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Impact of solar radiation on the climate of a passenger car

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Abstract. The volume of passenger traffic is constantly growing. Accordingly, the requirements for passenger transportation conditions are increasing - it is necessary to ensure improved comfort. Since the travel routes of passenger cars follow different climatic zones, comfort dictates the need to maintain a constant temperature in the car - 22-26˚C in summer, 20-24˚C in winter. The temperature regime in the car also depends on the materials used in car construction, namely: the heat transfer coefficient, the thermal properties of the car materials. In addition, window openings of passenger cars also participate in heat transfer processes, which also affects the climatic conditions in the car. The article presents the results in the form of calculations and graphs of temperature dependences of the influence of solar radiation on climate (temperature conditions) in a passenger car.

1 Introduction

Modern carriage building has great prospects for using scientific achievements. The basis for this statement is many publications on the topic of solving problems of railway transport [1-5]. For example, at the Research Center for Railway Car Building at the Tashkent State Transport University, it conducts targeted world-class research [6-10].

The works cover a wide range of topics. This includes the dynamics of cars, the use of new methods for calculating structural strength, and new materials and technologies for their processing in railway rolling stock, a discussion of the results of field tests [11-20].

However, the areas of research at the Research Center are constantly expanding. For example, an important aspect of research is to ensure comfortable conditions for passenger transportation.

The fact is, as is known, the countries of Central Asia, Uzbekistan in particular, have a high-temperature climate. Only a few months a year in the country the air temperature range allows the operation of railway trains (passenger cars) without additional energy consumption to ensure normal living conditions for passengers. Therefore, this work is relevant.

The purpose of the work is to assess the possibilities of using natural solar radiation to create regulatory conditions for passenger transportation.

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2 Research methodology

In the heat balance of passenger railway rolling stock, taking into account solar radiation is important, since the main heat flow into the car in the conditions of Central Asia is provided by the sun, especially its radiation in the summer.

Solar radiation is the main factor in the energy supply of rolling stock with rays of the visible region of the spectrum (wavelength 0.4-0.8 microns), as well as rays of the infrared region of the spectrum (wavelength up to 3 microns).

The spectral composition of solar radiation reaching the Earth's surface depends on the height of the Sun and consists of infrared, visible and ultraviolet rays. Direct solar radiation reaches the Earth through the atmosphere. In this case, direct radiation is usually divided into horizontal and vertical components, which are determined by formulas, according to which the roof and side wall of the car, respectively, receive:

$$J_{nr} = J_n \cdot \mathrm{Sinh} \tag{1}$$

$$J_{6.c.l} = J_n \cdot \mathrm{Cosh} \cdot \mathrm{Sin}(\alpha - x)$$

where ***Jn*** is total radiation; ***h***-height of the Sun in degrees; ***α*** – azimuth of the Sun; ***x*** is the angle between the vertical surface and the meridian.

Scattered radiation - part of the solar radiation scattered in the atmosphere goes back into space, but the main part of it arrives on Earth.

Reflected solar radiation - (Albedo) - the total radiation reaching the Earth's surface is reflected from it, creating reflected radiation directed from the Earth into the atmosphere.

Total direct solar radiation is determined by the Castrov-Savinov formula:

$$J_n = |36| \frac{\mathrm{Sinh}}{\mathrm{Sinh} + \frac{1-\rho}{\rho}} \tag{2}$$

where ***h*** is the height of the Sun, degrees; ***ρ*** - atmospheric transparency coefficient (***ρ*** = 0.7-0.8), |36| - solar constant.

The height of the Sun h is determined by the formula:

$$\mathrm{Sin}\, h = \mathrm{Sin}\, \varphi \cdot \mathrm{Sin}\, \delta + \mathrm{Cos}\varphi \cdot \mathrm{Cos}\delta \cdot \mathrm{Cos}\gamma$$

where: ***φ*** - geographic latitude; ***δ*** - declination of the Sun 1h-15˚, ***γ*** - hour angle.

In accordance with formulas (1) and (2), the total radiation on the roof of the car can be determined by the formula:

$$Jcr = Jn \cdot \mathrm{Sin}\, h \tag{3}$$

and on the side wall of the car illuminated by the Sun according to the formula:

$$Jb.s. = Jn \cdot \mathrm{Cos}\, h \cdot \mathrm{Sin}\, (\alpha - x) \tag{4}$$

3 Results and discussion

The amount of solar radiation acting on the roof of the car and the side wall of the car is calculated using formulas (3) and (4) at an outside air temperature of 40˚C in the Tashkent area.

Based on the calculation results, a graph of the dependence of radiation on the height of the Sun h was constructed. (Figure 1).

