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ON THE EFFICIENCY OF THERMOELECTRIC AIR-CONDITIONERS FOR VEHICLES

The paper presents the results of calculations and comparative analysis of the integral efficiency of thermoelectric and compression air-conditioners, subject to their use for air conditioning in vehicles during the whole year in different climatic conditions. Bibl. 25, Tabl. 2, Fig. 14.

Key words: thermoelectric air-conditioner, compression air-conditioner, efficiency.

Introduction

General characterization of the problem. The upward trend in the number of cars is well known. Already in 2010, their number exceeded 1 billion [1] and this figure is growing rapidly. Along with this, the requirements for safety, ecology and comfort in vehicles are growing. So, there is a need to create effective, reliable and environmentally friendly devices to ensure comfortable conditions in vehicles, i.e. air conditioners [2 – 8].

The literature mentions the possibility of air conditioning in vehicles by various methods [2 – 8]. Particular attention is paid to the use of compression air-conditioners. This is due to their relatively high performance. However, they also have a number of disadvantages, in particular the presence of environmentally hazardous refrigerants, which significantly reduces the attractiveness of such air-conditioners. This situation is intensified by the transition to environmentally friendly modes of transport, in particular electric cars [6 – 14].

The works [4, 8, 9] describe the use of thermoelectric converters for air conditioning in vehicles. Such air conditioners have a number of advantages over compression, namely: the absence of harmful refrigerants (environmentally safe), lower overall dimensions, high reliability and ease of maintenance [15, 16].

In addition, despite the higher maximum efficiency indicators of compression air-conditioners in cooling mode, during their operation in vehicles throughout the year, one should use the integral efficiency indicators (for both cooling and heating modes) in different time and geographical conditions, which can significantly change the understanding of the energy situation of air conditioners. Such indicators will become a true criterion for the energy efficiency of air conditioners in the real conditions of their operation.

The purpose of the proposed work is to determine the integral energy efficiency indicators of thermoelectric and compression air-conditioners of vehicles in different operating conditions.

Peculiarities of functioning of automobile air-conditioners in different climatic conditions in the course of a year

To obtain full picture of the operating conditions of air-conditioners in different climatic zones [17], we used data on the daily and monthly fluctuations of air temperature in different geographical regions of the planet [18]. The work considers temperature conditions in 10 cities which correspond to the most characteristic climatic regions of the Earth (Fig. 1): Kuala Lumpur (Malaysia) – equatorial climate; Mumbai (India) – tropical monsoon climate; Aswan (Egypt) – tropical dry climate; Athens (Greece) – Mediterranean climate; Ashgabat (Turkmenistan) – subtropical dry climate; Plimuth (Great Britain) – moderate maritime climate; Kyiv (Ukraine) – moderate continental climate; Harbin (China) – moderate monsoon climate; Point Hope (Alaska, USA) – subarctic climate; Tiksi (Russian Federation) – arctic climate.

Using the information obtained, you can determine the energy efficiency of the use of vehicle air-conditioners in almost all regions of our planet.

