Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XXXIX
Broj 1, 2014.
Strane: 1 – 8

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXIX
No. 1, 2014.
pp: 1 – 8

UDK: 629.06

Originalni naučni rad
Original scientific paper

NUMERICAL SIMULATION OF TRACTOR OPERATOR THERMAL LOADS CAUSED BY SOLAR RADIATION

Dragan Ružić*

University of Novi Sad, Faculty of Technical Sciences, Department for Mechanization and Design Engineering, Chair for Motor Vehicles and IC Engines, Novi Sad, Serbia

Abstract: This paper deals with analysis of solar radiation direction and intensity influence on thermal flux on agricultural tractor operator's body surface. The analysis was carried out on a virtuel model of a tractor cab. The results showed that the highest solar load can occur when the sun is shining on the side of the tractor cab. When the sun is behind the cab and relatively low in the sky, the back and neck are critical body parts regarding the solar irradiation.

Key words: *agricultural tractor cab, solar radiation, virtual thermal manikin, CFD, thermal comfort*

INTRODUCTION

Thermal conditions in agricultural tractor cab are more adverse in hot than in cold ambient. Higher ambient temperatures, accompanied with solar radiation, cause increase of both interior air and surface temperatures above safety limits. From that reason, although the tractor cab offers the mechanical protection and protection from adverse ambient conditions, on the other hand, even under moderate outside conditions the closed cab act like green house and its closed interior could become unpleasant, unbearable and even dangerous.

* Corresponding author. E-mail: ruzic@uns.ac.rs

Project TR31046 "Improvement of the quality of tractors and mobile systems with the aim of increasing competitiveness and preserving soil and environment", supported by Serbian Ministry of Education, Science and Technological Development

Experimental determination of local heat fluxes on human body surface caused by solar radiation demands the use of complex and expensive measurement equipment and test facilities. The other way is to simulate these processes in virtual experiments, as in other fields of research [3], [5]. This paper deals with numerical modelling of solar radiation transmitted through tractor cab glazing.

Number of researches is focused on person thermal load caused by solar radiation, and this problem is especially interesting in field of mobile machinery. An operator enclosure can be treated as a workspace and the conditions inside a tractor cab have significant impact on the performance of the operator. From the operator's point of view, tractor cab ergonomics is a key factor in ensuring his optimum working performance, which could easily become the weakest link in the working process.

The project presented in the report by Bohm *et al*. [1], concerns the thermal effect of glazing in cabs with large glass areas. The effect of different kind of glass and design of the windows as well as the effects of sun protection and insulation glazing have been studied and evaluated, using the thermal manikin called AIMAN. Results showed that neither in severe winter conditions, nor in sunny summer conditions, could acceptable climate be obtained with standard glazing in cabs with large glass areas.

In the comprehensive project focused on the reduction of vehicle auxiliary load, done by National Renewable Energy Laboratory [7], variety of researching methods were used to research and develop innovative techniques and technologies for lowering thermal loads. The aim of the research was to investigate solutions for improvement of fuel economy of air-conditioning system. They concluded that reflecting the solar radiation incident on the vehicle's glass is the most important factor in making significant reductions in the thermal loads. Using solar-reflective glass can reduce the average air temperature and the seat temperature. Using reflective shades and electrochromic switchable glazing is also effective techniques for reducing the solar energy entering the passenger compartment. They also found that solar-reflective coatings on exterior opaque surfaces and body insulation can reduce a vehicle's interior temperatures, but to a lesser extent than solar-reflective glazing, shades, and parked-car ventilation can.

Results of Ružić *et al.* [8], [9], [10] showed that tractor cab glazing is the most influencing factor for thermal loads. They concluded that the highest heat flux that enters the cab is caused by solar radiation through the glass, which could be several times higher than the heat transferred by other modes. Therefore, the selection of appropriate glass properties could be the way to reduce operator's thermal load. Furthermore, the shape of a cab, glass solar properties and thermal load of the operator are in close relation.

The aim of the paper is to investigate influence of sun position relative to the tractor cab on heat fluxes caused by solar radiation over the operator's body surface. Furthermore, the goal is to identify the worst case regarding solar heat load, since the exposed surfaces of the body must be either protected from the adverse effects of solar radiation or directly cooled by airflow from air-conditioner vents, in order to reduce risk of thermal discomfort.

