A study of energy consumption for office buildings in Vietnam for sustainable energy and climate change mitigation

Hoang Tuan Viet, Nguyen Duy Dong, Nguyen My Anh, Nguyen Duc Luong, Tran Ngoc Quang, Mac Van Dat, Joseph J. Deringer

Abstract—**This study used survey data to evaluate the current status of electrical energy use of commercial office (CO) and governmental office (GO) buildings in Hanoi and Ho Chi Minh City (HCMC) in Vietnam. Main data used in the analyses including floor area and monthly electricity consumption which were gathered from the questionnaire survey for 57 CO and GO buildings in two cities – conducted by the Vietnam Clean Energy Program in 2015. The basic statistical analysis techniques were used to evaluate the electricity consumption intensity of office buildings and preliminarily analyze key factors affecting the energy consumption of these buildings. The results generally showed that CO buildings consumed significantly more electricity than GO buildings in all months of the year and the variation and trend of mean monthly electricity consumption intensity of the buildings strongly depend on that of ambient air temperature. In addition, the energy use intensities (EUIs) of CO buildings, GO buildings, and both buildings (CO+GO) in HCMC (in a hot climate all year round) were higher than those in Hanoi (in a climate with four distinct seasons). The mean EUIs of these buildings in Hanoi, HCMC, and both cities were 105.9, 116.4, and 109.6 kWh/m² floor. year. The findings of this study are useful information on the status of energy use and energy efficiency of CO and GO buildings in Hanoi and HCMC, thereby contribute scientific bases to the development of policies and solutions to promote the energy efficiency of CO and GO buildings in the coming years and urgent actions for sustainable energy and climate change mitigation in Vietnam.**

Keywords—**Energy Consumption; Energy Use Intensity (EUI); Commercial Office and Governmental Office Buildings; Statistical Analysis; Sustainable Energy and Climate Change Mitigation; Vietnam.**

I. Introduction

Energy consumption by the building sector accounts for a large part (about 40%) of the total global energy consumption and about 30% of total CO2 emissions [1] that cause climate change, global warming, and environmental pollution. Therefore, cutting energy consumption by building sector to reduce greenhouse gas (GHG) emissions and environmental pollution is one of the important goals in long-term green growth strategies of not only Vietnam [2] but also many countries around the world such as Canada, Mexico, the USA [3]; Ukraine [4]; Japan, Costa Rica, Fiji [5]; EU, Korea, Singapore, Africa [6] and the UK [7].

According to the technical report of Vietnam's Nationally Determined Contribution (NDC) 2020, with its domestic resources, Vietnam commits to reducing about 9% of total GHG emissions compared to the national business-as-usual scenario, equivalent to 83.9 million tCO2eq by 2030 [8]. According to the draft of the National Strategy on Green Growth for the Period of 2021-2030, vision to 2050, the strategy sets a target that the GHG emissions intensity per GDP will be reduced about 10-15% by 2030 compared to that of the base year 2014 [2]. To achieve these national goals, a variety of solutions for each sector and field have been proposed, in which the construction industry is one of the sectors that play the most important role of the strategy in implementing GHG

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reduction targets. Accordingly, one of the groups of solutions for the construction industry to contribute to the priority group of solutions for implementing the strategy and other national energy efficiency promotion programs is to promote green buildings and energy-efficient buildings [2], [9]–[11]. However, how to set specific goals for this group of solutions appropriately, studies to evaluate the current status of buildings in using energy are essential. How many buildings, for example, will be certified as green buildings according to Vietnam's green building rating system by 2030 [12] to achieve the overall goal of the strategy while ensuring that it is suitable for the country's socio-economic conditions, technically and technologically applicable, thereby proposing solid scientific bases to support appropriate decision-making. However, up to now, there have been few studies that assessed the situation of energy consumption and energy efficiency of buildings in Vietnam during the last 10 years, including commercial office (CO) buildings and governmental office (GO) buildings - types of building that currently consume large amounts of energy [13, 14].

