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# On the relation between shape and downward radiation of overhead radiant heaters

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## Abstract

The paper aims on evaluating and assessing of the influence of a shape of overhead luminous infrared heater's burner on heat distribution to the ambient. These devices are mainly used for heating of industrial or other large space buildings. The contribution is based on comparison between the experimental results and created mathematical model. The latest experimental results show that the maximum of radiant intensity does not lay right below the radiant heater. Actually, there exists a ring of maximal values around heater's midpoint axis. Results prove that instead of reflectors' geometry, very complicated shape of gas luminous heater's burner plays the most significant role in radiant heat transfer from the luminous heater. It was evaluated that the position of the radiant intensity maximum is around 10° from the radiating surface's normal direction. All the findings can be summarized in conclusion that uniform distribution of radiant intensity required for thermal comfort of occupants can be maintained just by optimizing of the shape of radiant heater's burner. Besides this conclusion, it is also apparent that adding the reflector actually increases summary radiant heat flux to the desired zone and therefore radiant efficiency increases. It is also clear that varying the reflector shape, different improvement of the efficiency can be expected.

## Keywords

infrared heater, experiment, mathematical model, radiation distribution, burner shape, radiant heating

## Nomenclature

| | |
|---|---|
| $I$ [W.m$^{-2}$] | Radiant intensity |
| $I_n$ [W.m$^{-2}$] | Radiant intensity at normal direction |
| $I_\alpha$ [W.m$^{-2}$] | Radiant intensity at angle α from the normal |
| $I_y$ [W.m$^{-2}$] | Radiant intensity at distance y from the heater's midpoint axis |
| $\alpha$ [rad] | Angle measured from the normal of the surface |
| $\alpha_{max}$ [rad] | Angle, where the radiant intensity is maximal |

## Introduction

Thermal comfort of occupants depends on many factors such as air temperature, mean radiant temperature, relative humidity, air velocity, activity level of occupants and also their clothing. In heating systems where radiation heat transfer is dominant and especially in systems with luminous overhead heaters, mean radiant temperature is significantly place dependent. Therefore also thermal comfort of occupants can vary with place. Overhead luminous heaters are sharp heating sources which means, that energy is transmitted into relatively small area with high heat flux. Thus within whole heated space there are significant peaks and sinks in heat delivery. The main goal is to eliminate these fluctuations as much as possible and to provide gas radiant heaters with as uniform heat distribution as possible. This paper can open the discussion about the design of luminous overhead gas radiant heater from completely different point of view.

## Overhead luminous gas radiant heater

At the beginning it should be clear that the above used term *overhead luminous gas radiant heater* is technical term used in EN 419-2 [1], but there also exists mostly in American literature different denotation for these devices, *porous-matrix infrared radiation heater* (ASHRAE) [2]. Further on in the contribution will be used just the designation from European standards.

Construction of this device (fig. 1) varies from case to case according to the manufacturer, but in general the main principles are the same. Typical radiant heater consists of following parts: mixing chamber (1), ceramic plaques (2), metal reflector (3), ignition and ionization electrode (4), inlet nozzle (5), control unit (6) and finally suspenders (7). The most significant difference between such devices available on the market is the shape of the reflector. Although most of the manufacturers use planar reflectors there are variations in the setting angle. Nevertheless there are always at least two opposite sides set in the same way. In order to increase radiation efficiency there occur various improvements in the construction. For example, there can be found an austenitic steel grid located in front of the ceramic plaques. The grid is heated up by radiation and convection to the temperature that is higher than the temperature of ceramic plaques. The amount of generated heat is also higher because of its high emissivity. Another example, insulation of reflectors with top surface made of low-emissive (polished) metal. It is sometimes added to the reflector to decrease heat losses by convection and backward radiation. Some heaters even preheat mixing chamber to increase temperature of the mixture before burning and utilize more energy this way. However, because of complicacy of such construction improvements (hence higher price) there are a low number of such luminous heaters in operation.

