Accuracy in evaluation of view factors between small and far surfaces

Hojer, O., Basta, J., & Hensen, J. 2007.
Accuracy in evaluation of a view factor between radiant heater element and pyrometer sensor.
Proceedings of Indoor Climate of Buildings, 28 Nov - 1 Dec, pp. 6, Bratislava: SSTP.

ACCURACY IN EVALUATION OF A VIEW FACTOR BETWEEN RADIANT HEATER ELEMENT AND PYROMETER SENSOR

Ing.Ondřej Hojer[1], doc.Ing.Jiří Bašta, Ph.D.[1], prof.Ir.Jan Hensen, Ph.D.[2]

[1] Department of environmental engineering, Faculty of mechanical engineering,
Czech technical university in Prague
e-mail: ondrej.hojer@fs.cvut.cz, jiri.basta@fs.cvut.cz
[2] Building Physics & Systems, Technische Universiteit Eindhoven
www.bwk.tue.nl/bps/hensen

ABSTRACT

The contribution describes an approach that can be used during evaluation of a view factor between complex emitter and planar absorber surfaces. Rather than sophisticated mathematical attitude, practical way is offered. The source surface is divided into smaller parts with same surface normal and using some minor assumptions, summary view factor is calculated. The contribution is aimed on an error that can be caused considering these assumptions and further on, real differences are shown on a case study (evaluation of a view factor between ceramic plaques source surface and a pyrometer sensor).

INTRODUCTION

The contribution is a part of Ph.D. project “Optimization of overhead luminous radiant heater’s radiation geometry”. The main goal of the project is to minimize acquisition and running costs of heating systems where luminous overhead gas radiant heaters are used. The solution consists of two main parts, a mathematical model of the device in an open space and a validation measurement in-situ. After the model is validated, uncertainty and sensitivity analyses are performed to point out the most sensitive parameters. Then, partial influence of these parameters is further examined and hence recommendations for manufacturers and designers of the devices are formulated.

Luminous overhead gas radiant heaters (*fig. 1*) are in praxis mainly used for heating of large space buildings such as factories, warehouses or stadiums.

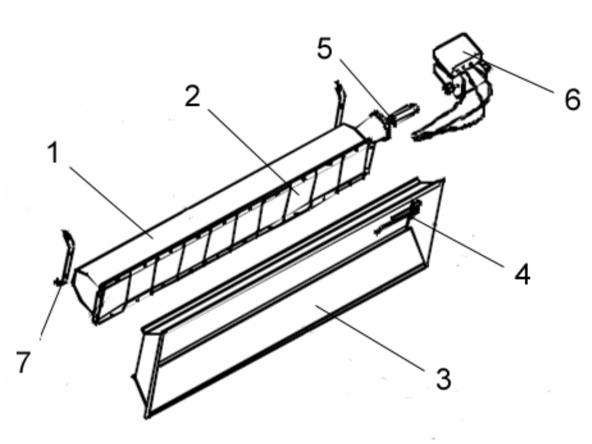

fig. 1 Typical medium intensity gas radiant heater (originates in [1])

Their construction varies from case to case according to a manufacturer, but main principles are always the same. Typical radiant heater consists of following parts: mixing chamber (1); ceramic plaques (2); reflector (3); ignition electrode (4); inlet nozzle (5) and control unit (6). Function of typical heater is very simple. Natural gas (or propane - butane) enters the device through inlet nozzle. There, primary ambient air is by ejection effect soaked according to gas overpressure into the mixing chamber. The air is completely mixed with gas and created mixture is, due to pressure conditions, evenly distributed to the ceramic plaque's surface. The mixture passes through porous plaques and it is ignited by ignition electrode. Finally, the mixture is burned with secondary air and produced heat is transferred to the ambient. These devices are called "radiant" because radiation heat transfer prevails. The temperature of burnt gas and ceramic plates is very close to 900 °C.

METHODS

The mathematical model is based on basic radiant heat transfer between two diffuse surfaces of certain temperature and emissivity. The first surface is represented by radiant heater itself (ceramic plaques and reflectors) and the second with absorber surface (pyrometer sensor). The amount of incident radiant heat is divided by absorber surface and hence radiation heat flux (W/m^2) is obtained. This value is later compared to the values received from the measurement.

The main problem of the model is in high complexity of radiant plaque's surface. Basically, it is a ceramic plaque with thousands of small cylindrical holes and polyhedral-shaped cavities (*fig. 2*). To be able to mathematically describe radiant heat transfer from such a surface, it was divided into smaller parts (groups) with same surface normal and these groups were further on considered separately. So, the problem was narrowed to an evaluation of a view factor between two simple surfaces with known geometries.