Stemming from the above research problem, this study was conducted to evaluate the energy consumption and energy efficiency of CO and GO buildings in Vietnam, focusing on the two largest cities of Vietnam which are Hanoi and Ho Chi Minh City (HCMC). Accordingly, this study analyzed and evaluated the energy consumption of CO and GO buildings in two cities based on the building data collected by the Vietnam Clean Energy Program conducted in 2015. The two objectives of this study were to: (1) provide useful information on energy consumption and energy efficiency of CO and GO buildings in Hanoi and HCMC; and (2) evaluate preliminarily factors that may affect the energy consumption of CO and GO building types.

II. MATERIAL AND METHODOLOGY

A. *Building data*

The data on CO and GO buildings and ambient air temperature (AAT) used for analysis in this study were gathered from the questionnaires survey conducted by the Vietnam Clean Energy Program sponsored by USAID in 2015 [15] and the homepage of Open Development Mekong [16], respectively.

The contractor will select a total of 75 buildings for 15 types of buildings being surveyed in detail in each region to ensure the reliability and statistical representation of the survey results. Buildings should have an average size of 2,500 - 15,000 m2 depending on the type of buildings and regions. The contractor selected by the Vietnam Clean Energy Program sponsored by USAID Clean Energy program will collect information before the field survey, conduct a detailed survey at the site, analyze and synthesize the data, and produce a report.

Building data includes gross floor areas (excluding basement and rooftop floors) and monthly electricity consumption of 57 CO and GO buildings in Hanoi and HCMC – 02 cities in the typical climate zones of Vietnam.

The quantity (percentage) of CO and GO buildings by 02 typical climate zones is presented in Table I. Hanoi has a climate with four distinct seasons (mild in spring and autumn, hot in summer, and cold in winter). The climate in HCMC is hot year-round.

One big difference between Hanoi and HCMC from October to April is the difference in temperature: in Hanoi the period from October to April experiences cooler and drier weather compared to HCMC.

TABLE I
QUANTITY (PERCENTAGE) OF CO AND GO BUILDINGS IN THIS STUDY

Type	Typical climate zone		
	Hanoi	HCMC	Total by type
CO building	27 (47%)	17 (30%)	44 (77%)
GO building	9 (16%)	4 (7%)	13 (23%)
Total	36 (63%)	21 (37%)	57 (100%)

The average temperature in Hanoi is 20°C with January being the coldest month with an average temperature of 17°C. The wet season starts in May, and by July the rain has increased to its heaviest. July and August are the wettest months of the year. Temperatures are high at this time of year with daily highs over 30°C and night time temperatures never dropping much below 25°C.

In HCMC the average temperature is pretty stable throughout the year: around 27°C. The temperatures are highest on average in April, at around 29.5 °C. In December, the average temperature is 25.9 °C. It is the lowest average temperature of the whole year. Rain season starts in May until October with heavy rainfall. Typhons are common during the rain season and they can be a destructive force along the coastline. Flooding of city streets are common during this period. The rain combined with the high humidity can make it quite uncomfortable, especially if you're doing any strenuous activities.

In this study, CO buildings included the offices of companies and private enterprises while GO buildings included the offices of government agencies and organizations. From Table I, it can be seen that more than half of the studied buildings are located in the four distinct seasons climate zone (63%), while those in the hot year-round climate zone are lower (37%). The majority (77%) of the studied buildings were the CO type, while the remaining (23%) of the studied buildings were the GO type.

B. *Energy use intensity*

Energy Use Intensity (EUI) is an important indicator used to evaluate the energy efficiency of a building, including the site energy intensity (site EUI) and source energy intensity (source EUI). Source energy represents the total amount of primary energy that is required to operate the building. It incorporates all transmission, delivery, and production losses, while the site energy is calculated based on the secondary energy (e.g. electricity, cooking gas, gasoline, etc.) [17]. Therefore, the site EUI is reflected directly on the monthly bill that the owner must pay for the energy use by their building.