MATERIAL AND METHODS

Determination of heat fluxes caused by solar radiation was done using the numerical simulations. The simulations were carried out in STAR CCM+ software. The CAD model of the virtual thermal manikin (VTM) is a simplified humanoid in the sitting posture. The manikin's body is symmetric, with its posture defined by characteristic points in places where the main body joints are (hips, shoulders, neck, elbows etc). Main body dimensions are adopted from CATIA database for a 50th percentile European male, and the body is divided into 18 segments (Fig. 1). According to the chosen sizes of the body, the VTM is 1.74 m tall and weighs 68 kg. The area of VTM body surface in sitting position is 1.796 m^2. The VTM surface is discretized in around 13,600 surface elements.

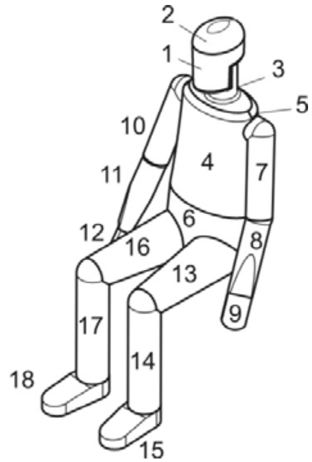

Figure 1. Virtual thermal manikin with numbered segments

The cab was modelled after the protective operator's cab of small agricultural tractor powered by 30 kW engine. The interior geometry was simplified, neglecting non-important and small details such command levers etc.

The amount of solar radiation energy that will be absorbed by the body will depend on the effective projected area and on the solar absorptivity of the body surface. The largest effective projected radiation area A_{eff} of a person in the sitting position is with the azimuth and altitude angles of 30° and 15° respectively [2], [6]. Solar absorptivity of the human skin is around 0.62, while solar absorptivity for clothing depends on the colour [4], [6]. In this research, solar absorptivity of all virtual manikin's segments was set to 0.62.

The problem was treated as a steady-state three-dimensional, with stationary bodies and boundaries. Solar load was calculated by *Solar load model* incorporated in CFD software STAR-CCM+. The coordinate system for the orientation of the direct solar flux is defined in the Fig. 2. In this study, the gray spectrum model is used and the total solar loads represent the full-thermal spectrum, including both direct and diffuse components. The solar load model is defined by the following properties: the sun direction vector in a specified coordinate system (azimuth and altitude angles), the direct and the diffuse solar fluxes ($W \cdot m^{-2}$) [15].

Solar irradiation is variable depending on the position of the sun as well as the orientation of the cab. Fig. 3 presents the values of maximum ("clear sky") intensity of normal irradiation and its variations during the daylight, in a central European region.

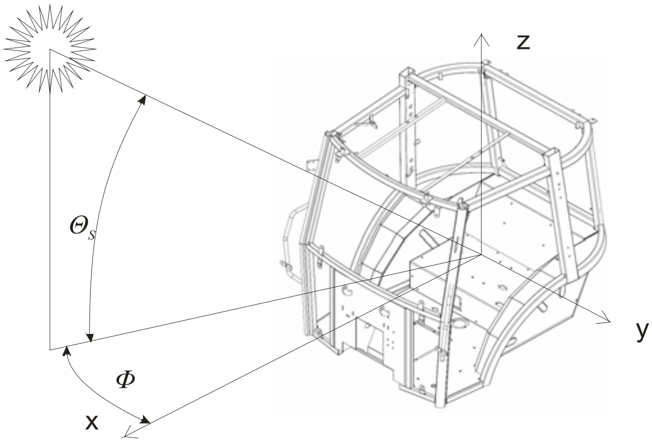

Figure 2. Solar coordinate system relative to tractor cab:
θ_S – solar altitude (sun elevation), Φ - azimuth angle

