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Research on energy consumption evaluation of electric vehicle considering air conditioning energy consumption

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Abstract This article discusses how to accurately evaluate the whole vehicle energy consumption under different refrigeration and heating working states of electric vehicles. Firstly, using the actual driving test data of electric vehicle, the weight coefficients of electric vehicle under refrigeration, heating and uncooled heating were obtained by algorithm. Then, the above weight coefficient was combined with the drum test results to obtain the annual comprehensive 100km energy consumption value of the vehicle, at the same time, the comprehensive energy consumption value of 100km of the vehicle under different comfort control modes of electric vehicle was analyzed. The related vehicle tests were carried out, the simulation and experimental results showed that the weight coefficient obtained by the least square method can better reflect the real energy consumption of the whole vehicle, the evaluation method of 100km energy consumption of electric vehicle proposed in this paper is a feasible evaluation method.

Key words: vehicle energy consumption test; least square method; air conditioning energy consumption; comfort control modes of electric vehicle

1. Instruction

Compared with traditional vehicles, researchers and users pay more attention to the parameters related to energy consumption，such as energy consumption loss and driving range of electric vehicles (Corazza et al. 2021,Cvok 2021,Fan et al. 2021). In addition, because the energy consumption of the accessory system of the electric vehicle comes from the battery (Li et al. 2018), and the energy consumption of the accessory system of the fuel vehicle comes from the internal combustion engine, the accessory energy consumption has a greater impact on the energy consumption of the electric vehicle during the use of the electric vehicle air conditioner(Zhao et al. 2020). Therefore, it is particularly urgent to study the impact of the accessory energy consumption on the energy consumption evaluation of the whole vehicle.

Summarizing the existing research results, the research on the impact of accessory energy consumption on the energy consumption of new energy electric vehicles is as follows. Takahisa Suzuki(Suzuki 2018) proposed and developed a new electric air conditioning system, and tested the energy consumption of the vehicle at different temperatures. Malakondaiah Naidu (Naidu et al.2005), Masahiko Makino (Makino et al. 2003) and others have conducted in-depth research on various components of the accessory system, especially the systematic analysis and research on the key components of the electric air conditioning system. At the same time, they have conducted the energy consumption test of the accessory system and the vehicle, and obtained the influence law of the key components of the air conditioning on the energy consumption of the vehicle. Du Qian and others tested the energy consumption of hybrid electric vehicles under different refrigeration and heating working conditions of electric vehicles. In addition, they studied the impact of different refrigeration and heating working conditions of electric vehicles on vehicle energy consumption and emissions. The test results show that the energy consumption of the vehicle increases by about 40% after the air conditioner is turned on (Qian 2008). Wu Zhongbin and others compared and analyzed the energy consumption of the vehicle under the cycle condition with and without considering the energy consumption of accessories, and rematched the voltage and capacity of the power battery on the premise of meeting the vehicle range(Wu 2012). Taking a certain model of bus as an example, Min Haitao and others carried out simulation calculation on the key parts of the electric air conditioning system, analyzed and compared the impact of the key parts of the air conditioning on the economy and endurance of the electric vehicle, and analyzed and compared the impact degree of different key parts (Min 2009).

In order to better develop and apply electric vehicles, the evaluation methods of energy consumption of electric vehicles considering accessory systems are summarized. Corresponding specifications and standards have been formulated in Europe and the United State (John 2016, López 2020) Europe previously proposed MACTP(Mobile Air Conditioning Test Procedure) cycle to conduct energy consumption test for the use of air conditioning in the vehicle. The United States also introduced SC03 air conditioning cycle into the five working condition method of fuel consumption test in 2008 and further introduced AC17 test cycle in 2013. In AC17 test cycle, air conditioning is rewarded based on the advanced technology adopted by air conditioning, This cycle is also applicable to the energy consumption evaluation of electric vehicles(Wu et al. 2015). In the process of electric vehicle development, China's vehicle enterprises mostly use the specifications of traditional fuel vehicle air conditioning energy consumption test or enterprise specifications in air conditioning energy consumption test (Qi 2021,Silva et al.2021).

To sum up, there are many researches on reducing the energy consumption of the vehicle. The research on the impact of accessories on the energy consumption of the vehicle mainly focuses on building the accessory model based on the vehicle model, so as to analyze the impact of accessories on the energy consumption of the vehicle. As for the research on the vehicle energy consumption test of electric vehicle considering the accessory energy consumption, the manufacturers have considered the impact of accessory energy consumption on the whole vehicle energy consumption to varying degrees when conducting product test, but the research on the evaluation method of electric vehicle energy consumption based on accessory energy consumption is not very sufficient and specific. In addition, there is no research on the impact of accessory energy consumption on the evaluation method of electric vehicle energy consumption based on human comfort index in the previous literature. It is very necessary to study the impact of accessory energy consumption, especially air conditioning energy consumption, on the evaluation method of electric vehicle energy consumption.

Aiming at the problem of how to accurately evaluate the whole vehicle energy consumption under different refrigeration and heating working states of electric vehicles, based on the actual driving test data of electric vehicle, the weight coefficients of electric vehicle under different working conditions of annual refrigeration, heating and uncooled heating are obtained, combined with the results of drum test, the 100km energy consumption of the whole vehicle is obtained, the accuracy of vehicle energy consumption evaluation results is improved, at the same time, the comprehensive 100km energy consumption of electric vehicle under different control modes is analyzed, which provides a new evaluation method for introducing air conditioning energy consumption into electric vehicle energy consumption evaluation.