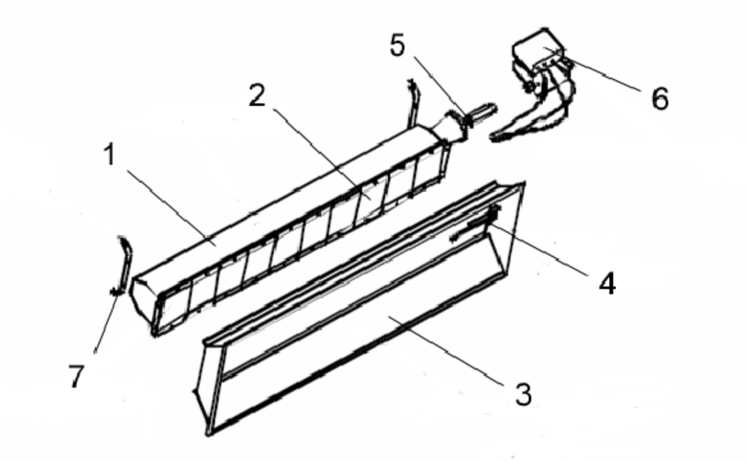


*Fig. 1 Typical overhead luminous gas radiant heater [3]*

Function of typical device is very simple. Natural gas (or propane - butane) enters inlet nozzle where primary air is by ejection effect drawn in. The air is completely mixed with gas in the mixing chamber and then created mixture is evenly distributed to the ceramic plaques' surface. Mixture passes through porous ceramic plaques and on their surface it is ignited and burned with secondary air. Although the temperature of the burnt gas is very close to 900 °C (1650 °F), the exhausts are quickly mixed with ambient air (3) and thus the temperature is gradually decreasing. Anyway, the burnt gas has still temperature high enough to create a large rising flow. Therefore radiation efficiency of a typical luminous heater (ratio between radiant heat produced and net heat input of burning gas) is between 60 and 80 %.

**Theory**

Not many papers have recently been published touching the problem of radiant intensity distribution below gas-burning luminous heaters. In this field, research is mainly driven by manufacturers of these devices. Construction of such devices doesn't vary that much, so any possible advantage of one of them is strictly kept secret. Nevertheless there exist some studies published on this topic. Results of these studies were summarized in fig. 2. There is a comparison among various sources of radiant intensity distribution below typical overhead luminous heater. The comparison is made in polar diagram where on x axis there is a ratio between radiant intensity at particular direction $I_\alpha$ to the radiant intensity at normal direction $I_n$ of the heater's surface. Two sources of the comparison are from measured data [4] and [5], one is obtained from ASHRAE materials [2] and all these are compared to the data for gray surface gained by evaluation of the relation describing Lambert's cosine law (eq. 1).

$$I_\alpha = I_n \cdot \cos(\alpha) \qquad (1)$$

From the fig. 2, it is apparent that at certain angles the $I_\alpha / I_n$ ratio is higher than one, which means that the radiant intensity at α direction is higher than at normal direction. Simply, the emitter cannot be considered as gray surface. Analyzed results show, that the maximal ratio is about 1.056, which is 5.6 % difference between the radiant intensity at $\alpha_{max}$ = 20° and at the normal.