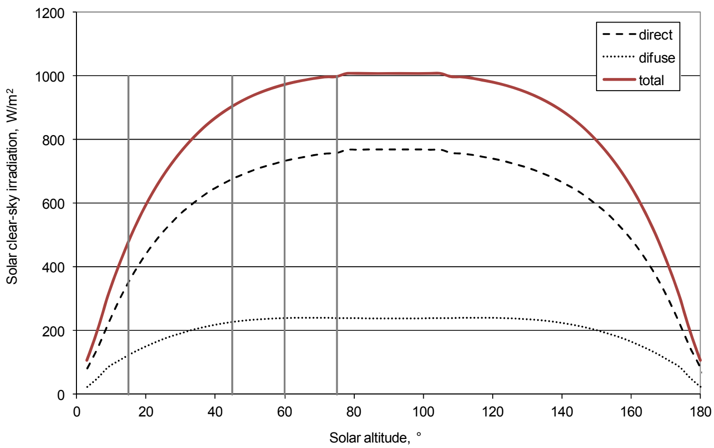

Figure 3. Solar clear-sky irradiation in a central European region on a day in July (http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php).
Vertical lines present the solar altitudes that were considered in the analysis

Tractor cab glazing is semi-transparent medium where solar irradiation can be partially reflected, absorbed and transmitted. Absorbed part of the solar energy will be emitted to the cab interior by both convection and long-wave radiation. When a tractor cab is exposed to the sun, the operator's body receives the heat partly by solar radiation transmitted through the glass and partly by long-wave thermal radiation from the surrounding surfaces. Total amount of heat transmitted through the glass caused by solar radiation is related with cab surface projection normal to the radiation direction.

In this research, only transmitted part of the solar radiation was analyzed, since it has direct effect on the operator, increasing his skin temperature and hence producing the discomfort. Using available values of glass properties for tinted glass (green, with 75% transmittance of visible light [14]) normal solar transmissivity was set to 0.5.

RESULTS AND DISCUSSION

The aim of the research is to investigate influence of sun position relative to the tractor cab on heat fluxes caused by solar radiation over the body surface. This mode of heat load is independent of other boundary conditions parameters, like ambient temperature, air velocity or radiant temperature.

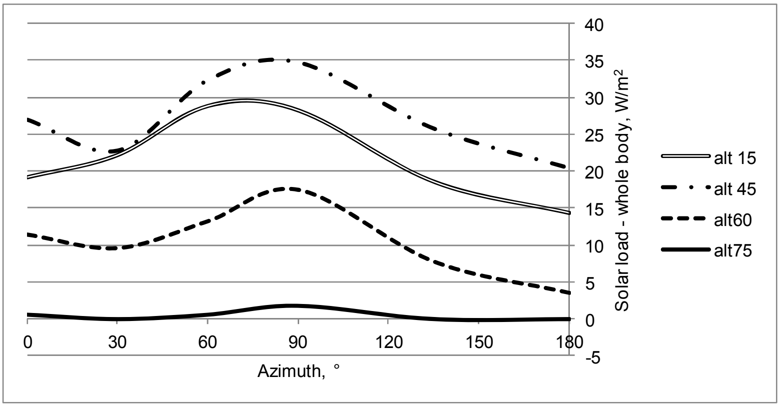

Figure 4. Values of the heat flux for the whole body in dependence of solar azimuth and altitude angles

Relevant standards for investigation of thermal conditions in tractor cabs do not define solar load during the tests of air-conditioning system [12]. Therefore, in order to find the worst case, simulations were performed for four different sun altitudes (θ_S = 15°, 45°, 60° and 75°) and six azimuth angles (Φ = 0°, 30°, 60°, 90°, 135° and 180°). The azimuth angles covered only the one half of the cab due to its longitudinal symmetry. Direct and diffuse solar irradiation were changed with sun altitude, according to the graph in Fig. 3. The sun position angles were including the direction when the largest area of body in sitting position is exposed to the radiation (θ_S = 15° and Φ = 30°), as mentioned above.

Values of the heat flux for the whole body in dependence of solar azimuth and altitude angles are shown on graph in Fig. 4. The highest heat flux averaged for the whole body was achieved for azimuth angle 90° and altitude 45°. Distribution of the heat flux on VTM's surface is visualized on Fig. 5 and values are given on graph in Fig. 6. It can be noted strong asymmetry of thermal loads on the operator's body.