2. The mathematical problems to be solved for the research problems proposed

In the previous research on the energy consumption test of electric vehicles, the impact of accessory energy consumption on the energy consumption of electric vehicles is less considered. In this paper, the impact of air conditioning energy consumption and heater energy consumption on the energy consumption of the whole vehicle under the refrigeration and heating conditions of electric vehicles is mainly considered. When calculating the annual comprehensive energy consumption of electric vehicles considering the influence of air conditioning energy consumption and heater energy consumption, in order to achieve better calculation results, it is very necessary to identify the weight coefficient of electric vehicles under refrigeration, heating and uncooled heating conditions(Li 2021).

The purpose of parameter identification is to comprehensively determine the weight coefficient of the electric vehicle under different working states according to the tested values corresponding to the energy consumption of the vehicle under different working states of the electric vehicle, and then combined with the vehicle test data under different cooling and heating states of the test vehicle, comprehensively obtain the 100km energy consumption value of the test vehicle. There are many commonly used parameter identification methods, among which the least square method has the advantages of simple implementation and easy understanding of the principle. The recursive least square method is also a method often used in the least square method. In this paper, the recursive least square method is used to identify and calculate the parameters for the weight coefficients under different working states of electric vehicle refrigeration and heating.

According to the above ideas, annual 100km comprehensive energy consumption of electric vehicles in the whole year FC_{tot} is listed as follows:

$$FC_{tot} = \alpha_1 FC_r + \alpha_2 FC_n + \alpha_3 FC_h \tag{1}$$

Where，

FC_r ——Energy consumption per 100km under electric vehicle refrigeration, unit: kwh / 100km;

FC_n ——Energy consumption per 100km of electric vehicle without refrigeration and heating, unit: kwh/100km;

FC_h ——Energy consumption per 100km of vehicle under electric vehicle heating, unit: kwh / 100km;

α_1 ——According to the test statistics, the utilization coefficient corresponding to the mileage of electric vehicle under refrigeration conditions;

α_2 ——According to the test statistics, the utilization coefficient corresponding to the mileage of electric vehicle under no refrigeration and no heating conditions;

α_3 ——According to the test statistics, the utilization coefficient corresponding to the mileage of electric vehicle under heating conditions.

In the above formula, the sum of α_1, α_2 and α_3 is 1, and $\alpha_1 > 0$、$\alpha_2 > 0$、$\alpha_3 > 0$. The specific values of α_1, α_2 and α_3 are determined according to the main sales and use regions of the vehicle. If it is determined according to the number of days the air conditioner and heater are used, it can be roughly considered that the three months in the whole year are summer, the electric vehicle works under cooling conditions, the three months are winter, the electric vehicle works under heating conditions, and the six months are the working state of the electric vehicle without cooling and heating. Through the above assumptions, we can get the coefficient $\alpha_1 = 0.25$, $\alpha_2 = 0.25$, $\alpha_3 = 0.5$. In this paper, the above weight solution method is called the method of determining the weight coefficient according to time. In the later simulation results, this paper makes a comparative analysis of the relevant data between the method of determining the weight coefficient according to time and the method of determining the weight coefficient by the least square algorithm.

When using the least square method for calculation, it is necessary to fit the weight coefficients α_1、α_2、and α_3 according to the annual comprehensive 100 km energy consumption value of vehicles corresponding to the sample and the 100 km energy consumption value of electric vehicles corresponding to the sample under refrigeration, heating and uncooled heating conditions. After calculating the annual use weight coefficient of electric vehicle under refrigeration, heating and uncooled heating by using the least square method. The 100km energy consumption under different cycle conditions and different working conditions is tested by vehicle bench test. Finally, combined with the weight coefficient, the annual comprehensive 100km energy consumption value of the research vehicle model is obtained.

3. Simulation study on the influence of air conditioning energy consumption on energy consumption evaluation of electric vehicle

3.1 Solution of weight coefficient by least square method based on example

First, actual road energy consumption per 100 km of the whole vehicle of a domestic testing institution is taken as the sample, 100km energy consumption value under refrigeration and 100km energy consumption value under heating of a vehicle model in Tianjin. There are 34 groups of sample data, as shown in Fig.1 below. The main parameters of the vehicles involved in the test are shown in Table 1.

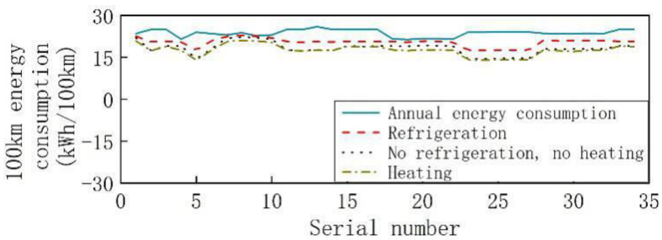


Fig.1 Sample information diagram corresponding to least square method

Table 1 Main technical parameters of electric vehicle

Parameter	Value
Curb weight (kg)	1648
Maximum torque of motor (N.m)	290
Maximum power of motor (kw)	132
Maximum speed (km/h)	156
Total energy of power battery pack (kW.h)	54.75
Maximum range (km)	410
Power consumption per 100km (kWh/100km)	14.7

Fig.1 shows the data of the samples used to fit the weight coefficient by least square method, which can be obtained from the sample data in the figure. During the whole year driving process of the vehicle model studied in this paper, the energy consumption of 100km under electric vehicle heating>100km under electric vehicle refrigeration>100km without refrigeration and heating. Among them, the annual comprehensive 100km energy consumption value of electric vehicles is between the 100km energy consumption value of the vehicle under the working state of no refrigeration and no heating and the 100km energy consumption value of the vehicle under the working state of refrigeration.

