Calculation of cooling seasonal power consumption and energy efficiency of household inverter air conditioners in the Vietnamese climatic conditions

Cung Duc Huy¹, Trinh Quoc Dung¹, Nguyen Viet Dzung¹ and Truong Minh Thang²
¹School of Heat Engineering and Refrigeration, Hanoi University of Science and Technology, Hanoi, Vietnam
²Faculty of Mechanical Engineering, University of Transport and Communications, Hanoi, Vietnam
dung.trinhquoc@hust.edu.vn

Abstract. The calculations of power consumption and energy efficiency for household air conditioners with inverter technology using bin method in the Vietnamese climatic conditions were shown in the paper. The data of 53 of the air-cooled air conditioners in the Vietnamese market with rated cooling capacity in the range of 9000 BTU/h to 24000 BTU/h were used in this study. Based on the National Standard on the air-cooled air conditioners and heat pumps (i.e., TCVN 10273-1:2013) and National Regulation on climate data for construction (i.e. QCVN 02:2009), the cooling seasonal power consumption and energy efficiency have been calculated for 10 cities/provinces, representatively of different climatic zones in Vietnam. The results show that there are quite large deviations between energy efficiency ($C_{SPF}$) and annual power consumption ($C_{CSE}$) from the national standard TCVN 10273-1:2013, national regulation QCVN 02:2009 and published data of manufacturers. The impact of the Vietnamese climatic zones on the power consumption was investigated in the study, also. The paper suggests the necessary of upgrading the national standard and regulation for inverter air conditioners to evaluate exactly their energy efficiency in the Vietnamese climatic conditions.

1. Introduction

Nowadays, air conditioning is a great achievement in the development of human civilization. It is responsible for over 8% of global electricity consumption and accounts for 3.12% global GHG emissions, respectively [1]. The role of air conditioners is not only to provide a comfortable living and working environment, but also constitutes lifesaving and health-protecting technology that address of climate change, and this role has been recognized increasingly by experts. In the case of developing countries like Vietnam, the room air conditioner market increases at the average rate of approx. 12% per year (i.e., about 2.4 million units), and it performed best in the seven major markets in South Asia.

The shortage of electricity has promoted the expansion of the energy saving air conditioner market, which can be seen in the rapid penetration of entry-level inverter (variable-speed compressor) room air conditioners in Southeast Asia and India. Governments of different countries have formulated standards to encourage the utilization of inverter air conditioners. In Vietnam, inverter split-type room air conditioners have been accepted by the market, and currently share of more than 70%, which is
much higher than that in other surrounding countries excluding Singapore [2]. Vietnam has been enforcing energy efficiency laws since 2011 and has developed Minimum Energy Performance Standards (MEPS) for inverter air conditioners in 2015, that is National standard TCVN 7830:2015 [4], derived from the methodology of the calculation about cooling seasonal performance factor (CSPF) in the national standard TCVN 10273-1:2013 (equivalent to ISO 16358-1:2013) [3]. Nevertheless, in this national standard the reference outdoor temperature distribution is not appropriate for determining CSPF and other energy parameters, because it is built at the moderate climates (e.g., European or USA). Consequently, there is a gap between the national standard and technical data from manufacturers in the inverter air conditioner market for the calculation of energy consumption, which are the significant factors due to the outdoor temperature variations.

The paper is the first attempt to fill the gap. The main goal of the study is to compare CSPF and power consumption for cooling of household inverter air conditioners (AC) in the range of 9000 BTU/h to 24000 BTU/h of rated cooling capacity $\phi_{ful}$ between the national standard TCVN 10273-1:2013 and the reference outdoor temperature bin distributions based on National Regulation on climate data for construction (i.e., QCVN 02:2009/BXD [5]). The effect of the climatic zones on the energy efficiency and power consumption was carried out in the paper, also. Finally, the study proposes to upgrade the national standard and national regulation for figuring out exactly the energy efficiency and power consumption of inverter air conditioners in Vietnam.

2. Calculation of CSPF and power consumption of the inverter air conditioners by the bin method

The calculations of cooling seasonal energy consumption and CSPF of the inverter AC has been described in [3]. The total annual power consumption and cooling seasonal performance factor shall be derived as:

$$CSPF = \frac{L_{CST}}{C_{CSE}}$$  \hspace{1cm} (1)

where:

$L_{CST}$ - cooling seasonal total load, W·h, is calculated by:

$$L_{CST} = \sum_{j=1}^{m} L_{c}(t_j) \cdot n_j + \sum_{j=m+1}^{p} \phi_{ful}(t_j) \cdot n_j$$ \hspace{1cm} (2)

$C_{CSE}$ - cooling seasonal energy consumption, W·h, is calculated by:

$$C_{CSE} = \sum_{j=1}^{k} \frac{x(t_j) \cdot p_{min}(t_j) \cdot n_j}{f_{pu}(t_j)} + \sum_{j=k+1}^{p} P_{mh}(t_j) \cdot n_j + \sum_{j=p+1}^{m} P_{hf}(t_j) \cdot n_j + \sum_{j=m+1}^{n} P_{ful}(t_j) \cdot n_j$$ \hspace{1cm} (3)