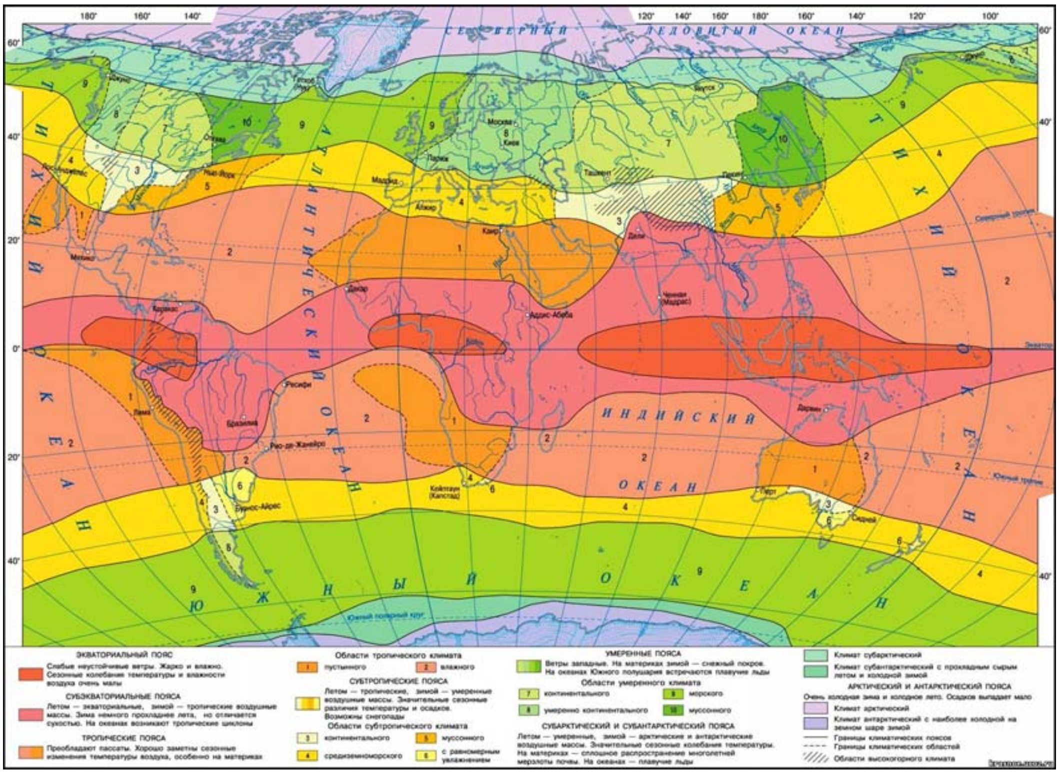

Fig.1. Climatic zones [17].

Figs. 2 - 11 show diagrams of annual temperature changes in different zones of the Earth. The line shows the change in average air temperature during the year and the outline indicates its maximum deviations. Analysis of these diagrams allows one to see the most general patterns of changes in temperature conditions in climatic zones during the year. Thus, it can be seen from Fig. 2 that the equatorial climate is characterized by virtually unchanged average air temperature during the year at +26 °C; tropical monsoon climate is characterized by average temperatures of January +20 °C and July +30 °C (Fig. 3); tropical dry climate is characterized by a more abrupt change in temperature during the year - average January temperature +12 °C and July +35 °C (Fig. 4); the Mediterranean climate is characterized by an average temperature of January +7 ° C and July +22 °C (Fig. 5); subtropical dry climate is notable for the most dramatic change in temperatures during the year - average January temperature is 0 °C and July +40 °C (Fig. 6); temperate marine climate is characterized by slight temperature changes - average January temperature +2 °C and July +17 °C (Fig. 7); temperate continental climate characterized by average temperatures in January -15 ° C and July +20 °C (Fig. 8); temperate monsoon climate is characterized by average temperatures of January -20 °C and July +23 °C (Fig. 9); subarctic climate is characterized by average temperatures of January -25 °C and July +8 °C (Fig. 10); the arctic climate is characterized by very severe average temperatures of January – 40 °C and July 0 °C (Fig. 11).

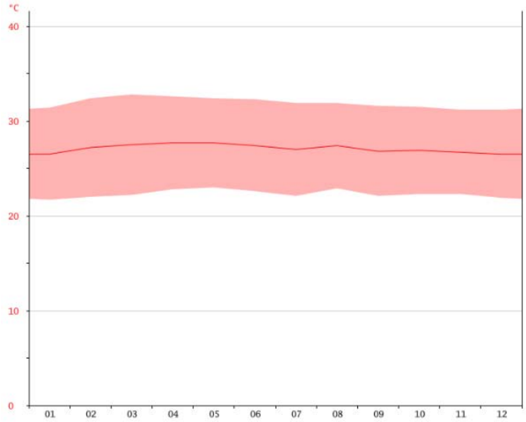

Fig.2. Diagram of annual change of air temperature in Kuala Lumpur, Malaysia [18]