This study focused on assessing the energy consumption and efficiency of CO and GO buildings through the site EUI indicator, hereafter referred to as the EUI [17] which is represented by the formula:

$$EUI = \frac{E}{A} \quad (1)$$

where EUI is the energy use intensity of building (unit as kWh/m²); E is the total amount of secondary energy consumed annually by building (kWh); A is the total gross floor area (excluding basement and roofs floors) of building (m²).

C. *End-use energy consumption*

In the building, electricity is provided to operate building mechanical and electrical (M&E) such as air conditioning and ventilation, lighting, elevator and escalators, and water supply and drainage systems, etc. In this study, data on building electricity consumption by the system was gathered, calculated, and analyzed. The electricity consumption of each system depends on several parameters such as the number of electricity use devices, the power of devices, the coincidence factor of the same-type group of devices, the energy efficiency cgoefficient of devices and systems, etc. The electricity consumptions of the main M&E system were calculated through formulas (2) – (5), as follows:

For air conditioning systems, the daily and annual electricity consumption were calculated through the formula (2) – (3), as follows:

$$EC_{\text{AirCon}}^{day} = \sum_{i=1}^{n} \frac{Q_i}{COP_i} \times h_i \times k_i \quad (2)$$

$$EC_{\text{AirCon}}^{year} = EC_{\text{AirCon}}^{day} \times d_2 \quad (3)$$

where EC_{AirCon}^{day}, EC_{AirCon}^{year} are the daily and annual electricity consumption of air conditioning systems in a building, respectively (unit as kWh); Q_i is the total cooling capacity of i-th air conditioning system (kW); COP_i is the energy efficiency coefficient of i-th air conditioning system; h_i is the number of working hours per day of i-th air conditioning system (hour), k_i is coincidence factor of i-th air conditioning system; d_1 is the number of working days per year of air conditioning system (day). In this study, CO buildings use split-type air-conditioners, while GO buildings are serviced by or split-type air-conditioners or central air-conditioning systems (air-cooled or water-cooled condenser) or combinations of both split-type air-conditioners and central air-conditioning systems.

For interior lighting systems, elevator systems, and other electric and electronic appliances, the daily and annual electricity consumption were calculated using the formula (4) - (5), as follows:

$$EC^{day} = \sum_{i=1}^{n} n_i \times P_i \times h_i \times k_i \times \mu_i \quad (4)$$

$$EC^{year} = EC^{day} \times d_2 \quad (5)$$

where EC^{day}, EC^{year} are the daily and annual electricity consumption of indoor lighting or elevator systems or other electric and electronic appliances, respectively (unit as kWh). Appliances include desktops, laptops, printers, photocopy machines, scanners, televisions, refrigerators, microwave ovens, kettles, hot water plants, etc. n_i is the number of electricity use devices of i-th same-type group of devices; P_i is the electricity consumption power of i-th device (kW); k_i is coincidence factor of i-th same-type group of devices; h_i is the number of operating hours per day of i-th indoor lighting systems or i-th elevator systems, or i-th same-type group of appliances (hour); μ_i is the working efficiency of i-th device (assume that = 1); d_2 is the number of working days per year of the systems (day).

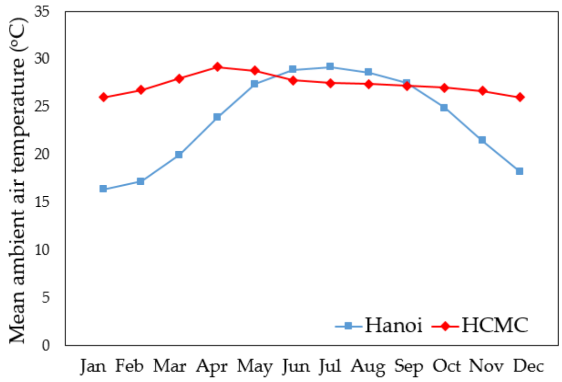

Fig. 1. Profile of mean monthly AAT in Hanoi and HCMC in 2015

D. *Data analysis*

The building data in this study were statistically analyzed using software R.4.1.0 [18]. The basic statistical indicators of the data (mean, standard deviation, maximum value, minimum value, 1st, and 3rd quartiles) were calculated and analyzed to evaluate the electricity consumption of CO and GO buildings in Hanoi and HCMC.