Solving the weight coefficients α_1、α_2、α_3, can be transformed into solving the following mathematical problems by double multiplication, as shown in the following formula:

$$y = a_1 x_1 + a_2 x_2 + a_3 \tag{2}$$

Where，

y ——Comprehensive energy consumption per 100km of electric vehicle in the whole year, unit: kwh/100km;

x_1 ——Energy consumption per 100km under electric vehicle refrigeration, unit: kwh / 100km;

x_2 ——Energy consumption per 100km of electric vehicle without refrigeration and heating, unit: kwh/100km;

x_3 ——Energy consumption per 100km under electric vehicle heating, unit: kwh/100km;

a_1 ——According to the test statistics, the utilization coefficient corresponding to the mileage of electric vehicle under refrigeration conditions;

a_2 ——According to the test statistics, the utilization coefficient corresponding to the mileage of electric vehicle under no refrigeration and no heating conditions;

a_3——According to the test statistics, the utilization coefficient corresponding to the mileage of electric vehicle under heating conditions.

Where, $a_1 + a_2 + a_3 = 1$ and $a_1 > 0$, $a_2 > 0$, $a_3 > 0$.

Fig.2, Fig.3 and Fig.4 show the data analysis and comparison of the solution results of the above problems. Fig.2 shows the 100km energy consumption of the vehicle based on the sample data, the 100km energy consumption of the whole vehicle calculated by fitting the weight coefficient by the method of the least square and the method of determining the weight coefficient according to time. Fig.3 shows the error comparison between the 100km energy consumption value of the whole vehicle calculated by using the double multiplication fitting weight coefficient and the 100km energy consumption value obtained by determining the weight coefficient according to time. Fig.4 shows the comparison between the error value calculated by the least square method fitting weight coefficient and the error rate obtained by the method of determining the weight coefficient according to time. The final weight coefficient calculated is: $a_1 = 0.222, a_2 = 0.753, a_3 = 0.025$.

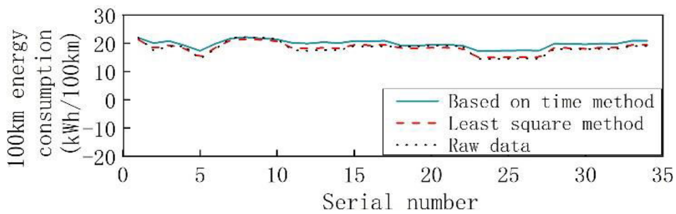


Fig.2 Comparison diagram of the vehicle 100km energy consumption based on sample data

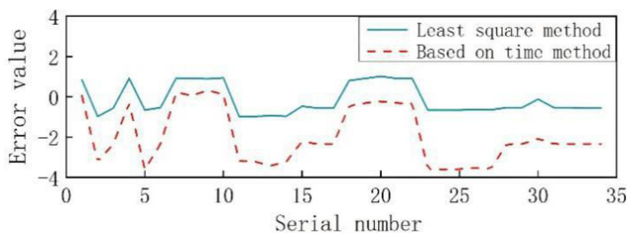


Fig.3 Comparison of error values

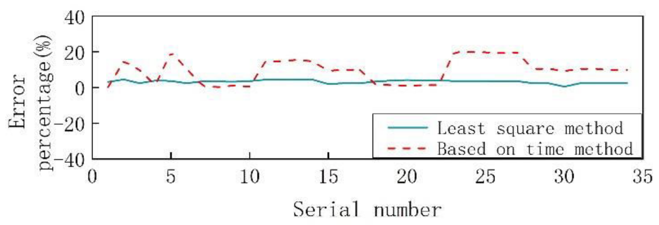


Fig.4 Comparison diagram of error rate

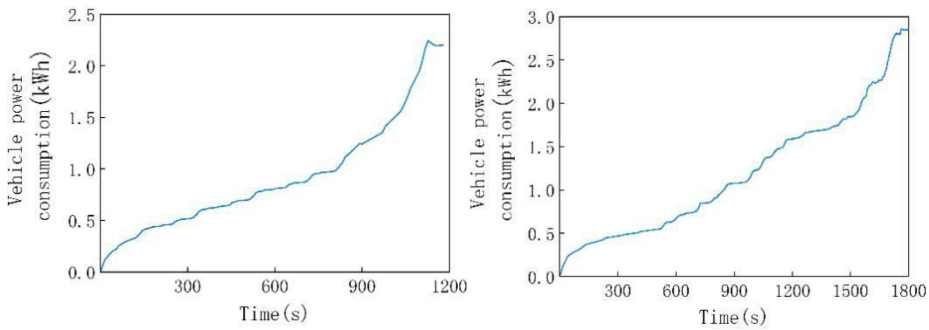
As can be seen from Fig.2, Fig.3 and Fig.4 above, compared with the energy consumption value of the whole vehicle calculated by the time determination weight coefficient algorithm, the energy consumption value of the whole vehicle calculated by the least square method fitting weight coefficient is closer to the real energy consumption of the whole vehicle, and the error value and error rate are smaller. The reason why the energy consumption value of the whole vehicle obtained by the method of determining the weight coefficient according to time is higher than the real energy consumption value of the whole vehicle is that the electric vehicle is not always in the cooling or heating state in summer or winter. Therefore, the coefficient of electric vehicle cooling in summer and electric vehicle heating in winter can not be simply defined by the length of season, which is 0.25.

