Effectiveness of Sun Protection of the Cab of a Mobile Agricultural Machine

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Abstract. The effectiveness of the translucent enclosing structures of the tractor cab in reducing solar radiation was tested, for which the value of the total heat flux entering the inside during the whole working day was determined, which is subsequently compared with hygienic standards. The result showed: on average, low efficiency of the shading of the tractor cab. In this regard, the use of more effective shading elements and the use of glasses with increased light and heat-shielding properties in skylights is proposed.

1. Introduction
Solar radiation is electromagnetic oscillations with non-uniform wavelengths. The composition of solar radiation includes ultraviolet radiation with a wavelength of 290 to 400 nm, visible – from 400 to 760 nm and infrared – from 760 to 2800 nm. Due to its low content in the solar spectrum (1%), ultraviolet radiation generally has a positive effect on the human body. On the other hand, infrared radiation (59%), with prolonged exposure, causes a negative effect – sunstroke. Often, such situations can be observed in natural conditions when working in confined spaces under direct sunlight, for example, when operating mobile agricultural machinery operators (tractors, combines, etc.) [1–3].

The aim of the study was to estimate the amount of solar radiation penetrating through the light openings of the tractor cab during the entire working day.

Objectives:
1) To calculate the total amount of heat entering the cab through the skylights;
2) To evaluate the effectiveness of sun protection in accordance with the hygienic standards of heat radiation.

2. Main part
The total area of the tractor cab glazing is 35% (figure 1).
Figure 1. The geometric dimensions of the light openings of the tractor cab.

Total heat gain entering the cab through the skylights, W/m²:

\[ q_\Sigma = q_{s.r.} + q_{h.t.} \]  \hspace{1cm} (1)

Heat gain into the cabin from solar radiation:
- when the light opening is vertical, W/m² (figure 2):

\[ q_{s.r.} = (q_{dir} \cdot K_{ins} + q_{scat} \cdot K_{irrad}) K_{rel} \cdot \tau_2, \]  \hspace{1cm} (2)

Where \( q_{dir}, q_{scat} \) – heat gain from direct and scattered solar radiation, W/m²; \( K_{irrad} \) – irradiation factor; \( K_{rel} \) – coefficient of relative penetration of solar radiation; \( \tau_2 \) – shading coefficient of the skylight by bindings; \( K_{ins} \) – insolation coefficient calculated by the formula (3):

\[ K_{ins} = \left( 1 - L_h \ \text{ctg} \ \beta - a \right) \left( 1 - L_v \ \text{tg} \ \text{A}_{s.g.} - c \right), \]  \hspace{1cm} (3)

Where \( L_h, L_v \) – width of horizontally and vertically protruding shading elements, m; \( \beta \) – the angle between the plane of the light opening and the plane of projection of the sunbeam perpendicular to it, °; \( \text{A}_{s.g.} \) – solar glazing azimuth; \( a, c \) – distance from horizontally and vertically protruding shading elements to the light opening, m; \( H, B \) – height and width of the light opening, m [2, 4–6].
when the light opening is vertically at an angle, W/m² (figure 3):

\[ q_{s.r.} = \left( q_{dir} \cdot K_{ins} \cdot \frac{\cot \beta}{\cot (\beta \pm \beta')} + q_{scat} \cdot K_{irrad} \right) K_{rel} \cdot \tau_2. \]  

(4)

Where \( \beta' \) – angle of deviation of the plane of the light opening from the vertical, °; \( K_{ins} \) – the coefficient of insolation, calculated by the formula (5):

\[ K_{ins} = \left( 1 - \frac{L_h \cot (\beta \pm \beta')}{H} - a \right) \left( 1 - \frac{L_v \tan A_{svg} \sin \beta}{B} \right). \]  

(5)
Heat gain into the cab due to heat transfer, W/m²:

\[
q_{\text{h.t.}} = \frac{(t_a - t_i)}{\frac{\delta}{\lambda} + \frac{1}{\alpha_{\text{out}}} + \frac{1}{\alpha_{\text{in}}}},
\]