The operator's head is well protected and is exposed only when the sun is low in the sky, i.e. altitude is around 15°. However, under this circumstance solar irradiation is approximately one-half of its maximum value. The segment with the highest heat flux is operator's back, for cases where the sun is behind the cab and relatively low in the sky (the sun altitude between 15 and 45°), graph in Fig. 7. When the sun is high in the sky (around the noon), the cab roof offers relatively good protection for the whole body.

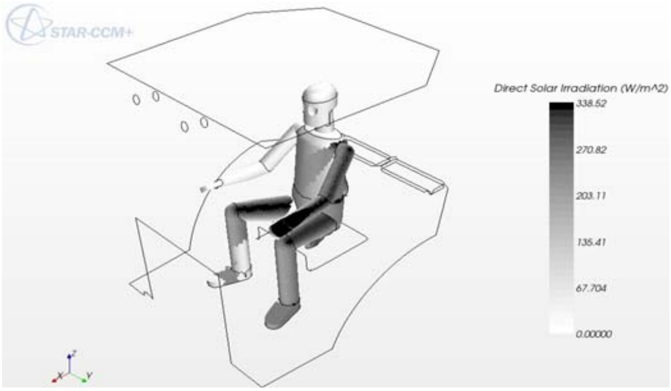

Figure 5. Distribution of solar heat load over the VTM's surface in the case with the highest heat flux for the whole body

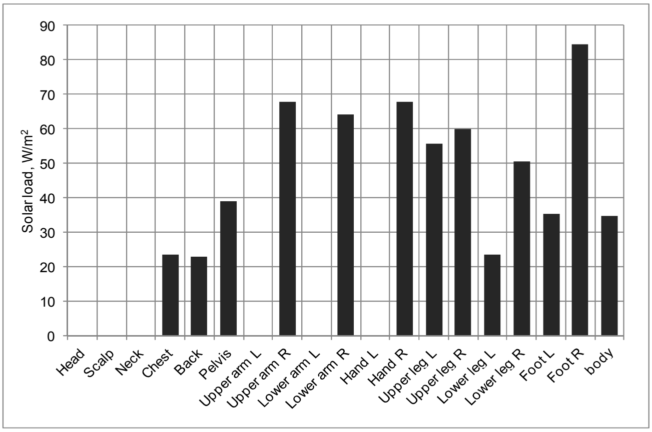

Figure 6. Values of solar load heat flux on VTM's segments in the case with the highest heat flux for the whole body

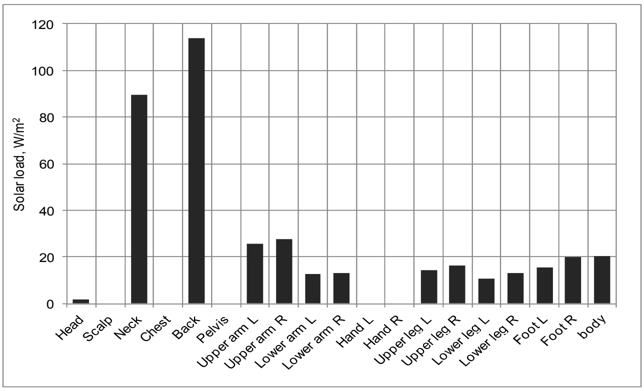

Figure 7. Values of solar load heat flux on VTM's segments when the sun is behind the cab and at altitude of 45°

CONCLUSION

Tractor cab design and the operator's position on the seat generally do not offer good protection from solar radiation, although roof ensures shading for the operator under some circumstances. The highest heat flux that the body receives is when the sun is shining on the side of the tractor cab. The back and neck are critical body parts regarding the solar irradiation, when the sun is behind the cab and relatively low in the sky. When the sun is low in the sky, the head and the trunk are exposed and protected only by solar properties of glass, unless some kind of solar shading devices or direct cooling by air-conditioning are used.

Shading devices can be placed on the inner side, or as a better solution, on the outer side of the cab. In both cases, the shading devices must not restrict the operator's normal field of vision in the working area of the tractor. For that reason, sun visors or curtains must be easily adjustable. In addition to shading the operator, the outer shading devices prevent increase of temperature of glass and other surfaces caused by the solar radiation. A common solution for these purposes is the use of cab roof overhangs, since aerodynamics is not an issue in agricultural tractors. Furthermore, paying attention to solar characteristics of glass and design of air distribution system in such way that air-conditioner vents can be directed to areas with the highest fluxes are an efficient way to reduce the operator's thermal load.