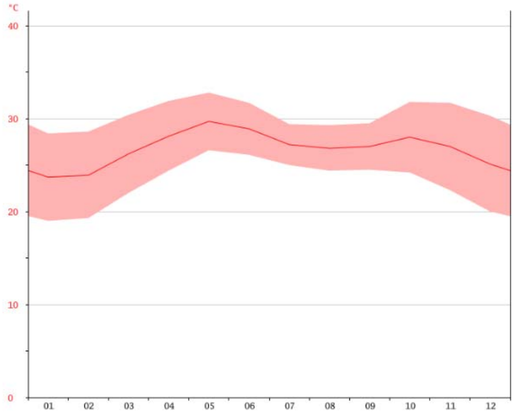

Fig.3. Diagram of annual change of air temperature in Mumbai, India [18]

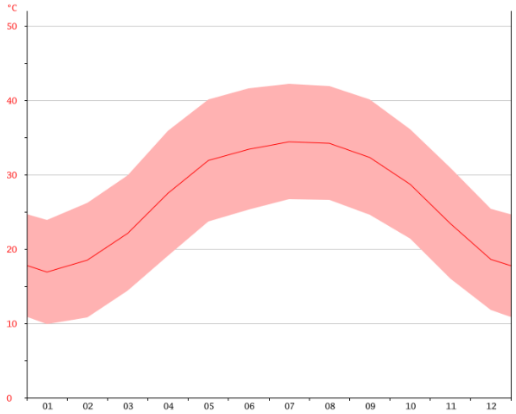

Fig.4.Diagram of annual change of air temperature in Aswan, Egypt [18]

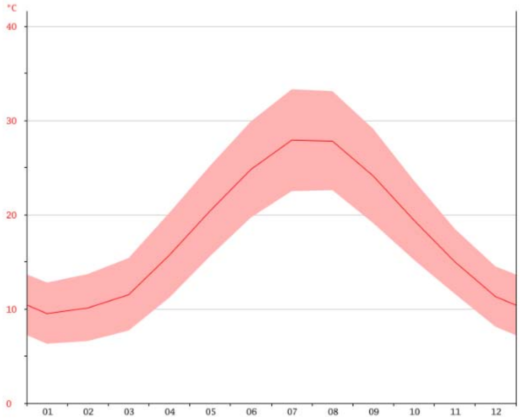

Fig.5. Diagram of annual change of air temperature in Athens, Greece [18]

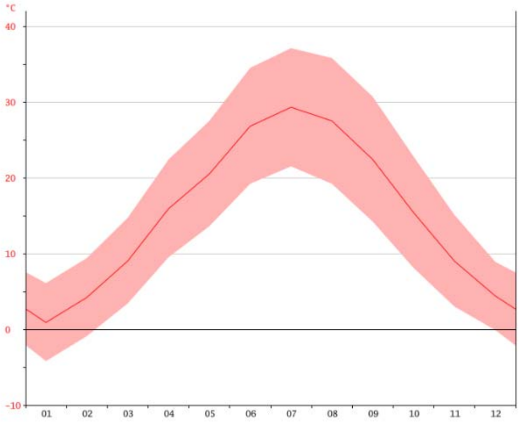

Fig.6. Diagram of annual change of air temperature in Ashgabat, Turkmenistan [18]

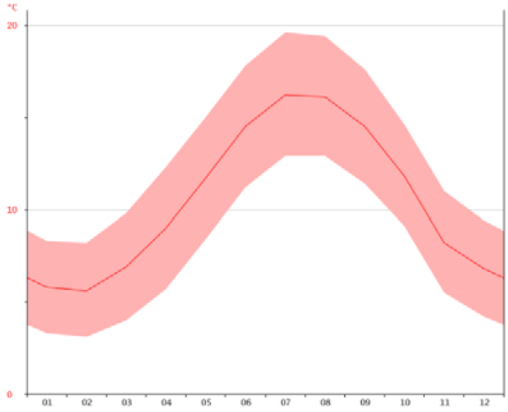

Fig.7. Diagram of annual change of air temperature in Plimuth, Great Britain [18]