Total solar radiation at midday is 1003 W/m^2, with 942 W/m^2 on the roof and 61 W/m^2 on the side wall. Thus, at noon, the greatest amount of radiation falls on the roof of the car, heating it greatly, which of course leads to increased heat transfer through the roof enclosures and thereby increasing the air temperature in the car.

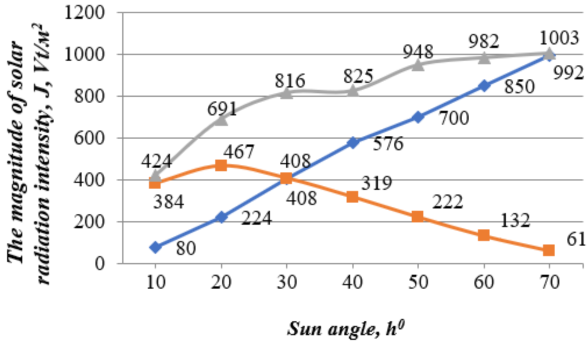

Fig. 1. Graph of changes in solar radiation

To check the degree of heating of the car body, a passenger car parked on the territory of TVSRZ was selected. The carriage stood on the platform, illuminated by the Sun throughout the day. The purpose of this experiment was to test the actual heating of the body of a passenger car from exposure to solar radiation. When the car moves at a certain speed, the surface is blown by a counter air flow, naturally the degree of heating of the body decreases, but when parked along the route and when preparing the car for a trip, the car body heats up from exposure to solar radiation, increasing the air temperature in the car, which does not meet the requirements of a comfortable climate for passengers. At the points where the train is equipped for the flight, the air in the carriage is not cooled, and this is almost impossible to do. Therefore, it was decided to measure the temperature of the surface of the car and inside when exposed to solar radiation. In Central Asia, in the summer months (June, July, August), the air temperature reaches 39-45˚C in the shade, and in the sun up to 60-75˚C.

To check the effect of the sun on the surface of the car, temperature measurements were taken in different parts of the car body. Figure 3 shows the temperature measurement points.

Fig. 2. Layout of temperature measurement points. 1-roof; 2 side wall

Measurements were made on the surface of the car, and on the Sun. The carriage was positioned so that the side wall faced south. Measurement time from 900 to 1800 with an interval of 1 hour.

Figure 4 shows a histogram of temperatures in different parts of the cars at 14:00 in July 2022.

The outside air temperature in the Sun varied from 43˚C (9 am) to 55˚C (14 pm), then the temperature dropped to 46˚C (18 pm). At the same time, the temperature in the shade was 33˚C (900 hours); 41˚C (1400 hours) and 36˚C (1800 hours).

The air temperature in the Sun at 1400 hours was 14 °C higher than in the shade. The heating temperature of the roof surface under the influence of solar radiation was 55.5˚C (900 hours), 66˚C (1400 hours) and 40˚C (1800 hours).

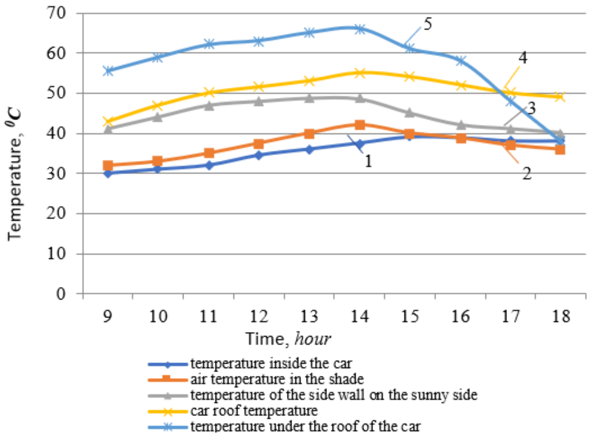

Fig. 3. Temperature graph on the surface and inside the car

The roof heating temperature difference was 11˚C higher than the air temperature in the Sun. The roof surface begins to heat up to high temperatures in the morning and reaches a maximum at 14:00. On the side wall illuminated by the Sun, the sun's rays at noon (12 o'clock in the afternoon) fall at an angle of 19˚, therefore the impact of solar radiation on the side wall is much less than on the roof and is only J = 467 W/m^2 at noon. The maximum temperature on the surface of the illuminated side wall was 49.6˚C at 13:00. At 900 o'clock in the morning the temperature of the side wall was 41˚C and at 18^{00}-40˚C.