It can be seen in Fig.2, Fig.3 and Fig.4 that the energy consumption value of the whole vehicle calculated according to the weight coefficient calculated by the least square method is staggered with the real energy consumption value of the whole vehicle. Sometimes the real value of the whole vehicle is greater than the energy consumption value of the whole vehicle calculated according to the weight coefficient fitted by the least square method, and sometimes the real value of the whole vehicle is less than the energy consumption value of the vehicle calculated according to the weight coefficient fitted by the least square method. This shows that the use of the least square method can control the overall trend of samples in the process of fitting coefficients, so as to minimize the synthesis error.

In addition, in Fig.4, the maximum error of the whole vehicle energy consumption value calculated according to the least square method fitting weight coefficient is 4.5%, and the error is acceptable. It is feasible to use the least square method to fit the weight coefficient of electric vehicles under different working conditions.

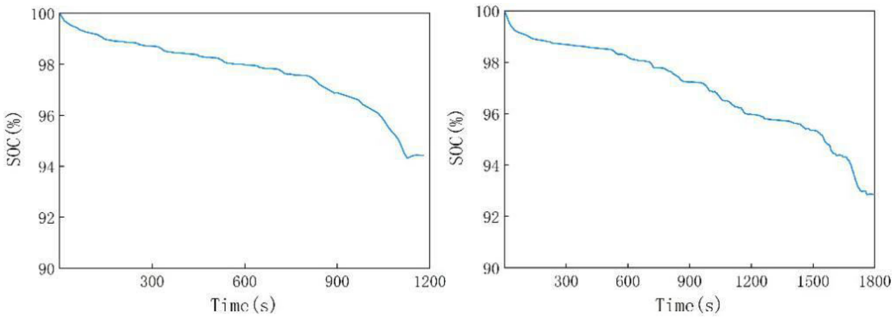
3.2 Comparison of influence results of air conditioning energy consumption on electric vehicle energy consumption under NEDC /CLTC-P cycle

The following Fig.5, Fig.6, Fig.7 and Fig.8 respectively show the comparison of relevant simulation data of vehicle energy consumption, SOC, the inside temperature, battery voltage and battery current under single NEDC and CLTC-P cycle, the outside temperature is 35°C, the radiation intensity is 1000W/m^2, and the inside temperature is set at 25°C.The whole vehicle energy consumption simulation data under NEDC cycle and CLTC-P cycle are shown in Fig.5(a) and Fig.5(b) respectively. The SOC simulation data under NEDC cycle and CLTC-P cycle are shown in Fig.6(a) and Fig.6(b) respectively, and the simulation data of vehicle interior temperature change under NEDC cycle and CLTC-P cycle are shown in Fig.7(a) and Fig.7(b) respectively. The simulation data of battery voltage and current under NEDC cycle and CLTC-P cycle are shown in Fig.8(a) and Fig.8(b) respectively.



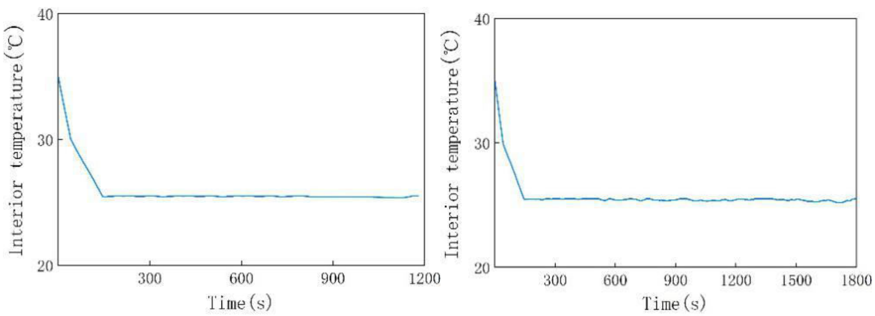
(a) NEDC cycle (b) CLTC-P cycle

Fig.5 Comparison of vehicle power consumption
simulation data of NEDC and CLTC-P cycle under refrigeration



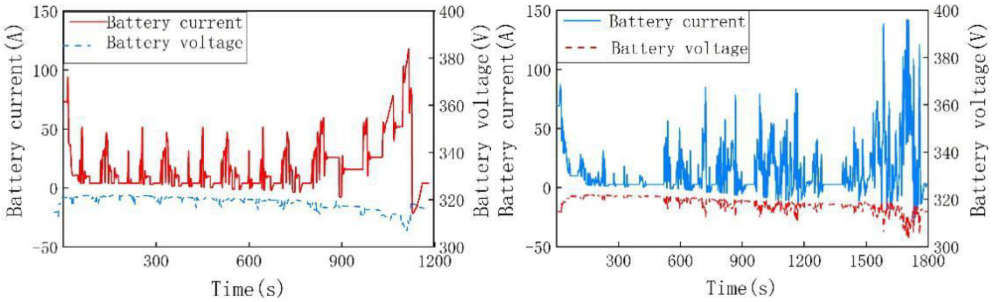
(a) NEDC cycle (b) CLTC-P cycle

Fig.6 Comparison of SOC simulation data
of NEDC and CLTC-P cycles under refrigeration



(a) NEDC cycle (b) CLTC-P cycle

Fig.7 Comparison of interior temperature
simulation data of NEDC and CLTC-P cycles under refrigeration



(a) NEDC cycle (b) CLTC-P cycle

Fig.8 Comparison of battery voltage and current
simulation data of NEDC and CLTC-P cycles under refrigeration

Under the refrigeration condition of electric vehicle, the air conditioning energy consumption under CLTC-P cycle is 27.55% higher than that of NEDC cycle, and the whole vehicle energy consumption is 19.38% higher than that of NEDC cycle. Under CLTC-P condition, the voltage and current of battery change more frequently.

