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# Theoretical basis and practice application calculation of radiation heat transfer by light design program

Jacek Hauser, Przemysław Skrzypczak
Poznań University of Technology
60-965 Poznań, ul. Piotrowo 3a, e-mail: {Jacek.Hauser; Przemyslaw.Skrzypczak}@put.poznan.pl

Marcin Wesołowski
Warsaw University of Technology
00-661 Warszawa, ul. Koszykowa 75, e-mail: mwes@interia.pl

In the article are presented the results of the irradiance obtained by using Dialux program. The calculations were made for two cases of simple geometries, which are known according to analysis to determine the average values of geometrical configuration factor. A comparison of the results obtained and confirmed their compliance. Dialux program for some systems which certain some conditions and simplifying assumptions described in section 1 can be used, and radiometric parameters obtained do not differ from those of analytically calculation. The program allows a adopt for radiating surface nolambertian radiation intensity distribution. This expands the applicability of the calculation to the areas where analytical calculations are time consuming and complicated. Confirmation are set out in section 6 of the calculations for the heating system of real more complicated situations.

KEYWORDS: Dialux program, radiation, infrared lamp, irradiance

## 1. Introduction

The main task of calculation of heat transfer it's a specification of irradiance and uniformity ratio of irradiance are presented. Transfer of the heat from heater to objects is implemented by convection, conduction and radiation. In the many of situations first two of this type hest transfer might by ignored. When heater haven't physical contact with object heat transfer by conduction don't occur. Heat transfer between objects locations on gas might by realized by convection and radiation. Some of situations heat transfer by convection it's limited. Examples wherein convective heat transfer are negligible presented Figure 1. When temperatures heating objects are much lower than temperature of heater, dominated heat transfer are realized by radiation and the true are equation (1) [1, 2]:

$$\varepsilon_T \sigma \left(T^4 - T_o^4\right) >> \alpha_k \left(T - T_o\right) \tag{1}$$

where: $\varepsilon_T$ – total emissivity, $\sigma$ – Stefan-Boltzmann constant, $T_o$ – ambient temperature, T – temperature of surface $S_1$ infrared lamp, $\alpha_k$ – coefficient of convection heat transfer.

Presented on Figure 1 situations: infrared heating peoples sitting under beer garden, heating outdoor area, believers on the church, support temperature of food and use in pigsty. Energy efficiency on this situations are higher with use radiation hest transfer compared to other heat transfer system. This is due to low efficiency convection heat transfer system, caused plenty of air at surround of heating objects and high heat loses by wall of building.

Radiation heat transfer occur between all elements whose temperature is higher than absolute zero. If the heat transfer with above simplifications: all surfaces (passive – active elements) both emit and reflect radiation temperature is obtained sets of equations showing the balances radiation streams for all N surface of the system. Difficult analytical calculations of this transfer it's a consequence of need to determine the (geometric) configuration factors $\varphi$ between the surfaces. They depend shapes, sizes, the relative position and distance between the surfaces involved in the transfer. Because usually a many of elements involved in the radiant heat transfer energy calculations become very complicated [1, 2, 4, 6].

