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Computer-aided Analysis of Thermal Convection near Electric Devices

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Introduction

Current-carrying capacity of the electric devices depends to a large extent on the intensity of the heat transfer to the environment [1–6]. The heat transfer is influenced by the thermal conductivity of the device insulation and by the thermal resistance of convection from the device surface to the environment. For instance, the current-carrying capacity I_z of an insulated conductor may be determined by (1)

$$I_z = \sqrt{\frac{\tau_{zmax} - \tau_o}{(R_{t1} + R_{t2}) \cdot R_e}}, \tag{1}$$

here I_z – current-carrying capacity of the conductor, τ_{zmax} – maximum service temperature, τ_o – ambient air temperature, R_{t1} – conduction thermal resistance of the insulation, R_{t2} – convection thermal resistance, R_e – electric resistance of the conductor.

The convection thermal resistance is given by the expression

$$R_{t2} = \frac{1}{\alpha \cdot A}, \tag{2}$$

here α – the convection heat transfer coefficient, A – the area emitting the heat to the environment.

An increase of the device current-carrying capacity can be achieved by increasing the heat transfer coefficient α, which in turn causes a decrease of resistance R_{t2} of the heat transfer to the environment.

The heat transfer can occur in a natural (free) or forced (artificial) way. The forced convection is generally effected with the use of air motion generators – ventilators. This is the heat transfer method of a relatively great effectiveness but of a limited use due to the inconvenient acoustic effects and the necessary periodic servicing and maintenance of the ventilators. Besides, the energy supply incurs additional costs. The natural convection-based heat transfer methods do not have the above mentioned deficiencies, but are characterised by lower energy efficiency.

Investigations of the convective heat transfer processes [7, 8] show that a significant impact on the heat transfer intensity may have placing, in the vicinity of the heat emitting object, of additional elements, e.g. vertical or inclined planes (screens) creating convection channels, which can influence the heat transfer intensity by their shape, size and positioning. Intensification of the convective heat transfer is possible through shaping the space in the vicinity of the heat emitting surface in such a way that, apart from the free convection, also the thermal draught caused by the difference of air density in the convection space and in the environment can be taken advantage of.

The paper presents an analysis of the thermal convection with the use of the Ansys/Flotran code. That code is based on solving the equations of energy, mass and momentum, used in the computational fluid dynamics (CFD). The example objects were modeled with the two-dimensional method. The results of the analysis of thermal convection with the use of an additional screen close to the electric device are presented. Optimum distance between the electric device and the screen is evaluated.

Testing of the example model

The analysis was carried out on a simplified electric device model emitting the heat to the environment from a 145×115 cm side surface. The assumed temperature of that surface was 328 K (55°C) and the environment temperature was 293 K (20°C). The model diagram is shown in Fig. 1. The analysis included the heat transfer through one side surface (the other surfaces were not taken into account) for the following cases:

- there is no screen in the vicinity of the analysed surface,
- screen is placed at a distance of x = 2, 4 or 6 cm from the analysed surface.

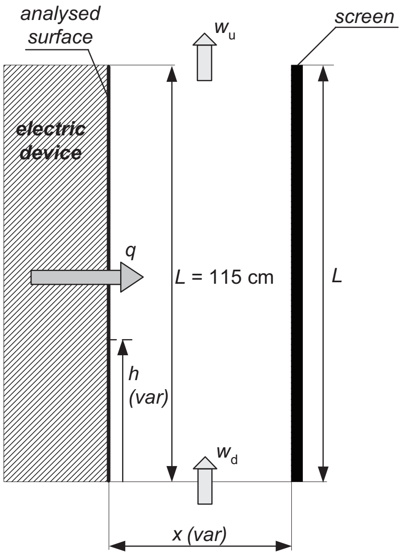
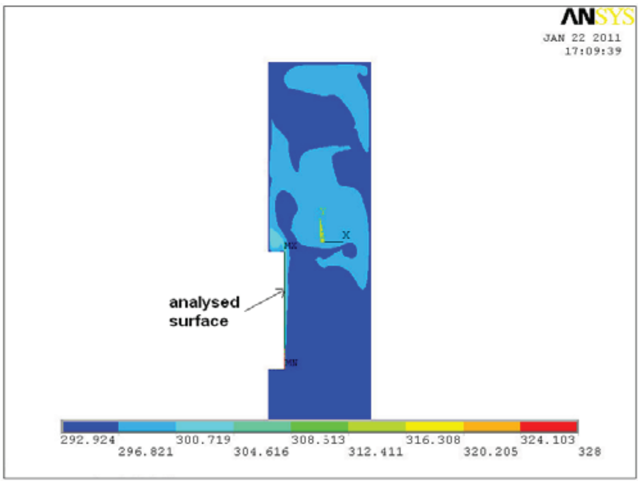