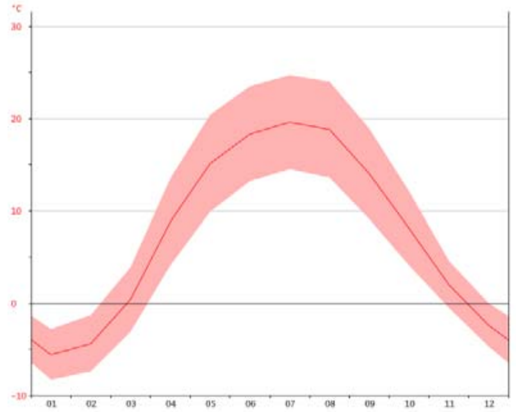

Fig.8. Diagram of annual change of air temperature in Kyiv, Ukraine [18]

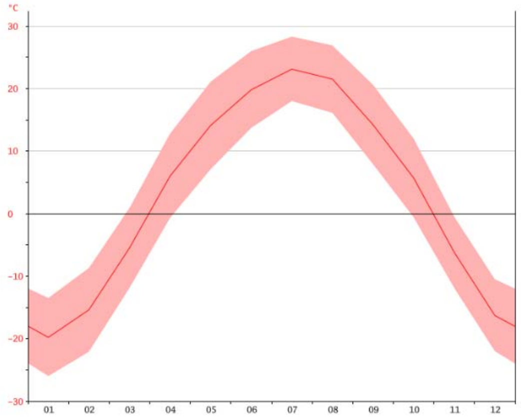

Fig.9. Diagram of annual change of air temperature in Harbin, China [18]

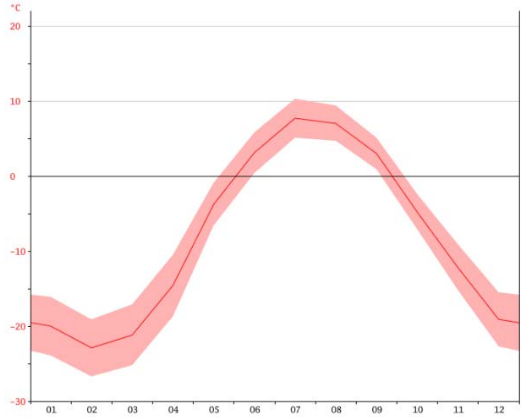

Fig.10. Diagram of annual change of air temperatur in Point Hope, Alaska, USA [18]

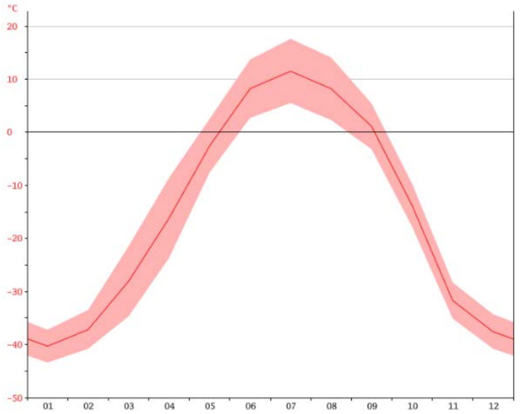

Fig.11. Diagram f annual change of air temperature in Tiksi, Russian Federation [18]

Calculation of the integral efficiency of thermoelectric and compression air-conditioners for different climatic zones

Calculation procedure

The selected calculation procedure lies in determination of the integral efficiency factor of air-conditioner for transport κ which is equal to the ratio between heat flow Q transferred by the air-conditioner and energy costs for its functioning W (1).

$$\kappa = \frac{Q}{W} \tag{1}$$

In so doing, in cooling mode, when the ambient temperature exceeds +20 °C (the temperature difference between the air outside and inside the vehicle $\Delta T > 0$ K), heat flow Q is refrigerating capacity of air conditioner, and, accordingly, factor κ is coefficient of performance ε (2). In the case when $\Delta T < 0$ K (ambient temperature is lower than +20 °C), coefficient μ is heating coefficient of air-conditioner (2).

$$\begin{array}{lcl} \Delta T > 0\ \text{K} & \rightarrow & \kappa = \varepsilon, \\ \Delta T < 0\ \text{K} & \rightarrow & \kappa = \mu. \end{array} \tag{2}$$

Further, the average values of the coefficient κ were determined at certain time intervals, which are a function of the temperature difference ΔT and the ambient temperature value. The 4 hours interval was selected. Thus, during the day 6 values of κ were determined.