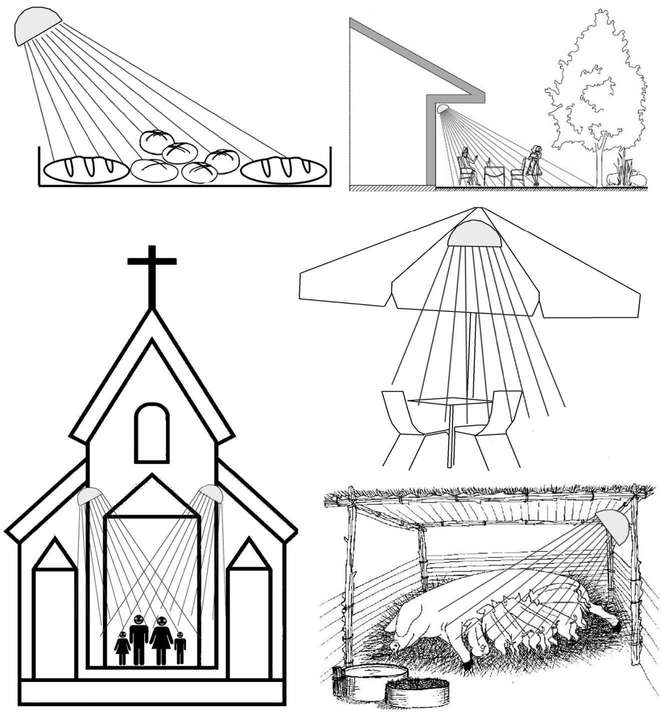

Fig. 1. Several situation application of infrared lamps [9]

As a result, only a small group of software for modeling physical fields allows to take into account radiation heat transfer between the components of the calculation model [5].

## 2. Typical infrared lamps

Commonly used infrared lamps are reflector bulb with single-coil tungsten filament, temperature of filament is equal (1650–2200)$^{o}$C depicted on Figure 2.

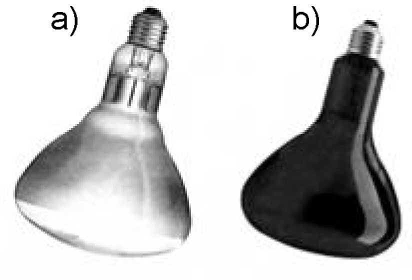


Fig. 2. Infrared lamps with tungsten filament [8]

Other types used infrared lamp, it's lamp with tungsten filament with quartz bulb, resistance or conductive wire with metal, quart cover or without that. Typical temperature that lamps of 800-900$^{o}$C. All this lamp are qualified as bright lamp – the spectral distribution emitted by heater on visual range. Examples this type of lamp are presented on Figure 3.

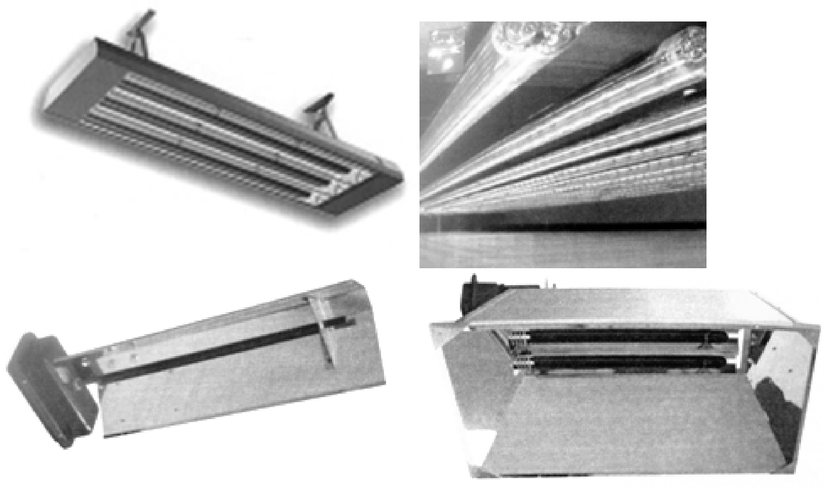

Fig. 3. Typical lamp with metal and quart cover [8]

Presented on Figure 1 applications, it's a type situations where temperature of heating element are much more than temperature of heater surfaces, objects and ambient: condition (1) is satisfied. Additional radiating element usually has a high rate of total emissivity $\varepsilon_T$, in particular for infrared radiation. In such cases, the heat from the heater to the surface of the preheated is transfer almost exclusively by radiation [1, 2].

## 3. Simplifying assumptions

Described in section 2 theoretical basis can be simplified in mathematical model and is popular use to calculate the parameters of lighting. Infrared radiation as well as light (visual radiation) can be calculated by geometrical rules.

If area of emitting surface are much less than area of heater objects surfaces, then it is acceptable to handle emitting object only as an active element, while the preheated surface as a passive element having no depend the radiant power sent by the radiating (passive) element.