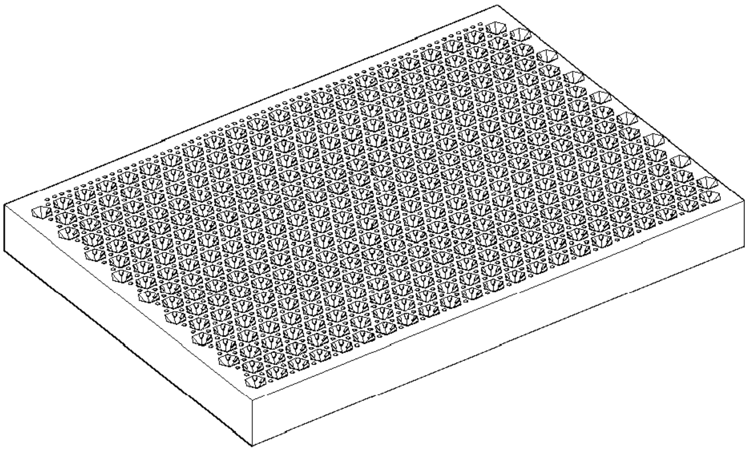

fig. 2 The most important part of luminous overhead gas radiant heater – ceramic plaque

Because convective heat transfer influences radiant heat transfer from a surface of such a high temperature just marginally, convection was completely omitted. Moreover, the main goal of the project was not aimed on thermal comfort of people, but rather on redistributing of heat given by radiant heaters in order to reduce acquisition and running costs while thermal comfort will be maintained the same.

THEORY

The rate between emitted energy from differential source surface dA_1 incident on differential surface dA_2, and all emitted energy from differential surface dA_1 is called view, exchange or sometimes even configuration factor [2]. The most widely known is a relation for a view factor between two finite areas.

$$\varphi_{1-2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos\theta_1 \cdot \cos\theta_2}{\pi \cdot S^2} \cdot dA_2 \cdot dA_1 \qquad (1)$$

For evaluation of such a view factor, both directional cosines must be defined and the distance S between an emitter and an absorber must be expressed. All in terms of directional variables. In simple cases such as two parallel surfaces, surfaces with common edge or even perpendicular surfaces, evaluation is possible. Not always easy, but possible. However, if you have two arbitrary surfaces, given just by their geometrical description arbitrary located in space, the task is very complicated.

Therefore, many simplifications are taken into account to get applicable results. There are various references and even catalogues with many view factors for various basic geometries, but the most comprehensive is a web page of an American professor John R. Howell [3]. For this contribution, view factors A-1, B-3, B-5 and C-13 were used.

Because the dimensions of the absorber and the emitter are very small compared to the distance between both surfaces (∅ 0,012 m vs. 3 m), following assumptions were used:

1. **absorber** surface was considered to be **differential**;
2. instead of separate view factor calculation, one **representative** for each surface group **was chosen** and the others were assumed to be the same;
3. instead of original trapezoidal shape of one of the emitter surfaces, **rectangular** shape **was considered**.

In case of the first assumption, following comparison was made (*fig. 3*). From the view factor catalogue [3], two similar cases for calculation of view factor were taken (B-3 and C-13). The question was, if we consider differential instead of finite surface, what is the difference in the view factor value. In order to get applicable results for our mathematical model, there were chosen the same geometrical conditions as in reality (dimensions of surfaces in millimeters and the distance between them in meters). The result in this case showed the difference in view factor about 0.0001 %.

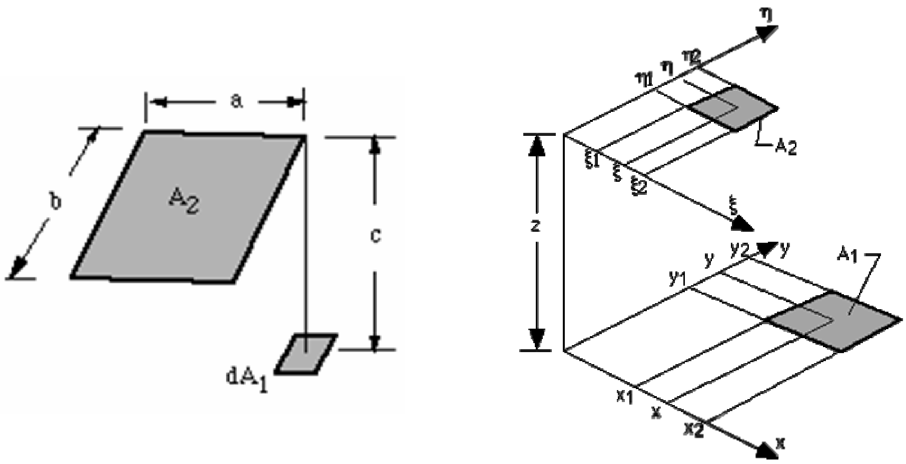

fig. 3 View factor comparison between finite-differential and finite-finite surfaces