To determine cooling seasonal energy consumption and CSPF in Equation (1), data from 53 types of inverter AC made by several manufacturers have been used. The full cooling capacity $\phi_{ful}(t_j)$ at the T1 temperature test condition is the range of 9000 BTU/h to 24000 BTU/h. The technical data of the AC, i.e., power input at full load $P_{ful}$, minimum load $P_{min}$, 50% load $P_{ha}$, and other parameters in Equations (2) and (3), were collected from catalogues published on the website of the manufacturers and calculated by [7], respectively (see Table 1). Reference temperature bin distributions of outdoor are used from the National Standard on the air-cooled AC and heat pumps (i.e., TCVN 10273-1:2013) and are presented in Table 2. As seen in Table 2, the bin distributions are determined at the moderate regions, whilst Vietnam is the tropical climate zone. Therefore, the different reference bin distributions have been set up based upon the National Regulation on climate data for buildings (i.e., QCVN 02:2009), independently. The aim of the distributions is to compare the effect of the two temperature distributions in calculation of annual power consumption and energy efficiency. The bin data of ten cities/provinces, which are typical of different climate regions in Vietnam, are shown in Table 3.
### Table 1. Performance data of the inverter AC

| Manufacturer | Label   | Performance data | Energy saving level (TCVN 7830:2015 [4]) |
|--------------|---------|------------------|------------------------------------------|
|              |         | Cooling capacity (BTU/h) | Power input (W) | CSPF |
| No. 1        | X-9A    | 9040 (2860 - 9890) | 800 (225 - 900) | 4.69 |
|              | X1-9A   | 8700 (2860 - 10900) | 680 (225 - 880) | 5.38 |
|              | X1-12A  | 11900 (3480 - 14300) | 920 (285 - 1250) | 6.24 |
|              | XA-12B  | 11600 (3480 - 15300) | 820 (245 - 1200) | 6.61 |
|              | A1-25S  | 8500 (4100 - 12300) | 520 (185 - 920) | 7.4  |
| No. 2        | A2-25M  | 8500 (3400 - 11600) | 680 (210 - 1100) | 5.7  |
|              | A2-35V  | 11900 (4400 - 14000) | 960 (250 - 1460) | 5.7  |
|              | B1-35E  | 11900 (4400 - 13000) | 1200 (250 - 1460) | 4.6  |
| No. 3        | Y1-25D  | 9554 (3753 - 11601) | 760 (230 - 1070) | 6.38 |
|              | Y1-35D  | 12624 (4777 - 13989) | 1080 (320 - 1370) | 5.69 |
| No. 4        | S-10K   | 9200 (3700 - 10900) | 600 (220 - 900) | 6.97 |
|              | S-13K   | 12200 (4700 - 13900) | 930 (320 - 1330) | 6.7  |
| No. 5        | F1-10L  | 8530 (3412 - 9212) | 670 (210 - 880) | 5.52 |
|              | H2-13Y  | 11942 (2730 - 12624) | 1100 (190 - 1310) | 4.79 |
| No. 6        | K-9C    | 9000 (6000 - 13000) | 750 (500 - 1700) | 4.72 |
|              | K-12C   | 12000 (7000 - 14670) | 1210 (280 - 1520) | 4.63 |
| No. 7        | C1-9F   | 8530 (3583 - 11942) | 880 (290 - 1400) | 5.44 |
|              | C1-12F  | 12000 (3240 - 12965) | 1205 (290 - 1400) | 5.44 |

### Table 2. Annual bin data in Vietnam according to TCVN 10273-1:2013 [3]

| Bin number \(j\) | Outdoor temp., \(^\circ\)C | Reference bin hours, h/year |
|-------------------|----------------------------|------------------------------|
| n_1               | 2                         | 31                           |
| n_2               | 1                         | 32                           |
| n_3               | 2                         | 33                           |
| n_4               | 1                         | 34                           |
| n_5               | 2                         | 35                           |
| n_6               | 1                         | 31                           |
| n_7               | 2                         | 32                           |
| n_8               | 1                         | 33                           |
| n_9               | 2                         | 34                           |

### Table 3. Annual bin data of 10 cities/provinces in Vietnam (based on QCVN 02:2009 [5])

| Bin number \(j\) | Outdoor temp., \(^\circ\)C | Reference bin hours in city/province, h/year |
|-------------------|-----------------------------|---------------------------------------------|
| n_1               | 22                         | 220                          |
| n_2               | 23                         | 300                          |
| n_3               | 24                         | 60                           |

...
Based on the annual bin data and technical performance of the AC, the CSPF and cooling seasonal power consumption \( C_{CSF} \) for a room with working hours from 8 a.m. to 6 p.m. daily have been implemented in the study.