However, when considering for the simplifications, but when use lambertian surface transfer radiation by primary radiant sources, transfer between of radiant systems consisting of primary sources (radiating heat) and surface radiating passive (reflecting and absorbing radiation).

The result of streams of radiation $P_i$ at each i = 1, ..., N surface illustrates the formula:

$$P_i = P_{ib} + P_{ip} = P_{ib} + \sum_{k=1}^{N} (1 - \delta_{ki})\, \rho_k\, \varphi_{ki}\, P_k \tag{2}$$

where: $P_i$ – sum of radiant flux to surfach $S_i$, $P_{ib}$ – sum of radiant flux directly from sources from to surface $S_i$, $P_{ip}$ – sum of radiant flux indirectly to surfach $S_i$ (after multi – reflections radiant flux from other surfaces), $P_k$ – total radiant flux to surface $S_k$, $\rho_k$ – average reflection factor surface $S_k$, $\varphi_{ki}$ – configuration factor surface $S_k$ to surface $S_i$, $\delta_{ki}$ – Kronecker symbol equal 1, if $k = i$, or equal 0, if $k = i$.

Equation (2) used in lighting technique to calculate transfer luminous flux.

## 4. Characteristics of Dialux program

Dialux program's Dial GmbH belongs to the group of calculation programs to calculate the parameters of lighting [3]. It features a simple graphical interface, allows enter multiple surfaces calculations and multiple light sources. The light source is characterized by a specified geometric dimensions and given a luminous intensity distributions. It is worth uncomplicated create files that define the parameters source of radiation.

Analogies between light and radiant parameters are shown in Table 1.

Table 1. Light and radiant parameters with they unit

| Light parameters | Symbol | Unit | Radiant parameters | Symbol | Unit |
|---|---|---|---|---|---|
| Luminous flux | $\phi$ | [lm] | Radiant flux | P | [W] |
| Luminous intensity | $I_\phi$ | [cd = lm/sr] | Radiant intensity | I | [W/sr] |
| Illuminance | $E_\phi$ | [lx = lm/m$^2$] | Irradiance | E | [W/m$^2$] |

To modeling the radiation of light and a radiation heat source it is necessary to create appropriate photometric files * .ldt or similar radiometric files. In the file radiative heat sources defined surfaces of the active elements, radiant flux $P$ and the radiant intensity distribution $I_\gamma$.

The correctness of the calculations irradiance $E$ using Dialux program was verified by comparing these calculations for "lambertian" (cosine) radiant intensity distribution with analytical calculations for simple geometries (see. section 4).

The identity results of calculations using the program Dialux above presented simple geometries of the irradiance, can be certain of the accuracy of the radiation intensity distribution for other geometries and with real radiant intensity distribution (primary sources), differing more or less from the lambertian distribution (see. section 5).

## 5. Verification Dialux program calculation

For simulation was created models circular radiators with radius $r_1$ equal 50 mm and 5 m with lamberian radiant intensity distribution. Assuming that the radiant flux $P$ is, for example 1500 W, the radiant intensity in the direction normal to the surface ($I_\gamma = 0$) according to equation (3) [1, 2]:

$$P = \pi\, I_{\gamma=0} \tag{3}$$

is equal $I_{\gamma=0} = 1500/\pi = 477{,}5$ W/sr. Surface $S_2$ heating element by radiation transfer is circular too with radius $r_2$ equal 5m and is arranged coaxially and parallel to the radiator surface: area equal $\Delta S_1$ i $S_1$ and distance $h$ equal 2 m.