Numerical values obtained from the simulations should be considered for comparison purposes only, and validation of the numerical model must be done by experiment on physical models.

REFERENCES

[1] Bohm, M., Holmer, I., Nilsson, H., Noren, O. 2002. *Thermal effects of glazing in driver's cabs, JTI-rapport 305*, JTI – Institutet for jordbruks, ISSN 1401-4963, Uppsala, Sweden

[2] Fanger, P. O. 1970. *Thermal Comfort*, Copenhagen, Denmark: McGraw-Hill,

[3] Glišović, J. Demić, M., Miloradović, M. 2011. Review of Virtual Reality Applications for Reducing Time and Cost of Vehicle Development Cycle. *Journal of Applied Engineering Science* Vol 9(3): 361-372

[4] Incropera, F. P., DeWitt, D. P. 1981. *Fundamentals of Heat and Mass Transfer*, New York, USA: John Wiley & Sons

[5] Ognjanović, M. 2008. Design in Mechanical Engineering - Multidisciplinary Approach. *Istraživanja i projektovanja za privredu*, 20/2008: 15-22

[6] Parsons, K. 2003. *Human thermal environments: The effects of hot, moderate and cold environments on human health, comfort and performance,* 2nd Edition. London, UK: Taylor & Francis

[7] Rugh, J. & Farrington, R. 2008. *Vehicle Ancillary Load Reduction Project Close-Out Report*, Technical Report NREL/TP-540-42454, Golden, USA: National Renewable Energy Laboratory

[8] Ružić, D., Časnji, F. 2011. Konstruktivni parametri kabine od uticaja na toplotnu interakciju između čoveka i kabine. *Poljoprivredna tehnika*, 36 (1): 11-19

[9] Ružić, D., Časnji, F. 2012. Thermal interaction Between a Human Body and a Vehicle Cabin, published in: *Heat Transfer Phenomena and Applications*, S. N. Kazi (ed.), InTech

[10] Ružić, D., Časnji, F., Muzikravić V. 2007. Karakteristike stakla kao faktor od uticaja na mikroklimu u traktorskoj kabini. *Traktori i pogonske mašine*, 12 (4): 92-97

[11] Türler, D., Hopkins, D., Goudey, H. 2003. Reducing Vehicle Auxiliary Loads Using Advanced Thermal Insulation and Window Technologies. *SAE Paper 03HX-36*, USA: Society of Automotive Engineers

[12] ***. 1997. ASABE/ISO 14269-2 Tractors and Self-propelled Machines for Agriculture and Forestry - Operator Enclosure Environment - Part 2: Heating, Ventilation and Air-conditioning Test Method and Performance

[13] ***. 1999. ASHRAE *Book of Applications, Chapter 32: Solar Energy Use*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, USA

[14] ***. 2003. *Saint-Gobain Sekurit - Glazing Manual*, available at http://www.sekurit.com, [accessed at july 2013]

[15] ***, *STAR-CCM+, User Guide*, CD-Adapco, 2011

NUMERIČKE SIMULACIJE TOPLOTNIH OPTEREĆENJA TRAKTORISTE PROUZROKOVANIH SUNČEVIM ZRAČENJEM

Dragan Ružić

Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Departman za mehanizaciju i konstrukciono mašinstvo, Katedra za motore i vozila, Novi Sad

Sažetak: U radu je prikazana analiza uticaja pravca i intenziteta sunčevog zračenja na toplotni fluks na površini tela rukovaoca u kabini poljoprivrednog traktora. Analiza je izvršena na virtuelnom modelu kabine. Rezultati su pokazali da najveće toplotno opterećenje tela usled sunčevog zračenja može nastati kada je kabina bočnom stranom okrenuta ka suncu, a da je najveće lokalno toplotno opterećenje na leđima i na vratu rukovaoca kada je sunce iza kabine.

Ključne reči: *traktorska kabina, sunčevo zračenje, virtuelna toplotna lutka, CFD, toplotni komfor*

Prijavljen:
Submitted: 16.8.2013
Ispravljen:
Revised:
Prihvaćen:
Accepted: 07.10.2013.