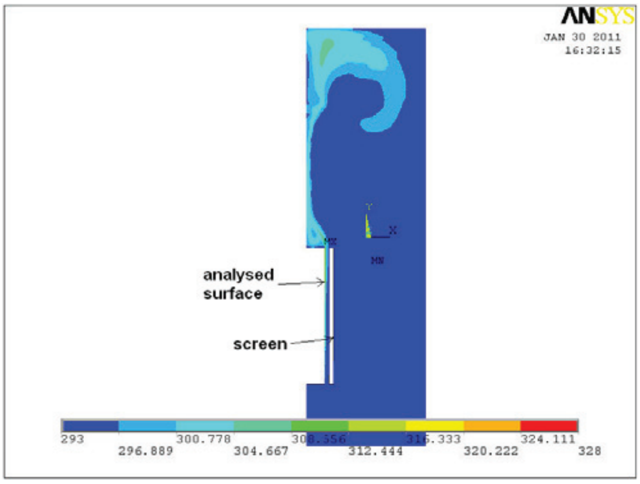
Fig. 1. Diagram of the analysed example; q – heat flux generated by the analysed electric device surface, w_d – air velocity at the system inlet, w_u – air velocity at the system outlet, L – electric device and screen height, h – variable computational height value, x – variable horizontal distance from the analysed electric device surface

Simulations of the air temperature fields (Fig. 2) and air velocity fields (Fig. 3) were carried out with the Ansys program for the cases of arrangement without screen and with screen at a distance of x = 4 cm from the analysed electric device surface. Comparison between Fig. 3a and Fig. 3b indicates that more intensive air motion occurs in the arrangement with screen (stack effect), which has a positive impact on the heat transfer to environment.

From the results of calculations carried out with the Ansys program, diagrams are drawn presenting the air temperature distribution (Fig. 4) and the air velocity distribution (Fig. 5) as a function of the distance from the electric device at selected heights h.

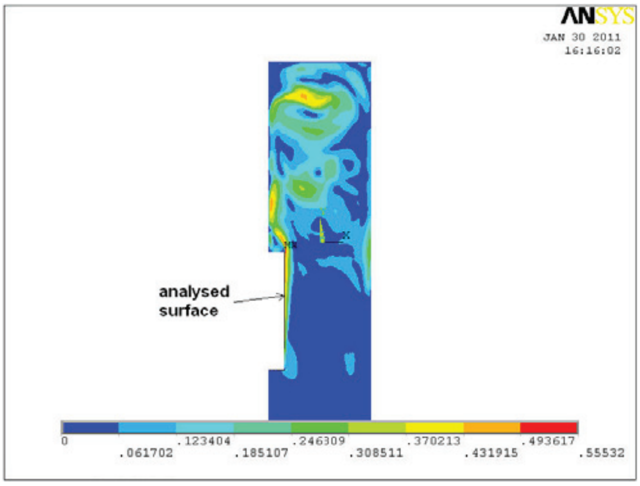


a)

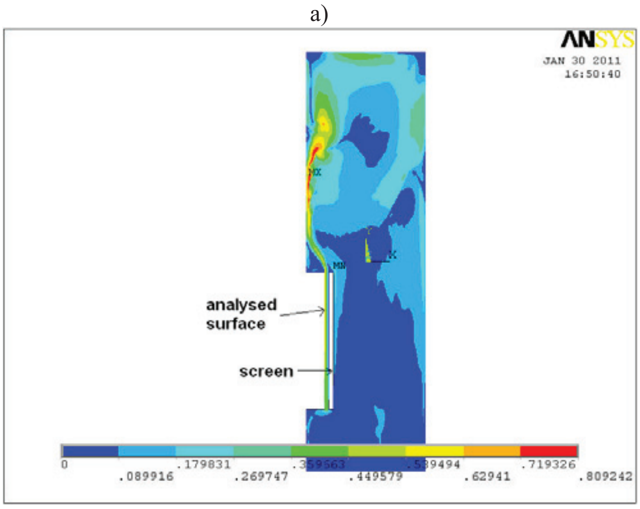


b)

Fig. 2. Air temperature fields – results of simulation investigations of the analysed surface: a) without screen, b) with screen at a distance of x = 4 cm



a)



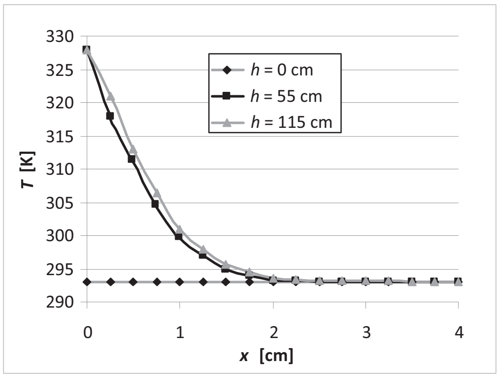
b)