Average value: irradiance $E_{2(\Delta S1)}$ and $E_{2(S1)}$, radiant flux $P_{2(\Delta S1)} = P_{\Delta S1\text{-}S2} = E_{2(\Delta S1)}S_2$ i $P_{2(S1)} = P_{S1\text{-}S2} = E_{2(S1)}S_2$ equal respectively: 16,84 W/m$^2$ and 11,5 W/m$^2$, 1322 W and 1048 W, a ratios $P_{2(\Delta S1)}/P_1$ and $P_{2(S1)}/P_1$ equal (4):

$$\frac{P_{2(\Delta S1)}}{P_1} = \frac{P_{\Delta S1-S2}}{P_1} = 0{,}882 \quad and \quad \frac{P_{2(S1)}}{P_1} = \frac{P_{S1-S2}}{P_1} = 0{,}699 \tag{4}$$

Presented in the literature formulas and charts describing the geometric configuration factor $\varphi_{1\text{-}2}$ ($\varphi_{S1\text{-}S2}$, $\varphi_{\Delta S1\text{-}S2}$), say what part of the radiant flux $P_1$ emitted from the surface 1 ($S_1$, $\Delta S_1$), come to the surface 2 ($S_2$). For the described geometries the formula for calculation a geometric configuration factor would be (4-5) [1, 2, 4, 6]:

$$\varphi_{1-2} = \frac{P_{1-2}}{P_1} = \frac{1}{S_1}\int_{S_1} dS_1 \int_{S_2} d\varphi_{d1,d2} = \cdots$$
$$= \frac{1}{2R_1^2}\left[1 + R_1^2 + R_2^2 - \sqrt{(1 + R_1^2 + R_2^2)^2 - 4R_1^2 R_2^2}\right] \qquad (5)$$

where:

$$R_1 = \frac{r_1}{h}; \qquad R_2 = \frac{r_2}{h} \qquad (6)$$

For this parameters, calculation by formula (5) i (6) for above presented geometric situations, equal respectively (7):

$$\varphi_{\Delta S1-S2} = \frac{P_{\Delta S1-S2}}{P_1} = 0{,}863 \quad and \quad \varphi_{S1-S2} = \frac{P_{S1-S2}}{P_1} = 0{,}672 \qquad (7)$$

Verification of the correctness calculations by Dialux program to calculate radiant transfer with the simplifying assumptions described in section 3 was presented at other paper [7]. Summary results of this paper it's comparison of average values of the geometric configuration factor $\varphi_{1-2}$, calculated from analytical models and formulas by the values of the same coefficients calculations by using the program Dialux shows good agreement of the results obtained, and error equal by 2.2- 4.0%.

## 6. Heating system with infrared lamps

Presented in section 1 – Figure 1 examples to use infrared lamps was construction at Dialux program. For the purposes of simulation was used 150 W and 250 W infrared lamp by real radiant intensity distribution shows in Figure 4. Total energy transferred from this lamp as infrared is equal 105 W and 175 W.

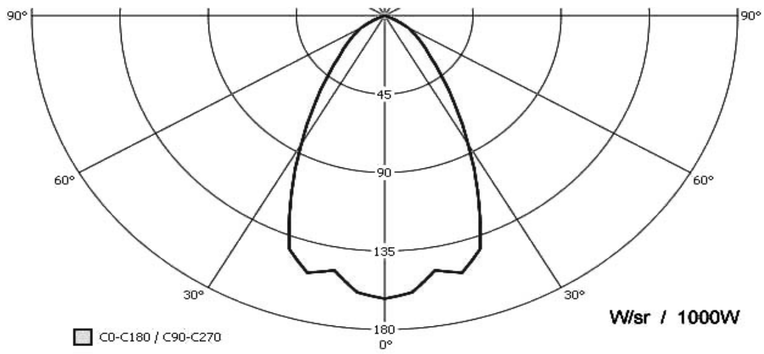


Fig. 4. Radiant intensity distribution of used infrared lamp

Below is an example of calculations made using Dialux. Real situations presented in Figure 1, was calculated and results presented in Figure 5 at false color mode. Though a large complication situation and many surfaces, time of construct all scene and calculation is simple and quickly.