III. RESULTS AND DISCUSSION

For a better understanding of the situation on energy consumption and efficiency of CO and GO buildings in Hanoi and HCMC, this study focused on analyzing the mean monthly and annual electricity consumption of buildings and preliminarily assessed factors that affect the energy consumption of CO and GO buildings.

A. *Typical mean monthly temperature of the two cities*

The mean monthly AAT in 2015 in Hanoi and HCMC - representing two typical climate zones of Vietnam is presented in Fig. 1. Generally, the mean monthly AAT in

HCMC was higher than those in Hanoi for 2/3 months of the year. The mean monthly AATs in HCMC from January to May and from September to December were always higher than those in Hanoi, while those in HCMC from June to August were lower than those in Hanoi. The range of mean monthly AAT of Hanoi was wider than that of HCMC. The mean monthly AAT in Hanoi and HCMC were in the ranges of 16.4 – 29.2 °C and 26.0 – 29.2 °C, respectively. The highest mean monthly AATs in HCMC and Hanoi were in April and June, respectively, while the lowest mean monthly AATs in HCMC and Hanoi were in December and January, respectively.

B. *Mean monthly electricity consumption*

The profile of mean monthly AAT and mean monthly electricity consumption intensity (electricity consumption per meter floor for one month) of the studied buildings in Hanoi and HCMC are showed in Fig 2 and 3, respectively. In general, the variation and trend of AAT had a strong influence on the electricity consumption of the buildings in both cities. Furthermore, the electricity consumption intensity of CO buildings was always higher than those of GO buildings for all months of the year. The profile of electricity consumption intensity of buildings in Hanoi followed the trend of AAT, as illustrated in Fig. 2. Almost similar to Hanoi, the profile of electricity consumption intensity of the buildings in HCMC also followed the trend of AAT in February, March, and April, as shown in Fig. 3.

In Hanoi, the electricity consumption of the buildings was always proportional to AAT. The electricity consumption increased when the AAT increased and vice versa, as shown in Fig. 2. In HCMC, from April to the last months of the year, when the AAT started to decrease gradually, the electricity consumption of the buildings during this period tended to fluctuate continuously. The strongest and lightest fluctuations were between April and August and between December and September, respectively, as illustrated in Fig. 3.

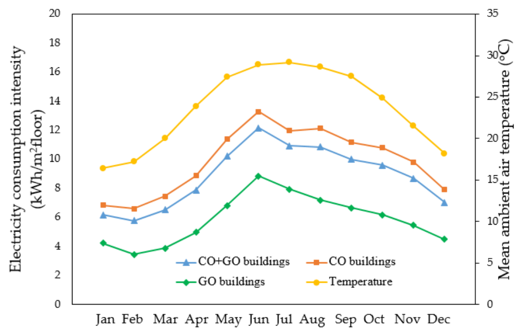

Fig. 2. Profile of mean monthly AAT and mean monthly electricity consumption intensity of CO and GO buildings in Hanoi.

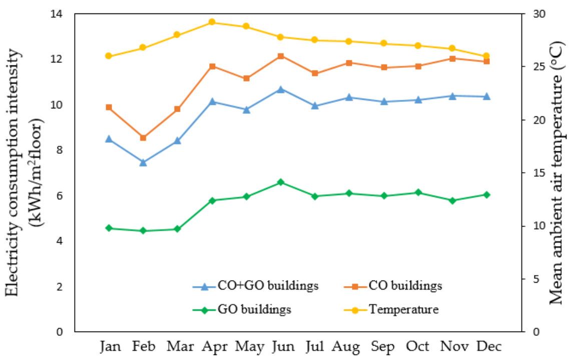

Fig. 3. Profile of mean monthly AAT and mean monthly electricity consumption intensity of CO and GO buildings in HCMC.