Table 2 shows the energy consumption of electric vehicles under refrigeration, heating and uncooled heating conditions under NEDC and CLTC-P cycles.

Table 2 Energy consumption of electric vehicle under different refrigeration and heating conditions

Working condition	Refrigeration (kWh)	Heating(kWh)	No refrigeration, no heating (kWh)
NEDC	2.27	3.32	1.80
CLTC-P	2.71	3.80	2.11

The data in the heating state of electric vehicle in Table 2 is the simulation data obtained by setting the temperature outside the vehicle to -7°C and the target temperature inside the vehicle to 23°C.

Finally, according to formula(2), the energy consumption per 100km of the whole vehicle under different refrigeration and heating working conditions of electric vehicles in the whole year calculated by the method of the least square and the method of determining the weight coefficient according to time respectively under NEDC cycle and CLTC-P cycle are obtained. The data are shown in Table 3.

Table 3 Energy consumption per 100km of the whole vehicle under each cycle during simulation process

Working	Refrigeration	Heating	No	Least square	Method of

condition	(kWh/100km)	(kWh/100km)	refrigeration, no heating (kWh/100km)	method (kWh/100km)	determining weight coefficient based on time (kWh/100km)
NEDC	20.56	30.11	16.29	17.58	20.81
CLTC-P	18.72	26.24	14.56	15.78	18.52

4. Vehicle test study on the influence of air conditioning energy consumption on energy consumption evaluation of electric vehicle

4.1 Preparation for vehicle test

The whole vehicle test is carried out in the environmental simulation and emission test room of Ningbo automobile testing center of China automobile technology research center. The test room is composed of the emission and performance environmental warehouse of ETAS company in Germany and ROADSIM 48”4×Type4 chassis dynamometer of AVL company in Austria. Fig.9 below shows the photos of the vehicles participating in the test. The relevant parameters of the whole vehicle refer to the information in Table 1.

Fig.9 Photos of vehicles participating in the test

The test process is as follows:

1) Preheating and heating stage

Before the test, the preparations before the test shall be carried out according to the provisions in Table 4.

Table 4 Test vehicle preheating process

Stage	Environment setting	Vehicle status	Purpose
Stage1	Test requires temperature, humidity and no light.	The door and window are open and the vehicle does not start.	Preheat the car to make it reach the set ambient temperature.
Stage2	Set the target temperature, humidity and light intensity.	Close the door, open the window, the blower runs, and the external circulation.	Preheat the air conditioning system to make the air conditioning outlet and air duct meet the test environment conditions.
Stage3	Set the target temperature, humidity and light intensity.	Close the door, close the window, the vehicle will not start.	The vehicle is heated in the light to simulate the vehicle immersion process under sunlight.

2) Experimental phase

Before starting the vehicle, the vehicle battery should be fully charged first record the relevant data with the computer, then start the vehicle and carry out the NEDC cycle test. After the test, save the test data and fully charge the vehicle. After charging, record the charge with the computer. Other test precautions and test steps refer to the requirements of standards (QC/T 2010) and (T/CSAE 2021).

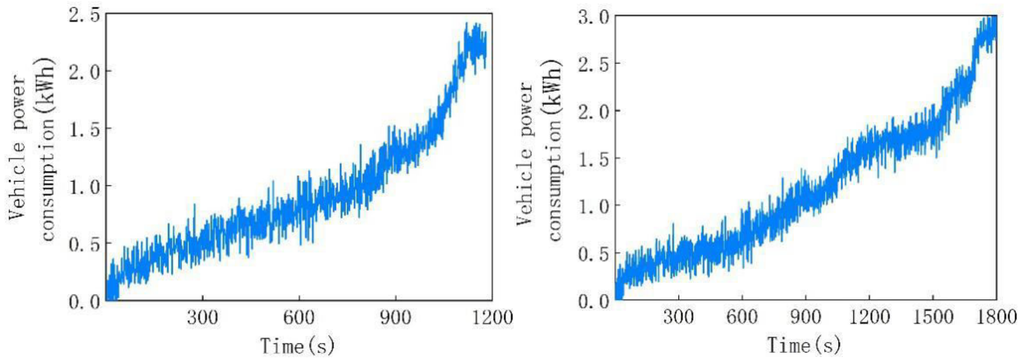
4.2 Result analysis of vehicle energy consumption test data under different operating conditions

During the vehicle test, the ambient temperature, solar radiation intensity and inside temperature settings are consistent with the simulation process. During the whole vehicle test, the ambient temperature, solar radiation intensity and in vehicle temperature settings are consistent with the simulation process. During the heating test of electric vehicle, the specific vehicle immersion and test steps referred to the requirements in standard (T/CSAE 2021), and the vehicle test cycle is NEDC and CLTC-P cycle. In addition, due to the slow heating speed of electric vehicles. In order to facilitate the smooth test, generally, the target temperature in the vehicle set by the heating system of electric vehicle is relatively low. Considering that users are sensitive to the power consumption of electric vehicles in winter, refer to the reference materials to set the temperature in the vehicle in winter during the test[Li et al. 2020], and the PMV value ranges of comfort mode, economic mode and power saving mode under the condition of heating in winter are obtained, as shown in Table 5.