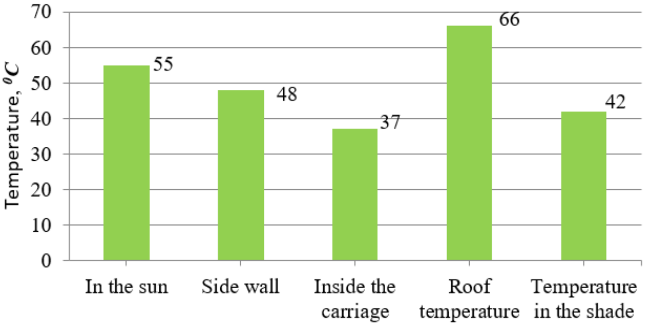

Fig. 4. Temperature histogram on the surface of the car

At this time, the shadow side of the side wall was subjected to scattered irradiation. The temperature inside the car varied from 31˚C (900), 39˚C (1400) and 38˚C (1800). The slow drop in temperatures inside the car can be explained by the fact that the intensity of solar radiation at this time dropped sharply, and the roof, side walls and internal equipment (walls, partitions, shelves) heated during the day continued to release accumulated heat into the air inside the car.

To confirm the results of experimental temperature measurements, a 1:30 scale model of the car was made.

The model is made of St3 steel, the same as the casing of the passenger car. The body of the model is made detachable and there are no seals at the ends for natural ventilation. Mounted on the top of the model are two reference thermometers, one to measure the temperature inside the model and the other on the surface of the model. Figure 5 shows a photograph of a model with thermometers.

Fig. 5. Model with thermometers at the test site

The model was installed in an open area so that the Sun illuminated the model throughout the day. Temperatures were recorded from 900 am to 1800 pm at intervals of one hour.

Figure 6 shows a graph of temperature changes due to the influence of the sun on the surface and inside the model.

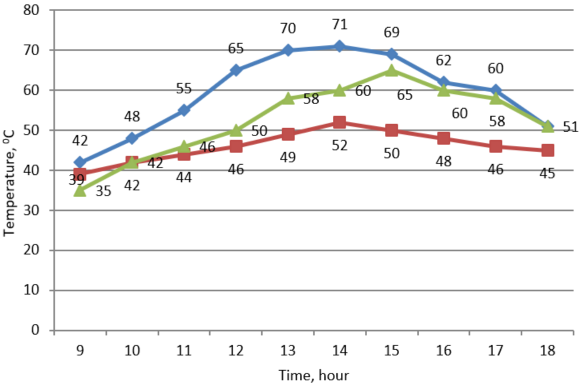

Fig. 6. Graph of temperature changes on the surface and inside the model without Corundum coating

The outside air temperature in the shade on the test day at 1400 hours was 41˚C. The surface temperature tsur model in 1400 was 71˚C, inside the model the temperature tin was 60˚C, and the air temperature tc on the Sun was 52˚C. The temperature difference on the surface and inside the model is 11˚C.

The 2 mm thick steel cladding of the model retards heat flow by 11˚C due to its thermal conductivity and conductive heat transfer.

At the second stage of the experiment, the inner surface of the model was covered with Corundum (thermal insulating material) with a thermal conductivity coefficient of 0.0012 W/m·K with a layer thickness of 1 mm. The tests were repeated at an outside air temperature in the Sun tc=52˚C and in the shade tshadow=40˚C. Figure 7 shows a graph of temperature changes on the surface and inside the model.

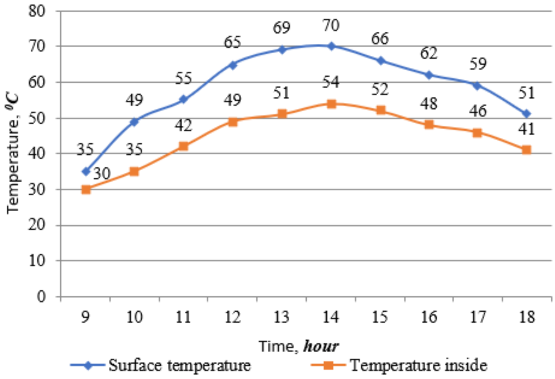

Fig. 7. Graph of temperature changes on the surface and inside the model with Corundum treatment

The maximum temperature on the surface of the model was noted (Figure 9) at 1400 hours t_{surf}=70˚C, and inside the car t_{in}=54˚C, i.e. the difference was 16˚C.

Consequently, the surface of the model, coated from the inside with Corundum, delays the heat flow through the model's enclosures by 6˚C more than that of the model without Corundum coating. Due to the low thermal conductivity of corundum, tests of the proposed body fencing samples will be carried out in the future.

4 Conclusion

Thus, we can conclude that solar radiation has a great influence on the temperatures inside the car, heating the air to 38-39˚C. Therefore, it is necessary to consider thermal protection systems for the car. It is necessary to select materials for fencing the body that could provide the necessary protection from solar radiation. Promising materials for car building are composite materials made of light alloys with polymer coatings.\

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