(6)

where \( t_a \) – temperature of the ambient air, °C; \( t_i \) – temperature inside the cabin, °C; \( \delta \) – glass thickness in the light opening, m; \( \lambda \) – thermal conductivity of glass, W/(m·K); \( \alpha_{\text{out}}, \alpha_{\text{in}} \) – heat transfer coefficient for the outer and inner surface of the light opening, W/(m²·K), calculated by formulas (7) and (8) depending on the speed of air movement outside and inside the cab [4–6, 7–10]:

\[
\alpha_{\text{out}} = 5 + 3.4v_{\text{out}};
\]

(7)

\[
\alpha_{\text{in}} = 6\sqrt{v_{\text{in}}};
\]

(8)

3. Results and discussion

The initial data for calculating solar radiation penetrating through the light openings located on the eastern side are presented in the table 1.

| Indicator | True solar time, h | 6–8 | 8–10 | 10–12 | 12–14 | 14–16 | 16–18 |
|-----------|--------------------|-----|------|-------|-------|-------|-------|
| \( q_{\text{dir}}, \text{W/m2} \) | 481 | 431 | 115 | 0 | 0 | 0 | 0 |
| \( q_{\text{scat}}, \text{W/m2} \) | 121 | 111 | 77 | 63 | 60 | 50 | 50 |
| \( K_{\text{ins}} \) | 1.001 | 0.997 | 0.979 | 0.979 | 0.985 | 1.001 | 1.001 |
| \( \beta, ^\circ \) | 65.85 | 43.35 | 15.6 | 15.6 | 43.35 | 65.85 | 65.85 |
| \( A_{\text{s.g.}} \) | 10 | 18.5 | 58.5 | 58.5 | 18.5 | 10 | 10 |
| \( a, \text{m} \) | | | | | | | 0.01 |
| \( L_n, \text{m} \) | | | | | | | 0.02 |
| \( H, \text{m} \) | | | | | | | 1.561 |
| \( B, \text{m} \) | | | | | | | 1.091 |
| \( \beta', ^\circ \) | | | | | | | 2.17 |
| \( t_a, ^\circ \text{C} \) | | | | | | | 45 |
| \( t_i, ^\circ \text{C} \) | | | | | | | 24 |
| \( \alpha_{\text{out}}, \text{W/(m²·K)} \) | | | | | | | 8.4 |
| \( \alpha_{\text{in}}, \text{W/(m²·K)} \) | | | | | | | 3.29 |

The results of calculating the total heat flow penetrating into the cabin through the light openings are presented in the table 2.
Table 2. The results of calculating the total heat flow.

| Indicator | True solar time, h |
|-----------|--------------------|
|           | 6–8 | 8–10 | 10–12 | 12–14 | 14–16 | 16–18 |
| $q_{s,r}$, W/m$^2$ | 41.85 | 50.3 | 52.8 | 160.3 | 456.15 | 508.5 |
| $q_{h,t}$, W/m$^2$ | 18.09 | 34.22 | 50.06 | 68.44 | 84.66 | 81.94 |
| $q_{\Sigma}$, W/m$^2$ | | | | | 1607.31 |

To check the effectiveness of the sun protection of the tractor cab, let us compare the value of the total heat flow penetrating into the cab through the light openings with the hygienic standards of thermal radiation used in the hygienic assessment of the classes of working conditions according to the microclimate indicators (table 3) [2, 3, 11].

Table 3. Evaluation of the effectiveness of sun protection.

| Indicator | effectiveness of sun protection |
|-----------|--------------------------------|
|           | max (> 85 %) | average (85–61 %) | low (60–35 %) | extremely low (< 34 %) |
| Heat irradiation, W/m$^2$ | 1 | 2 | 3.1 | 3.2 | 3.3 | 3.4 | 4 |
| < 140 | 140 | 1500 | 2000 | 2500 | 2800 | > 2800 |

The results of calculating the total heat input from solar radiation into the tractor cab indicate, in general, a low efficiency of sun protection. As measures to reduce the total heat gain from solar radiation, it is proposed to use more effective sun-protection devices (visors, sun-protection casings, glasses with low solar radiation transmittance).

4. Conclusion

Solar radiation makes the main contribution to the thermal balance of the cab of a mobile agricultural machine, therefore, its correct assessment is an important step in the calculation and selection of microclimate normalization systems, for example, a climate system. The parameters of the selected climate system will provide a high degree of reduction in the air temperature inside the cab, which will have a beneficial effect on the well-being of the operator.

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