Table 5 Three different heating control modes of electric vehicles in winter

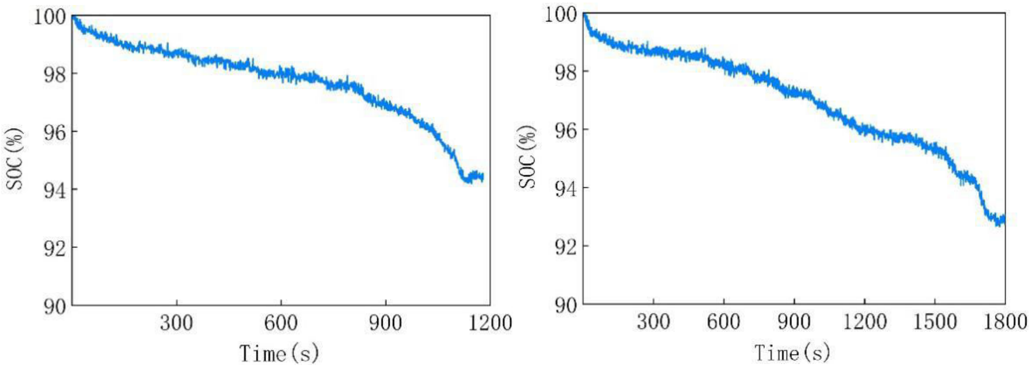
Working mode	Comfort mode	Economic model	Power saving mode
PMV	-2~-1	-2.5~-0.5	-3~0

Through the vehicle test, the test data of vehicle energy consumption, SOC, vehicle inside temperature, battery voltage and battery current under the refrigeration condition of electric vehicle are obtained, as shown in Fig.10, Fig.11, Fig.12 and Fig.13 below.



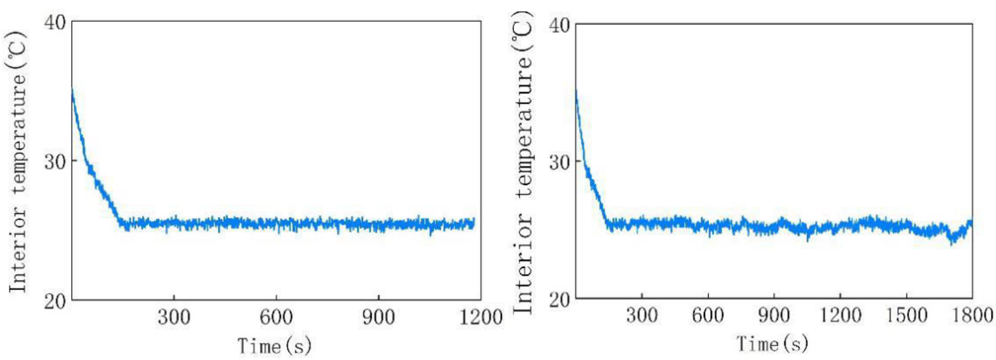
(a) NEDC cycle (b) CLTC-P cycle

Fig.10 Comparison of vehicle power consumption
test data of NEDC and CLTC-P cycle under refrigeration



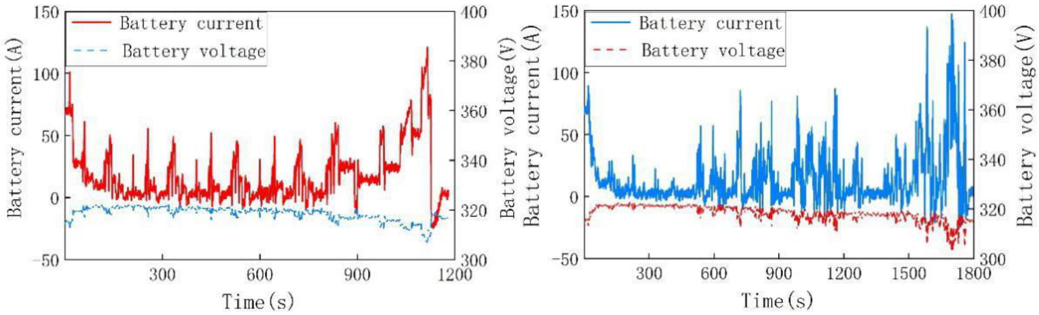
(a) NEDC cycle (b) CLTC-P cycle

Fig.11 Comparison of SOC
test data of NEDC and CLTC-P cycle under refrigeration



(a) NEDC cycle (b) CLTC-P cycle

Fig.12 Comparison of interior temperature
test data of NEDC and CLTC-P cycle under refrigeration



(a) NEDC cycle (b) CLTC-P cycle

Fig.13 Comparison of battery voltage and current test data of NEDC and CLTC-P cycle under refrigeration

In Fig.10, Fig.11, Fig.12 and Fig.13, the energy consumption test data of the vehicle under NEDC cycle and CLTC-P cycle are shown in Fig.10(a) and Fig.10(b) respectively. The SOC test data under NEDC cycle and CLTC-P cycle are shown in Fig.11(a) and Fig.11(b) respectively. The temperature change test data in the vehicle under NEDC cycle and CLTC-P cycle are shown in Fig.12(a) and Fig.12(b) respectively. The battery voltage and current test data under NEDC cycle and CLTC-P cycle are shown in Fig.13(a) and Fig.13(b) respectively.