TABLE II
MEAN MONTHLY ELECTRICITY CONSUMPTION INTENSITY OF CO AND GO BUILDINGS

Month	Hanoi (kWh/m² floor)			HCMC (kWh/m² floor)		
	All	CO	GO	All	CO	GO
Jan	6.18	6.85	4.23	8.49	9.89	4.57
Feb	5.78	6.59	3.45	7.47	8.55	4.46
Mar	6.53	7.45	3.87	8.41	9.80	4.53
Apr	7.88	8.88	4.98	10.14	11.70	5.78
May	10.21	11.38	6.82	9.78	11.14	5.96
Jun	12.15	13.29	8.86	10.68	12.14	6.58
Jul	10.94	11.98	7.94	9.96	11.38	5.98
Aug	10.86	12.13	7.19	10.32	11.84	6.10
Sep	10.00	11.17	6.65	10.14	11.63	5.98
Oct	9.60	10.79	6.17	10.23	11.69	6.14
Nov	8.69	9.81	5.46	10.39	12.04	5.78
Dec	7.03	7.92	4.48	10.36	11.90	6.05

The lowest electricity consumption of the buildings in both Hanoi and HCMC fell in February, about 5.84 and 7.47 kWh/m² floor, respectively. The buildings in both cities reached the highest electricity consumption in June, about 12.41 and 10.68 kWh/m² floor in Hanoi and HCMC, respectively. Details of the mean monthly electricity consumption intensity of CO and GO buildings in Hanoi and HCMC are summarized in Table II.

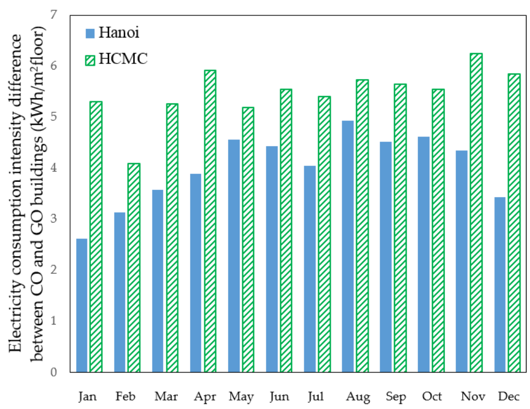

Fig. 4. Difference of electricity consumption intensity between CO buildings and GO buildings.

Fig. 4 a comparison of the difference of electricity consumption intensity between CO buildings and GO buildings in Hanoi and HCMC. As shown in Fig. 4, in both cities, the electricity consumption intensity of CO buildings was always higher than that of GO buildings. For HCMC, the difference in electricity consumption intensity between the two types of buildings was quite stable throughout the year, the differences remained in the range of 4–6 kWh/m2 floor. For Hanoi, the differences were in the range of 2.5–5 kWh/m2 floor, consistently lower than those in HCMC in all months.

To explain the reason why CO buildings consumed more electricity than GO buildings, the electricity consumption intensity of the key end-use devices was analyzed. The electricity consumption intensities of air conditioning systems, interior lighting systems, elevators, and other electric and electronic fappliances of CO and GO buildings in Hanoi and HCMC are presented in Table III.

TABLE III
ELECTRICITY CONSUMPTION INTENSITY OF THE KEY END-USE DEVICES IN CO BUILDINGS AND GO BUILDINGS

City	Key systems /devices	Unit	CO build -ings	GO build -ings
Hanoi	Air-conditioning	kWh/m2 floor	69.0	27.6
	Lighting	kWh/m2 floor	13.1	11.0
	Elevator	kWh/m2 floor	8.9	8.0
	Appliance	kWh/m2 floor	17.7	19.2
HCMC	Air-conditioning	kWh/m2 floor	79.3	-
	Lighting	kWh/m2 floor	8.1	-
	Elevator	kWh/m2 floor	15.7	-
	Appliance	kWh/m2 floor	20.0	-

In Hanoi, the difference in electricity consumption intensity of lighting systems, elevators, and other electric and electronic appliances between the CO and GO buildings was negligible, about 1 kWh/m2 floor. However, for air conditioning systems, the electricity consumption intensity of CO buildings was approximately 2.5 times higher than that of GO buildings (which is equivalent to 41,4 kWh/m2 floor). The higher electricity consumption intensity (based on total floor area) by air conditioning in CO buildings is due to their higher air-conditioned area density (air-conditioned area/total floor area) compared to those in CO buildings.