Fig. 3. Air velocity fields – results of simulation investigations of the analysed surface: a) without screen, b) with screen at a distance of x = 4 cm

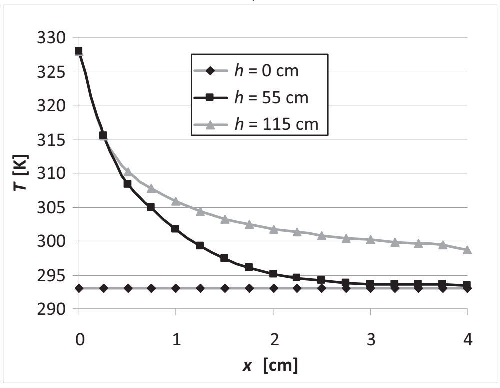
Height h = 0 cm means calculations performed at the bottom of the analysed surface, h = 55 cm means calculations performed at almost half of the surface height and

$h = L = 115$ cm means calculations at the top of the surface.

The diagrams in Fig. 4a indicate that for the arrangement without screen the air temperatures at the heights of $h = 55$ cm and $h = 115$ cm are close to the ambient temperature 293 K already at a small distance from the analysed surface. A different situation is observed in the arrangement with screen (Fig. 4b). Particularly, for the height of $h = 155$ cm the temperature decrease is distinctly slower with increasing horizontal distance from the analysed surface. This means the heat exchange takes place in a greater air volume around the analysed surface, which increases the heat transfer intensity.



a)

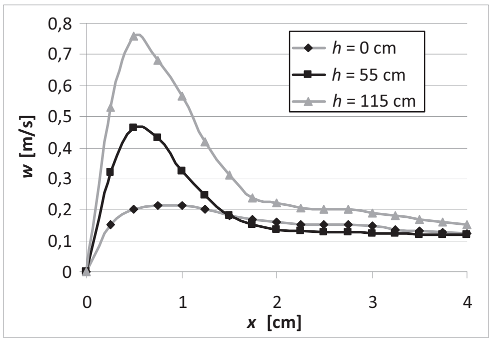


b)

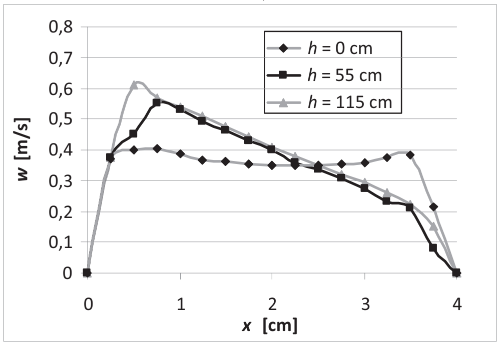
Fig. 4. Air temperature distribution at different heights h as a function of distance x from the analysed device surface: a) arrangement without screen, b) arrangement with screen at a distance of $x = 4$ cm

A similar tendency can be seen in the air velocity distribution (Fig. 5). In the vicinity of the analysed surface the velocity is greater in the arrangement without screen, but in the arrangement with screen the air velocity reduction with increasing horizontal distance from the analysed surface is slower. The benefit of using the screen can be seen in Fig. 6. The areas marked "–" and "+" show the difference of air velocity in the arrangements without and with screen, respectively. The "+" marked area is greater than the "–" marked area, which means that the screen arrangement is more effective.

In the analysis, an optimum distance of the screen from the analysed surface was assessed. The results are presented in Fig. 7 and Fig. 8. The optimum distance appears to be $x = 4$ cm. With this distance the greatest value of the local heat transfer coefficient α (Fig. 7) and the greatest transferred energy Q (Fig. 8) are achieved.



a)



b)

Fig. 5. Air velocity distribution at different heights h as a function of distance x from the analysed device surface: a) without screen, b) with screen at a distance of $x = 4$ cm

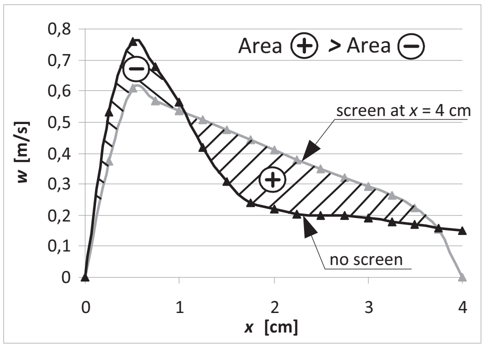


Fig. 6. Air velocity distribution at the height of $h = 115$ cm as a function of distance x from the analysed device surface, for the arrangements without screen and with screen (screen at a distance of $x = 4$ cm)