According to the above Fig.10, Fig.11, Fig.12 and Fig.13, the energy consumption per 100km of electric vehicle under refrigeration, heating and uncooled heating conditions under CLTC-P and NEDC cycles can be obtained. The energy consumption per 100km of the vehicle in the whole year can be calculated according to the formula. The data are shown in Table 6.

Table 6 Energy consumption per 100km of the whole vehicle under each cycle

Operating mode	Refrigeration (kWh)	Heating (kWh)	No refrigeration, no heating (kWh)	Least square method (kWh)	Simple weight method (kWh)
NEDC	20.57	29.18	16.50	17.72	20.69
CLTC-P	18.65	26.17	14.64	15.82	18.53

It can be seen from Fig.10, Fig.11, Fig.12 and Fig.13 that the change trend of simulation test data of air conditioning power consumption, vehicle power consumption, SOC, vehicle inside temperature, battery voltage and battery current is consistent and the values are slightly different, no matter under NEDC cycle or CLTC-P cycle. Due to many environmental factors, test equipment and human factors involved in the test, there are some fluctuations and differences in the test data. The annual 100km energy consumption of the vehicle calculated by the weight coefficient obtained by the least square method increases by 0.80% compared with the simulation results, compared with the simulation results, the annual 100km energy consumption of the vehicle calculated by the weight coefficient obtained by the method of determining the weight coefficient according to time is reduced by 0.58%; For CLTC-P cycle, the annual 100km energy consumption of the vehicle calculated by the weight coefficient obtained by the least square method increases by 1.90% compared with the simulation results, and the annual 100km energy consumption of the vehicle calculated by the weight coefficient obtained by the method of determining the weight coefficient according to time increases by 0.19% compared with the simulation results. The error of energy consumption is within ±5%, which is acceptable.

It can be seen from Fig.10, Fig.11, Fig.12, Fig.13 and Table 6 above that under NEDC working condition, the annual energy consumption of electric vehicles calculated by using the weight coefficient obtained by the least square method is simpler, and the annual energy consumption of electric vehicles obtained by the method of determining the weight coefficient according to time is 14.35% less.

Under CLTC-P working condition, the annual energy consumption of electric vehicles calculated by using the weight coefficient obtained by the least square method is simpler, and compared with the method of determining the weight coefficient according to time, the annual energy consumption of electric vehicles is 14.62% less. It can be seen from the above data analysis that since the air conditioner and heater do not work all the time in summer and winter, the weight coefficients under cooling and heating of electric vehicles calculated by the least square method are less than 0.25. Using the weight coefficient obtained by the least square method to calculate the vehicle energy consumption can better reflect the real energy consumption of the vehicle.

4.3 Result analysis of vehicle energy consumption test data under different comfort control strategies

According to the actual needs of different users, this paper uses three different air conditioning control modes, namely comfort mode, economic mode and power saving mode. Table 7 describes the three modes and their corresponding PMV values. For the calculation of specific PMV values, refer to reference[6]. After selecting the corresponding control mode, the user controls the target temperature in the vehicle between PMV_{min} and PMV_{max} according to the strategy.

Table 7 Three different refrigeration control modes of electric vehicles in summer

Mode	Comfort	Economic	Power saving
PMV value	-0.5~0.5	-1~1	-1.5~1.5

In addition, people are sensitive to electric energy consumption during the use of electric vehicles in winter. Due to the slow heating speed of electric vehicles in the heating process, in order to facilitate the smooth test, the temperature in the vehicle set by the heating system of electric vehicles is generally low. In the process of calculating PMV values in Table 7 and Table 8, considering the sensitivity of users in winter, the temperature in the vehicle in winter is set in combination with reference materials, and the PMV value ranges of three modes under winter heating, comfort mode, economic mode and power saving mode are obtained, as shown in Table 8.

Table 8 Three different heating control modes of electric vehicles in winter

Mode	Comfort	Economic	Power saving
PMV value	-2~-1	-2.5~-0.5	-3~0

Taking summer as an example, after the user selects the working mode, the system starts to calculate the real-time PMV value, and controls the PMV value by switching the air conditioning system to make the PMV value between PMV_{min} and PMV_{max}. PMV_{min} is the lower limit of thermal comfort, which represents the critical value of the coldest and hottest comfort state acceptable to the user, and PMV_{max} is the upper limit of thermal comfort, which represents the critical value of the hottest comfort state acceptable to the user. For example, after the user selects the comfort mode, the air conditioning control system will control the PMV value in the vehicle between -0.5 and 0.5.

In order to further analyze the impact of air conditioning energy consumption on energy consumption evaluation of electric vehicles under three thermal comfort modes. This paper also analyzes the energy consumption data under three different thermal comfort control strategies under NEDC and CLTC-P cycles.Fig.14 and Fig.15 show the energy consumption data of the whole vehicle under NEDC and CLTC-P cycles when the air conditioner is in refrigeration working state.