It should be noted that, in accordance with the sanitary requirements for air-conditioned rooms [25], the temperature difference between the ambient air and the cooled air-conditioner should not exceed 17 K. However, depending on the value of the ambient air temperature, this difference is different [25]. These requirements were also used in the calculations.

Then, the obtained data on energy conversion coefficients κ averaged over a time interval were summed up and their average value $\hat{\kappa}$ was determined over a whole year (3).

$$\hat{\kappa} = \frac{\sum_{i=0}^{n} \kappa_i}{n}, \tag{3}$$

where n is the number of intervals in which the average value κ was determined ($n = 365 \cdot 6 = 2190$).

The following is a calculation procedure of κ and $\hat{\kappa}$ for compression and thermoelectric air-conditioners.

Compression air-conditioners

The data on the properties of compression air-conditioners in cooling and heating modes [2 - 24] were used to determine in the form of polynomials the dependences of energy efficiencies of compression air-conditioners on ambient air temperature and temperature difference between the air inside a car (20 ^{0}C) and the ambient air.

It is significant that energy conversion coefficient of compression air-conditioners in heating mode is lower than in cooling mode. Morover, as is shown in [15, 16], their effcieincy decreases with decreasing power and and a rise in the ambient temperature. A compression air-conditioner was selected as a prototype for calculations; its maximum cooling power 4kW corresponds to typical values for air-conditioners of vehicles.

Based on the obtained data arrays, calculations were made of the averaged energy conversion coefficients of compression air-conditioners to determine time intervals in the course of a year and their integration was performed to obtain the values of the integral efficiency factor.

Table 1 shows the results of calculations in the form of integral efficiency factor values for different climatic zones (climate types) – 1. equatorial climate; 2. tropical monsoon climate; 3. tropical dry climate; 4. subtropical dry climate; 5. Mediterranean climate; 6. moderate maritime climate; 7. moderate continental climate; 8.moderate monsoon climate; 9. subarctic climate; 10. arctic climate.

As is seen from Table 1, with a change in climatic zones from equator to poles, the integral efficiency factor of compression air-conditioners decreases from 3.18 to 1.2.

Table 1

Dependence of integral efficiency factor
of compression air-conditioners on different climatic zones

Climatic zones	1	2	3	4	5	6	7	8	9	10
Integral efficiency factor	3.18	3.17	2.98	3.02	2.76	2.66	2.25	2.06	1.5	1.2

Thermoelectric air-conditioers

As is shown in [15, 16], the real coefficient of performance and heating coefficient of thermoelectric air-conditioner are found from the relationships (4, 5):

coefficient of performance

$$\varepsilon_r = \frac{Q_c}{W_{TE} + W_1 + W_2} = \frac{\alpha I(T_c + Q_c N_1) - 0.5 I^2 R - \lambda(T_h - T_c - (Q_h N_2 + Q_c N_1))}{W_{TE} + W_1 + W_2}, \quad (4)$$

where χ_i are thermal resistances of heat-exchangers, Q_c is refrigerating capacity, Q_h is thermal productivity, W_{TE} is electric power of thermoelectric converter, α is the Seebeck coefficient, I is electrical current, R is electrical resistance, λ is heat transfer coefficient of heat exchangers, T_h, T_c are the hot and cold side temperatures of thermoelectric converter, W_i is additional power supply of heat exchange system,

$N_1 = \frac{(\chi_1 + \chi_2)}{\chi_1 \chi_2}$, $N_2 = \frac{(\chi_3 + \chi_4)}{\chi_3 \chi_4}$.