In HCMC, the electricity consumption by air conditioning systems of 4 GO buildings was not available data to calculate. However, a similar situation to Hanoi was expected.

C. *Energy use intensity*

The box plot of the CO and GO buildings' EUI in Hanoi and HCMC is presented in Fig. 5. In general, the range of EUI and the mean EUI of the buildings in HCMC were wider and higher than those in Hanoi, respectively. The range of EUI of the studied buildings in HCMC, Hanoi, and both cities were 9.9 – 238.7; 29.8 – 210, and i9.9 – 238.7 kWh/m2 floor.year, respectively, while the mean EUI were 116.4; 105.9 và 109.6 kWh/m2 floor.year, respectively.

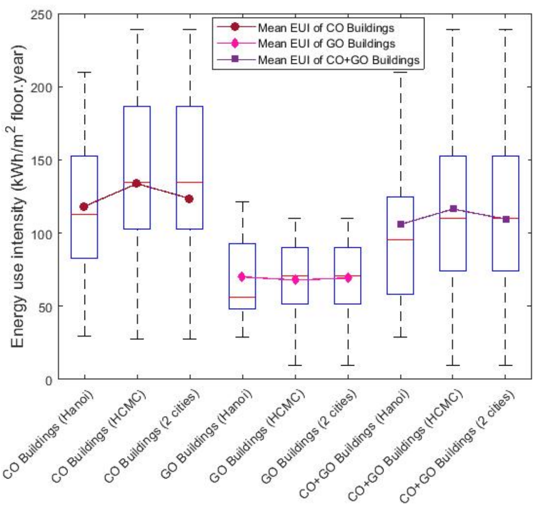

Fig. 5. EUI of the buildings in Hanoi and HCMC.

The EUI difference of the buildings between Hanoi and HCMC could be partly attributed to the electricity consumption by air conditioning systems. In fact, air conditioning systems consume electricity at the most among the service engineering systems inside of the building (i.e. lighting systems, elevator and escalators, fire-fighter fire-alarm system, water supply, and drainage systems, building security and control systems, closed-circuit television monitoring systems, building management systems, and other electric and electronic appliances, etc), possibly up to 50% of the total electricity consumed by the building. Therefore, the higher the amount of electricity consumed by the air conditioning system, the higher building's EUI was seen. Normally, air conditioning systems are operated in hot weather to ensure thermal comfort (about 24°C - 27°C) of the indoor environment [19]. Because HCMC is located in a hot climate all year round, its mean monthly AAT was high year-round. Whereas, the high AATs often occur in Hanoi during the summer months (May-August). Therefore, the duration and frequency of air conditioning systems must operate to ensure the thermal comfort of occupants inside of CO and GO buildings in HCMC is generally higher than those in Hanoi. Statistical indicators that characterize the EUI of CO and GO buildings in Hanoi and HCMC are summarized in Table IV.

To get insights into the electricity consumption and energy efficiency of CO and GO buildings in Vietnam's cities compared to those in other countries in the world, the CO and GO buildings' EUI of Hanoi and HCMC (hereafter referred to as Vietnam) are roughly compared to that of several countries, including China, the UK, Japan, Hong Kong, and the US. The EUI of CO and GO buildings in the above countries are referenced from similar studies [20], [21].