The second assumption is based on a view factor additive rule. Radiant surface was divided into three surface groups, planar surfaces with normal perpendicular to base plane xy, tilted planar surfaces (parts of polyhedral cavities) and cylindrical hole's surfaces. Because these surface groups don't create one continual surface, there occurred a question what error will be caused by the evaluation of a single view factor for whole surface group instead of separate calculations. In our case, surfaces with same normal are regularly located in rows and columns, but between them there are "empty" spaces (similar situation as in *fig. 4*).

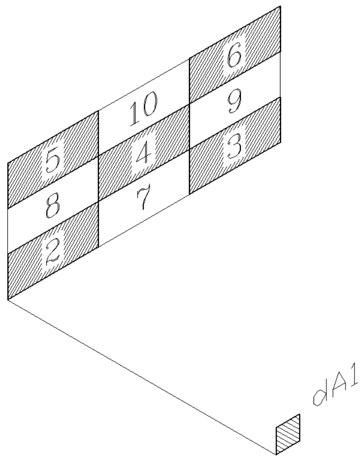

fig. 4 Uniformity surface error evaluation

In this case two approaches were tested. The first was considering just an envelope surface for view factor calculation (in case of *fig. 4*, surfaces 2÷10 together), but for heat transfer calculation multiplication by particular area (in case of *fig. 4*, surfaces 2÷6) was applied. The second approach was to choose one partial surface (in case of *fig. 4*, surface 4) and multiply heat transfer from this surface by total number of considered surfaces (in case of *fig. 4*, five). The results (*tab. 1*) show that the difference in the first approach was about 0.03 % and it further decreases with increasing number of partial surfaces. On the other hand the difference in the second approach varies with chosen surface from 0.04 % up to 0.70 %. Nevertheless the difference is again very small; the first approach is much more precise.

tab. 1 View factor and transferred heat between surface n and differential surface dA_1

	2-1	**3-1**	**4-1**	**5-1**	**6-1**	**7-1**	**8-1**	**9-1**	**10-1**
φ_{n-1} [-]	7.07e-4	6.98e-4	7.03e-4	7.05e-4	6.96e-4	7.04e-4	7.06e-4	6.96e-4	7.02e-4
Q_{n-1} [W]	0.2564	0.2532	0.2551	0.2558	0.2526	0.2553	0.2562	0.2530	0.2547

	(2÷10) - 1	**(2÷6) – 1 approach 1**	**(2÷6) – 1 sum (right)**	**Q_{4-1} x 5 approach 2**
φ_{n-1} [-]	7.02e-4	7.02e-4	-	-
Q_{n-1} [W]	2.2925	1.2736	1.2732	1.2757

Polyhedral cavities at ceramic plaque’s surface consist of six tilted trapezoid sides and two hexagons. The third assumption was stated because an evaluation of a view factor of original trapezoid surface is very difficult. Therefore, possible substitution between trapezoid and rectangle was examined. Again if there are assumed the same geometrical conditions as during the measurement, the difference between rectangle – absorber and trapezoid – absorber view factors is 0.009 %.

CONCLUSION

As was mentioned above, an evaluation of view factors for complex geometries is not a simple task and various assumptions always needs to be taken into account. In this contribution was proven that if the distance between surfaces is large compared to surfaces dimensions the shape of examined surface doesn't play such an important role. If the differential area is considered instead of finite, the difference is less than **0.0001 %.** If a view factor from a non-consistent surface is needed, it can be calculated just for an envelope surface and in heat transfer equation right surface area is substituted. The total error is not larger than **0.03 %.** And finally, rectangular surface can be used instead of trapezoidal, because the difference is smaller than **0.009 %.** This evaluation proves applicability of the above posted assumptions for the mathematical model. The error between right and simplified value is smaller than four hundredths of percent.

ACKNOWLEDGEMENT

The paper was supported by grant MSM 6840770011 “Technika životního prostředí”.

REFERENCES

[1] Kotrbatý, s.r.o. *Příručka světlý infračervený plynový zářič*. 2005; Available from: www.kotrbaty.cz.

[2] Siegel, R. and J. Howell, *Thermal radiation heat transfer*. 4th ed. 2002, New York: Taylor & Francis. 868 pgs.

[3] Howell, J. *A Catalogue of Radiation Heat Transfer Configuration Factors*. 2001; 2nd: Available from: http://www.me.utexas.edu/~howell/.