Heating coefficient in this case will be given by:

$$\mu_r = \frac{Q_h}{W_{TE} + W_1 + W_2} = \frac{\alpha I(T_h + Q_h N_2) + 0.5 I^2 R - \lambda(T_h - T_c - (Q_h N_2 + Q_c N_1))}{W_{TE} + W_1 + W_2}. \quad (5)$$

The coefficient of performance and heating coefficient of thermoelectric air-conditioner are related as:

$$\mu_r = \varepsilon_r + 1. \quad (6)$$

Relationship (6) indicates that the use of thermoelectric air-conditioner in heating mode has the advantage over a similar mode of compression air-conditioner.

It is also noteworthy that unlike compression air-conditioners, the efficiency of thermoelectric air-conditioners increases with decreasing power and a rise in air temperature [15, 16], which creates additional advantages for them.

Fig.12 shows a typical dependence of the coefficient of performance of thermoelectric air-conditioner on supply current for different values of temperature difference between its hot and cold sides. The data is given for the ambient temperature of 30 ^{0}C. Similar dependences were obtained for all considered temperature ranges and were written in the form of polynomials.

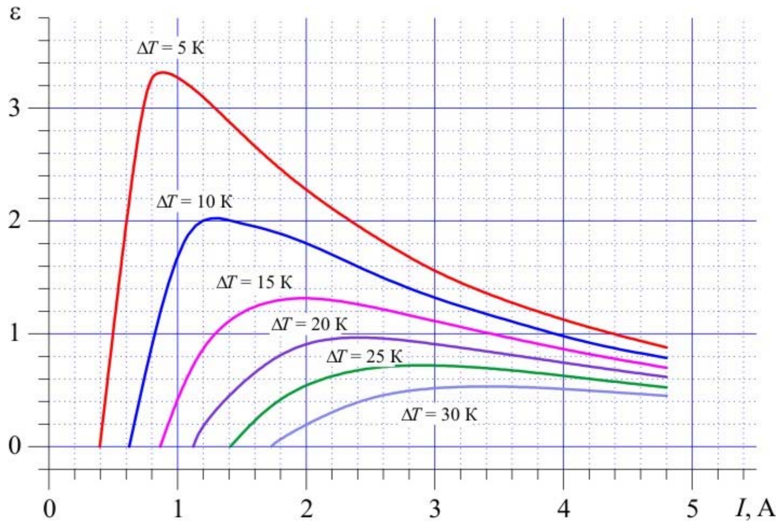

Fig. 12 Typical dependence of the coefficient of performance of t hermoelectric air-conditioner on supply current for different values of t emperature difference between its hot and cold sides.

Based on the obtained data arrays, the averaged energy conversion coefficients of thermoelectric air-conditioners were calculated for the selected time intervals in the couse of a year and their integration was performed to obtain the values of the integral efficiency factor.

Table 2 shows the results of calculations in the form of the values of the integral efficiency factor of thermoelectric air-conditioners for different climatic zones.

As is seen from Table 2, with a change in climatic zones from equator to poles, the integral efficiency factor of thermoelectric air-conditioners changes from 1.5 for a dry tropical climate to 3.06 for a moderate maritime climate.

Table 2

Dependence of integral efficiency factor of compression air-conditioners on geographic latitude

Climatic zones	1	2	3	4	5	6	7	8	9	10
Integral efficiency factor	1.99	2.09	1.5	2.14	2.62	3.06	2.38	2.21	1.75	1.55

Comparison of compression and thermoelectric air-conditioners

Thus, comparison of the values of averaged efficiency of thermoelectric and compression air-conditioners from Tables 1 and 2 testifies to the advantage of compression air-conditioners under hot climatic conditions of equator, tropics and subtropics (Fig.13). However, starting from moderate climatic conditions, thermoelectric air-conditioners offer the advantage in efficiency up to 20 %.