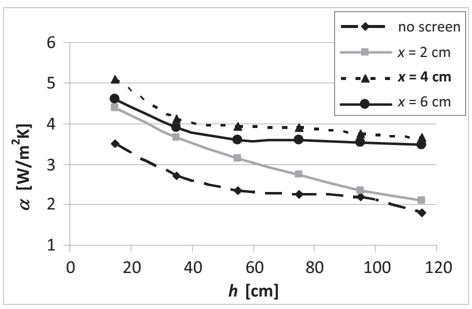


Fig. 7. Distribution of the local heat transfer coefficients α at different heights h for selected distances of screen from the analysed surface: $x = 0$ (no screen), 2, 4, 6 cm

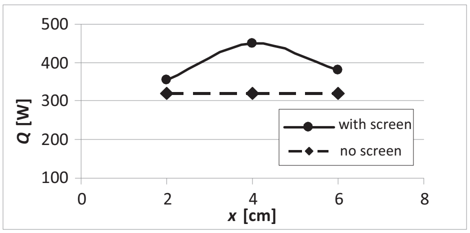


Fig. 8. Transferred energy Q for the arrangement without screen and with screen at a distance of $x = 2, 4, 6$, cm

Conclusions

The performed numerical analyses of the heat transfer from a vertical surface indicate that the heat transfer intensity can be distinctly increased by placing a screen in the vicinity of analysed surface. It has been found that the intensity depends on the distance of the screen from the surface. The model tests indicated that the greatest intensity was achieved with the screen at a distance of $x = 4$ cm from the analysed surface. The use of a screen can have an impact on increasing the current-carrying capacity of an electric device.

References

1. **Brakelmann H., Anders G.** Increasing Ampacity of Cables by an Application of Ventilated Pipes // Industry Applications Conference, 39th IAS Annual Meeting 2004. – Vol. 4. – P. 2288–2295.
2. **IEC 60364-5-523** Electrical installations of buildings – Part 5: Selection and erection of electrical equipment – Section 523: Current-carrying capacities in wiring systems.
3. **Czapp S.** Comparison of Residual Current Devices Tripping Characteristics for Selected Residual Current Waveforms // Elec-tronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 7–10.
4. **Liao C. M., Chen C. L., Katcher T.** Thermal Analysis for Design of High Performance Motors // The Sixth Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems ITHERM '98. – 1998. – P. 424–433.
5. **Oner Y.** Thermal Analysis of the Three-Phase Induction Motor and Calculation of its Power Loss by using Lumped-Circuit Model // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 8(104). – P. 81–84.
6. **Staton D. A., Cavagnino A.** Convection Heat Transfer and Flow Calculations Suitable for Analytical Modelling of Electric Machines // IEEE 32nd Annual Conference on Industrial Electronics IECON 2006. – P. 4841–4846.
7. **Szpakowska M., Czapp M.** Investigation of Intensity Convective Heat Transfer on the Isothermal Surface // XIII Sympozjum Wymiany Ciepla i Masy, Koszalin – Darlowko, Poland, 2007. – Vol. 2. – P. 993–997.
8. **Czapp S.** Elimination of the negative effect of earth fault current higher frequency on tripping of residual current devices // Electronics and Electrical Engineering. – Kaunas: Techno-logija, 2009. – No. 3(91). – P. 85–88.

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Current-carrying capacity of electric devices strictly depends on the heat transfer between electric devices and surroundings. For example, in order to increase the current-carrying capacity of devices, a forced circulation of air is applied. Comprehensive observation and analysis of natural thermal convection indicates that the process intensity depends on positioning of the electric devices and additional elements as screens or canals close to the device. In the paper analysis of thermal convection with the use of Ansys/Flotran code is presented. The results of the analysis of thermal convection with the use of additional screen close to the electric device are presented. Optimum distance between the electric device and the screen is evaluated. Ill. 8, bibl. 8 (in English; abstracts in English and Lithuanian).

S. Czapp, M. Czapp. Elektros įrenginių terminės konvekcijos įtakos tyrimas kompiuterizuotais programų paketais // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 3(109). – P. 21–24.

Dabartiniu metu elektros įrenginių maksimali galia priklauso ir nuo šilumos atidavimo aplinkai. Keliamajai galiai padidinti naudojama priverstinė oro cirkuliacija. Natūralios šilumos srautų stebėsena ir analizė rodo, kad analizuojamo proceso intensyvumas priklauso nuo elektros įrenginio padėties erdvėje ir papildomų kanalų bei naudojamų „ekranų" padėties įrenginio atžvilgiu. Terminės konvekcijos analizė atlikta naudojant programų paketus Ansys ir Flotran. Pateikti terminės konvekcijos tarp elektros įrenginio ir „ekrano" analizės rezultatai. Nustatytas optimalus atstumas. Il. 8, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).