sector). This is consistent with the higher level of use of air-conditioning systems in the Residential sector. Figure 4.1 shows the increase in cooling degree days of Hong Kong from 1990 to 2007. With the use of air-conditioning systems highly dependent on weather conditions, the warmer weather of Hong Kong over the years contributed positively to the increase in the energy end-use of the sector.

Figure 4.1 Cooling Degree Days, 1990–2007



Source: [7]

5. SUMMARY AND CONCLUSION

This section summarized and analyzed the decomposition results for the Residential sector. The decomposition analysis provides the following conclusions.

The energy consumption of the Residential sector increased by 62.92% above the 1990 level and resulted in an increase of 20,340 TJ in 2007. The major increase in energy consumption came from the Private and HASS segments, which respectively contributed 48.3% and 33.9% of the total energy increase in the period. The other two segments also showed an increase in energy consumption in the period, resulting in the Residential sector consuming more energy in 2007 than 1990.

Decomposition analysis revealed that the major driver of the energy increase of the Residential sector was the activity effect (an increase of 15,397 TJ, or 75.7% of the total energy increase of the sector). The activity effect is mainly attributed in the Private (37.7%) and Public (25.4%) segments. The major structural effect was contributed in the HASS segment (+20.3%), whereas the Public segment had a negative structural effect of -18.1% showing an increase in the share of HASS household number in the sector in 2007 compared to 1990, whereas the share of the Public segment declined. Such structural shift is expected to revert as the Government has announced its policy not to further construct home ownership households but build more public housings.

Compared with the activity and structural effect, the intensity effect is a better representation of the energy efficiency of the Residential sector. From 1990 to 2007, the Residential sector consumed 1,754 TJ more energy, or 5.43% above 1990 level due to the intensity effect. Among the segments of the Residential sector, the Private segment contributed most of the increase followed by the HASS segment. This finding shows that these two segments were becoming more energy intensive, or as a proxy, less energy efficient. The energy increases due to the intensity effect of these two segments were 1,440 TJ for the Private and 589 TJ for the HASS segment, resulting in 2,029 TJ or 6.3% above the 1990 level. If the energy intensity effect remains unchecked, by 2030, the energy increase due to the intensity effect of the Private segment alone would be 3,538 TJ, which is 2.5 times the increase for the period from 1990 to 2007.

Several factors could have contributed to the worsening energy intensity in the Private segment, such as the recent increase in the number of Class D&E dwellings with larger floor areas. Further studies can be conducted to investigate and confirm the contributing factors for the Private segment.

The contribution of weather effect from 1990 to 2007 for the Residential sector resulted in an energy increase of 2,369 TJ or 7.3% above the 1990 level. This high value is a result of an increase in the use of air-conditioning systems, the usage of which being weather-sensitive.

The above decomposition analysis shows that the Private segment is the most important segment in contributing to the energy end-use change of the Residential sector. This segment is also the most energy intensive. The segment could well serve as a prime target for promoting energy efficiency. In addition, the HASS segment also has a positive intensity effect; this could be the secondary target for promoting energy efficiency.

The Hong Kong SAR Government, in view of the increasing electrical appliance usage, has enacted the "Energy Efficiency (Labelling of Products) Ordinance" in November 2009 to mandate the use of energy efficient room air-conditioners, refrigerating appliances, and compact fluorescent lamps in the first phase[1]. With such introduction, similar analysis can be conducted to ascertain the effectiveness of such measures.

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