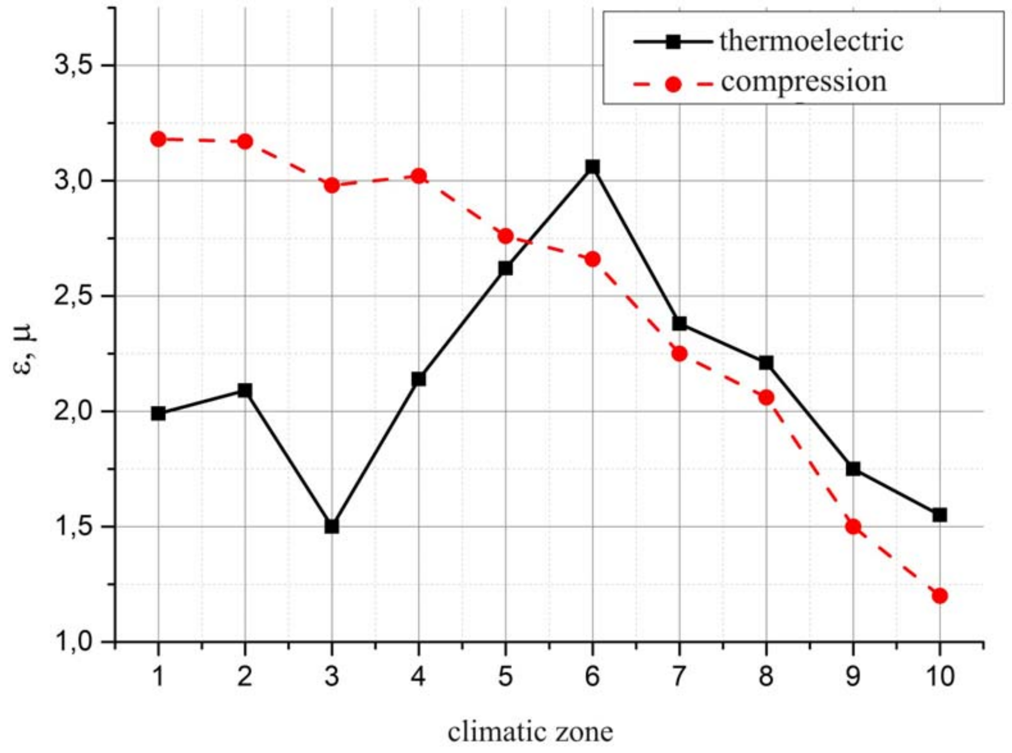

Fig. 13. Comparison of the integral efficiency factor (ε, μ) of compression and thermoelectric air-conditioners in different climatic zones.