3. Results and discussions

The CSPF of the different labels of inverter AC with \( \phi_{full} \) equal to 9000 BTU/h in Hanoi can be seen in Fig. 1. The results of the others with \( \phi_{full} \) up to 24000 BTU/h are presented in [7], and thus, did not shown in the paper. The deviations of CSPF calculated from national standard TCVN 10273-1:2013, the bin temperature distributions and manufacturer’s performance data are shown in Fig. 2.

![Figure 1. The variation of CSPF of inverter AC.](image-url)
inverter types [6]. Consequently, CSPF of both cases calculated by Eq. 1 have the different behaviors as described.

**Figure 2. Deviation of CSPF of the manufacturer data, national standard TCVN 10273:2013 and new bin temperature distributions.**

As seen in Fig. 1, the CSPF derived by the new bin temperature are lower than those of TCVN 10273-1:2013, excluding two labels XA-9B and K-9C (see in Fig. 2). The deviations of both calculations increase quite large in the range of -7.4% to -26.3%, because the new bin distributions were set up by the weather data in the tropical climatic zone. This leads to the reference bin hours increase in comparison to TCVN 10273-1:2013 - due to the hotter temperature - especially in the summer and the peak load for demand of cooling, regularly.

**Figure 3. Cooling seasonal performance factor CSPF of inverter AC (ϕ_{fut} = 12000 BTU/h) at the climatic zones.**
The impact of the different climatic conditions through the cities from the North to the South in Vietnam on energy efficiency (CSPF) and power consumption (CSE) has been illustrated in Fig. 3 and 4, respectively. The power consumption varies in the climatic zones and is higher than that in TCVN 10273-1:2013. The seasonal energy consumption of inverter AC in Da Lat is the lowest and increases from Hanoi, Da Nang and Ho Chi Minh City, respectively. This is explained that Da Lat have the similar weather as moderate climate. It is clearly the energy efficiency of the air conditioner in this city always higher in comparison to other cities as seen in Fig. 3. Furthermore, the outdoor temperature bin hours in Da Nang as well as Ho Chi Minh City are more than the other ones, especially in the range of 27 °C higher, that the ideal temperature for household owners use the inverter AC. The higher $\phi_{ful}$ of the AC is, the effect of the climate zones significant is, with the mean deviation of approx. 21.8%.

**Figure 4.** Cooling seasonal power consumption $C_{CSE}$ of the inverter AC ($\phi_{ful} = 12000$ BTU/h) at the climate regions.

**4. Conclusion**

The computation of energy efficiency and annual power consumption for inverter AC with rated cooling capacity in the range of 9000 BTU/h to 24000 BTU/h in the Vietnamese climatic conditions have been carried out in the study. Ten cities/provinces from the north to the south, which are representatives of the different climatic regions in Vietnam, were selected for making the new reference bin temperature of outdoor based on the data of the national regulation QCVN 02:2009. The results show that there are relatively large deviations with maximum of 27.6% of cooling seasonal energy performance calculated by the national standard TCVN 10273-1:2013 and the new reference bin temperature. The effect of different climate zones on the energy efficiency and annual power consumption were also evaluated in the study. The energy efficiency and power consumption are still higher than those in TCVN 10273-1:2013. As the result, the prediction of energy consumption of inverter AC at the different weather zones does not agree with the measurements or monitoring. Obviously, upgrading the weather data in the national standard TCVN 10273-1:2013 and national regulation QCVN 02:2009 is mandatory to calculate more exactly energy efficiency, and of course, power consumption of the inverter AC.

**References**

[1] International Institute of Refrigeration (IIR), 06/2020. The role of Refrigeration in the Global Economy. 38th Informatory Note Refrigeration Technologies.

[2] Japan Air conditioning, Heating & Refrigeration news, 01/2021. Special Issue on World Air Conditioner Markets – 2021 update.
[3] Vietnam National Standard (TCVN 10273-1:2013). *Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 1: Cooling seasonal performance factor.*

[4] Vietnam National Standard (TCVN 7830:2015). *Non-ducted air conditioners - Energy Efficiency.*

[5] S, D., & H, A. (2019). AODV Route Discovery and Route Maintenance in MANETs. 2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS). doi:10.1109/icaccs.2019.8728456

[6] H. Anandakumar and K. Umamaheswari, An Efficient Optimized Handover in Cognitive Radio Networks using Cooperative Spectrum Sensing, Intelligent Automation & Soft Computing, pp. 1–8, Sep. 2017. doi:10.1080/10798587.2017.1364931

[7] D. Devikanniga, A. Ramu, and A. Haldorai, Efficient Diagnosis of Liver Disease using Support Vector Machine Optimized with Crows Search Algorithm, EAI Endorsed Transactions on Energy Web, p. 164177, Jul. 2018. doi:10.4108/eai.13-7-2018.164177

[8] H.D. Cung, 01/2021. *Calculation of energy efficiency and power consumption for inverter room air conditioner in the Vietnamese climatic conditions.* Thesis of the Master degree, HUST, Hanoi, Vietnam.