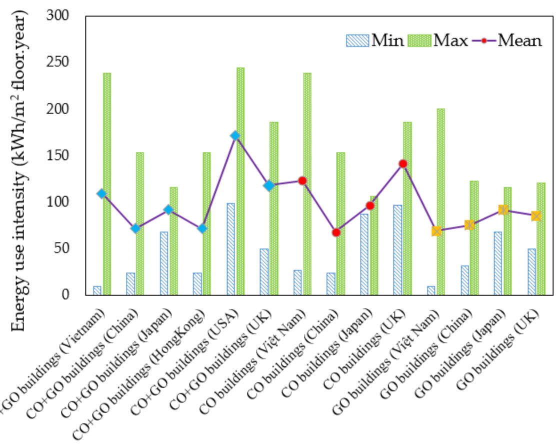

Fig. 6. EUI of the CO and GO buildings in Vietnam compared to those in other countries.

energy consumption of two types of building in Vietnam. The results showed that: (1) CO buildings consumed significantly more electricity than GO buildings in all months of the year; (2) the variation and trend of mean monthly electricity consumption intensity by the buildings followed the trend of AAT; (3) the EUIs of CO buildings, GO buildings, and both buildings (O+GO) in HCMC (in a hot climate all year round) were higher than those in Hanoi (in a climate with four distinct seasons). The mean EUI of CO and GO buildings in Hanoi, HCMC, and both cities were 105.9; 116.4; and 109.6 kWh/m² floor.year. In addition, this study also compared the situation of energy consumption and efficiency of CO and GO buildings in Vietnam with other countries in the world. In general, the

TABLE IV
EUI OF CO AND GO BUILDING IN HANOI AND HCMC IN 2015

Statistical indicators	Hanoi (kWh/m² floor.year)			HCMC (kWh/m² floor.year)			Both cities (kWh/m² floor.year)		
	CO buildings	GO buildings	CO&GO buildings	CO buildings	GO buildings	CO&GO buildings	CO buildings	GO buildings	CO&GO buildings
Building quantity	26	9	35	14	5	19	40	14	54
Mean	118.2	70.1	105.9	133.7	67.9	116.4	123.6	69.3	109.6
Standard deviation	58.3	32.7	56.6	61.9	36.8	62.9	59.3	32.8	58.5
Minimum	29.8	29.3	29.3	27.3	9.9	9.9	27.3	9.9	9.9
First quartile (25%)	83.5	48.5	60.8	102.9	65.0	77.2	85.4	48.7	66.8
Median (50%)	112.9	56.1	95.1	134.9	70.8	110.2	119.1	67.9	106.1
Third quartile (75%)	152.5	84.5	124.3	179.3	83.6	148.3	156.6	84.3	138.9
Maximum	210.0	121.1	210.0	238.7	110.2	238.7	238.7	110.2	238.7

Fig. 6 presents a comparison of the mean EUI of CO and GO buildings in Vietnam and the other countries. In general, Vietnam had a wider range of mean EUI of the buildings than those of the compared countries, about 9.9 – 238 kWh/m² floor.year. The EUI range of the buildings in the compared countries was not large, possibly because CO and GO buildings in these countries were built and operated quite similarly in terms of factors affecting energy consumption characteristics (architecture, technical equipment systems, materials...). However, the mean EUI of the CO and GO buildings in Vietnam was not significantly different from those in most of the compared countries. 109,6 kWh/m² kWh/m² floor.year was the mean EUI of the CO and GO buildings in Vietnam compared to about 71.8 – 118 kWh/m² floor.year of the compared countries, and about 171.5 kWh/m² floor.year of the USA. The United States had the highest figure among the above countries.

IV. CONCLUSION

This study analyzed the data of 57 CO and GO buildings in Hanoi and HCMC of Vietnam which were surveyed by the Vietnam Clean Energy Program in 2015 to evaluate the mean EUI of CO and GO buildings in Vietnam was not much different from that of some countries in the world. The results of this study could provide useful information and scientific basis in supporting the development of policies and solutions to promote energy efficiency in buildings (especially CO and GO buildings), and urgent actions for sustainable energy and climate change adaptation in Vietnam.

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