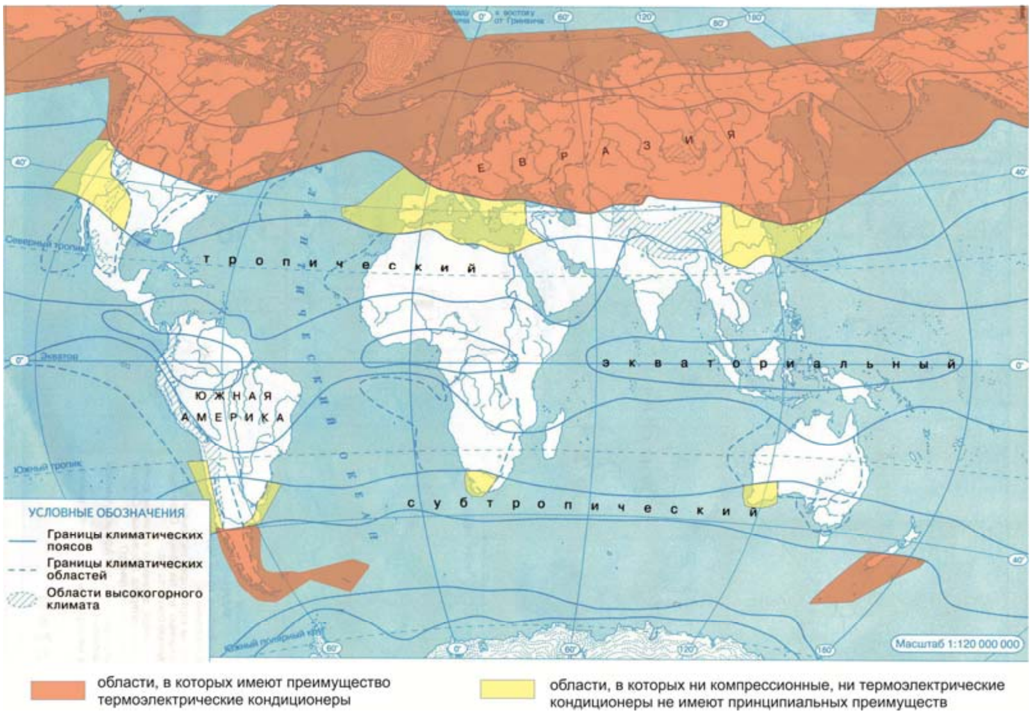

Fig. 14. Areas on the planet where the use of thermoelectric air-conditioners is rational.

To illustrate Fig.13, on the map of the Earth (Fig.14) areas have been plotted where the use of thermoelectric air-conditioners has evident advantages in efficiency (marked in red), and the areas where the use of thermoelectric and compression air-conditioners is approximately equal in efficiency (marked in yellow).

As is seen from Fig.14, the rational areas of using thermoelectric air-conditioning includes almost all Europe, China, Russia, Canada, part of the USA and the Mediterranean countries, which alongside with other advantages thereof (ecological compatibility, lower mass-dimensional indicators), makes this variant of air-conditioning attractive for use in automobile transport, especially in electric vehicles.

Conclusions

1. Calculations were made of the averaged efficiency factor of compression air-conditioners with their constant use in the course of a year in different climatic zones. It was established that with a change in climatic zones from equator to poles, the integral efficiency factor of compression air-conditioners is reduced from 3.18 to 1.2.
2. Calculations were made of the integral efficiency factor of thermoelectric air-conditioners with their constant use in the course of a year in different climatic zones. It was established that with a change in climatic zones from equator to poles, the integral efficiency factor of thermoelectric air-conditioners is changed from 1.5 for a dry tropical climate to 3.06 for a moderate maritime climate.
3. Comparison of the integral efficiency values of thermoelectric and compression air-conditioners testifies to the advantage of compression air-conditioners in the hot climatic conditions of equator, tropics and subtropics. However, starting from the moderate climatic conditions, thermoelectric air-conditioners offer the advantage in efficiency up to 20 %, which, alongside with other advantages thereof (ecological compatibility, lower mass-dimensional indicators, reliability), makes this variant of air-conditioning attractive for use in automobile transport, especilaly in electric vehicles.

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ПРО ЕФЕКТИВНІСТЬ ТЕРМОЕЛЕКТРИЧНИХ КОНДИЦІОНЕРІВ ДЛЯ ТРАНСПОРТНИХ ЗАСОБІВ

У роботі наводяться результати розрахунків та порівняльного аналізу інтегральної ефективності термоелектричних та компресійних кондиціонерів при умові їх використання для кондиціонування повітря у транспортних засобах протягом цілого року в різних кліматичних умовах. Бібл. 25, Табл. 2, Рис. 14 .

Ключові слова: термоелектричний кондиціонер, компресійний кондиціонер, ефективність.

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ОБ ЭФФЕКТИВНОСТИ ТЕРМОЭЛЕКТРИЧЕСКИХ КОНДИЦИОНЕРЫ ДЛЯ ТРАНСПОРТНЫХ СРЕДСТВ

В работе приводятся результаты расчетов и сравнительного анализа интегральной эффективности термоэлектрических и компрессионных кондиционеров при условии их использования для кондиционирования воздуха в транспортных средствах в течение целого года в различных климатических условиях. Библ. 25, Табл. 2, Рис. 14 .

Ключевые слова: термоэлектрический кондиционер, компрессионный кондиционер, эффективность.

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