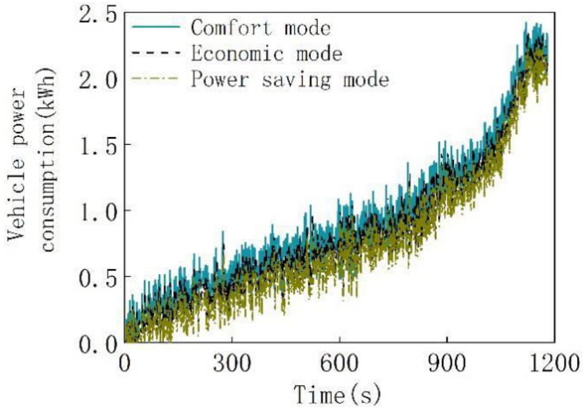


Fig.14 Energy consumption test data

of the vehicle under three control strategies of NEDC cycle

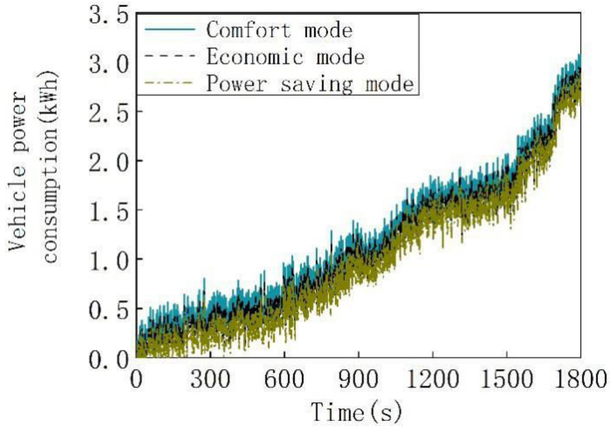


Fig.15 Energy consumption test data

of the vehicle under three control strategies of CLTC-P cycle

Through the calculation of energy consumption value, the electric vehicle energy consumption test results of CLTC-P and NEDC cycles under different refrigeration and heating conditions. See the data in Table 9 for details.

Table 9 Electric vehicle energy consumption test results of different cycles

under different refrigeration and heating conditions

Working condition	Refrigeration (kWh)	Heating (kWh)	No refrigeration and no heating (kWh)
NEDC comfort mode	2.32	3.36	1.84
NEDC economic mode	2.21	3.19	1.82

NEDC power saving mode	2.13	2.75	1.80
CLTC-P comfort mode	2.73	3.90	2.12
CLTC-P economic mode	2.64	3.73	2.10
CLTC-P power saving mode	2.55	3.59	2.07

The annual comprehensive energy consumption per 100km of the vehicle of different working cycles under the corresponding three modes is calculated by the least square method. See the data in Table 10 for details.

Table 10 Electric vehicle 100km energy consumption test results of different cycles under different refrigeration and heating conditions

Working condition	Refrigeration (kWh/100km)	Heating (kWh/100km)	No refrigeration and no heating (kWh/100km)	Least square method (kWh/100km)
NEDC comfort mode	21.03	30.44	16.68	17.99
NEDC economic mode	20.07	28.89	16.46	17.57
NEDC power saving mode	19.31	24.93	16.33	17.21
CLTC-P comfort mode	18.86	26.93	14.67	15.91
CLTC-P economic mode	18.23	25.76	14.53	15.63
CLTC-P power saving mode	17.61	24.79	14.30	15.30

According to the data in Fig.14, Fig.15, Table 9 and Table 10, the energy consumption per 100km under refrigeration, heating and uncooled heating of electric vehicles obtained by NEDC and CLTC-P cycles are different, the energy consumption per 100km corresponding to NEDC cycle is relatively high. In addition, under three different thermal comfort control strategies, whether NEDC cycle or CLTC-P cycle, using the vehicle test data and weight coefficient, the final calculation shows that the order of 100km energy consumption of the whole vehicle from large to small is comfort mode, economic mode and power saving mode.

5. Conclusion

This paper studies the energy consumption evaluation method of electric vehicle considering air conditioning energy consumption. The main conclusions are as follows:

(1) According to the annual energy consumption data of electric vehicles under real operation, the weight coefficient of energy consumption of electric vehicles under refrigeration, heating and uncooled heating conditions was obtained by using the algorithm. Then, the annual comprehensive energy consumption value of 100km of corresponding models was calculated through bench test combined with weight coefficient, the annual comprehensive 100km energy consumption of electric vehicles under different cycle conditions was compared and analyzed. It provided a new evaluation method for introducing air conditioning energy consumption into the energy consumption evaluation of electric vehicle.

(2) According to the data in this paper, since the air conditioner and heater do not work all the time in summer and winter, the weight coefficients under refrigeration and heating of electric vehicles calculated by the least square method were less than the simple weight coefficient weight of 0.25. The calculation of vehicle energy consumption by using the weight coefficient obtained by the least square method can better reflect the real energy consumption of the whole vehicle.

(3) The annual comprehensive 100km energy consumption value of the research vehicle under three different thermal environment comfort control modes of electric vehicle was analyzed. Through the vehicle test data, it was obtained that the order of the annual comprehensive 100km energy consumption value from large to small was comfort mode, economic mode and power saving mode.

Further work will be carried out in the following areas: in view of the impact of air conditioning energy consumption on the evaluation method of vehicle energy consumption, the working weight of air conditioning can be calculated according to the selected vehicle model and six climate regions in China, and then the 100km energy consumption data of electric vehicle under refrigeration, heating and uncooled heating can be obtained through bench test. Combining the above data with the weight coefficient, the annual comprehensive 100km energy consumption of the test vehicle considering the air conditioning energy consumption can be obtained.

Ethical approval and consent to participate Not applicable.

Consent to Publish Not applicable.

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Availability of data and materials Not applicable.

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