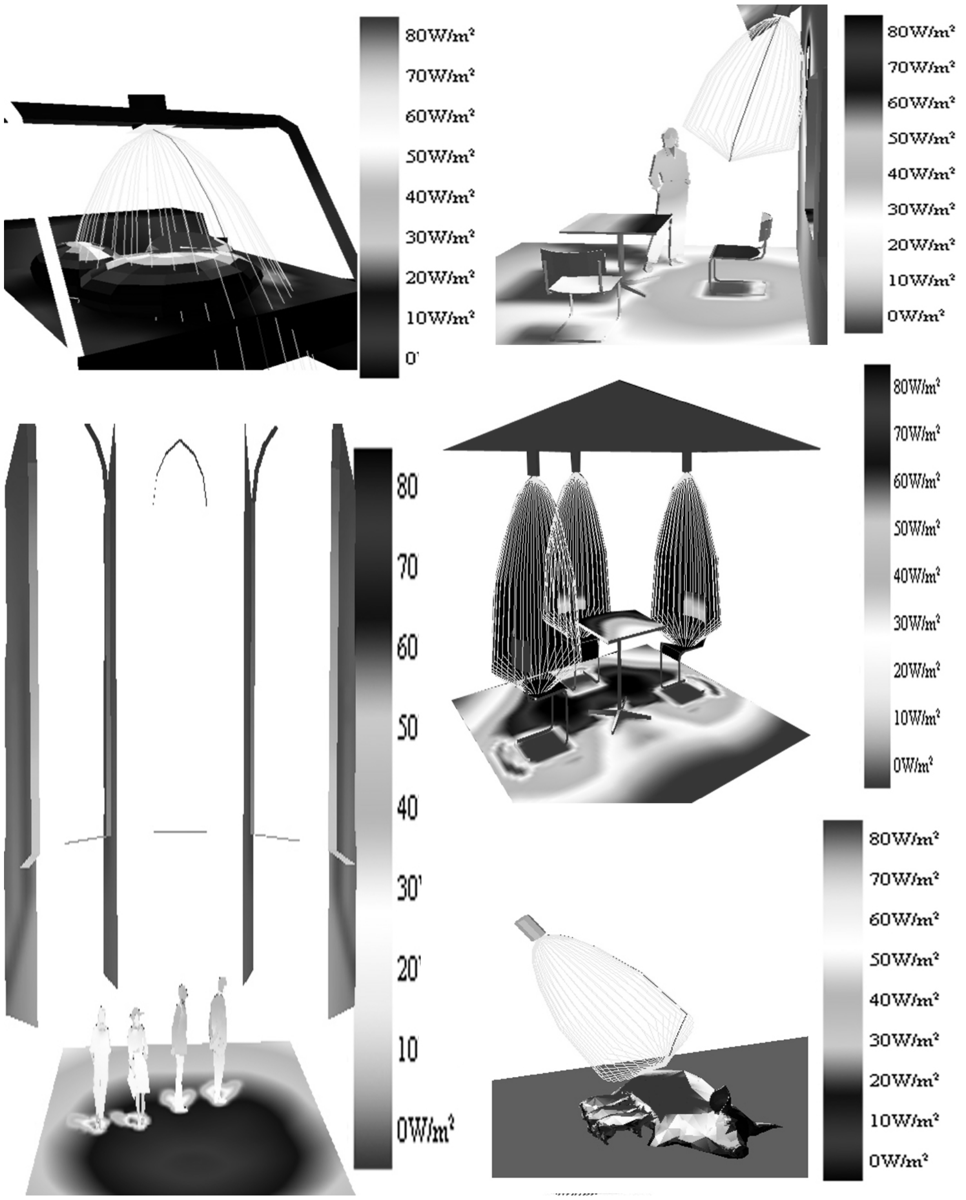


Fig. 5. Several situation application of infrared lamps - results of calculations by Dialux in false color mode

## 7. Conclusions

Presented in section 1 theoretical basis of heat transfer all of possible way, focused at practical situations where heat transfer by radiation are main way transport of heat. Because classical calculations heat transfer by analytical models are very complicated may use some simplifications presented in section 3. Good agreement of the results obtained by Dialux and analytical calculations are presented in section 5. Based on that, was simulations and calculations irradiance on situations presented in Figure 1 and 5. Presented method calculations and visualizations result even very complicated situations are very effective and useful.

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