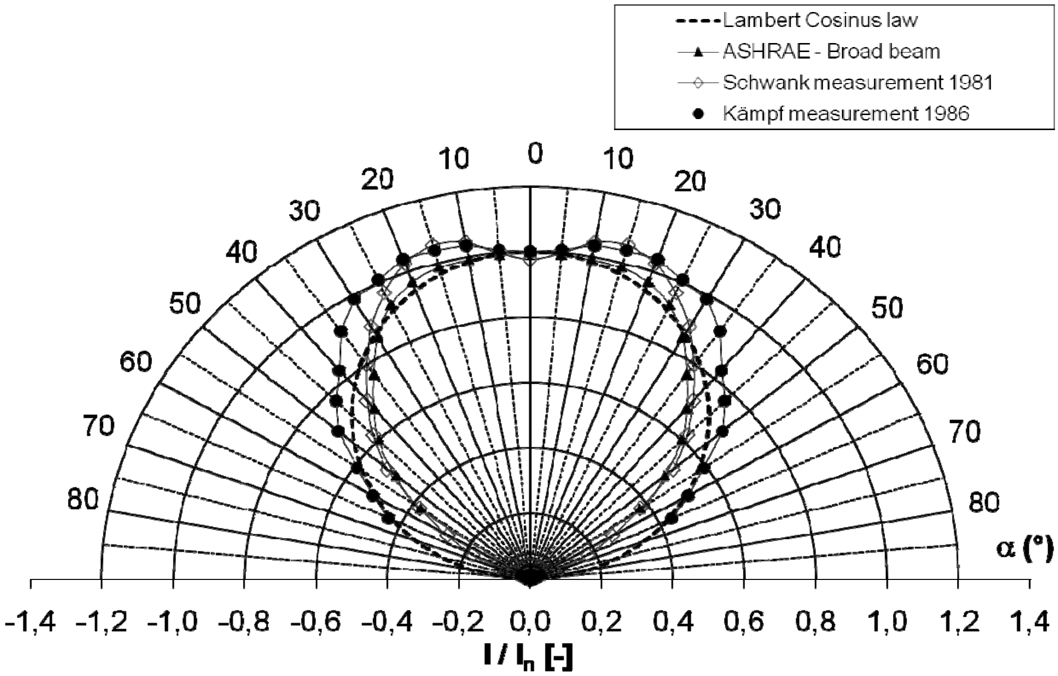


*Fig. 2 Comparison of measurements of radiant intensity distribution below typical luminous heater*

In previous studies [2], [3] the authors tried to explain the displacement of the radiant intensity maximum by shape of the reflector, but there are actually no proofs to support this theory. Because of the aim of their studies, they actually neglected the influence of the radiant heat flux maximum dislocation and further on they considered these luminous heaters just as lambertian surfaces (which follow Lambert's cosine law). Based on these studies an objective for further work was formulated: to find scientifically supported answers to the dislocation of a radiant intensity maximum.

**Methodology**

To be able to fulfill the objective a new experimental setup was designed. Firstly, typical overhead gas luminous heater available on the market was chosen and three variants with different shapes of the reflector were prepared. The first variant was completely without the reflector. The second was with the reflector all sides set to 45°. The third was the reflector with two opposite sides (x axis) set to 45° and the other two (y axis) to 90°. The experiment was done in a small separate building 8 x 11 x 6 m (to the top of the roof). The radiant heater was suspended 3.8 m above the floor. A pyrometric sensor was arranged for measuring of the radiant intensity distribution at plane 3 m below the luminous heater. The radiant intensity was measured just in one quadrant because the others were found to be symmetrical. A final grid in one quadrant was 3 x 3 meters (step 0.5 meters). The power output of the luminous heater was chosen to be 7 kW. The reason for such a small power output (smallest on the market) is in the small volume of the room, directional type of the sensor and limited height of suspension.

Besides the experimental setup a mathematical analysis was done. The experimental study offered some answers but in order to go more in detail and to be able to generalize the results it was necessary to go into the theory. A model of radiation heat transfer from a radiant heater to the ambient space was created. Because of a complicated shape of the heater's burner (fig. 3) whole surface was divided into smaller parts (cylindrical holes – 1, polyhedral cavities - 2). These parts were later on calculated separately and at the end, contributions of all these parts were summed. Because of high complicacy of whole problem (convection and radiation heat transfer, combustion, gas absorption and emission, scattering), various simplifications were taken into account. Simply, an appropriate level of abstraction was chosen. It results in considering of all the separate parts as grey surfaces, omitting of scattering and considering of the burning process as ideal. Actually, problems with combustion and with exhausts production were eliminated by a measurement of surface temperatures of all considered parts. Convective heat transfer was also omitted.

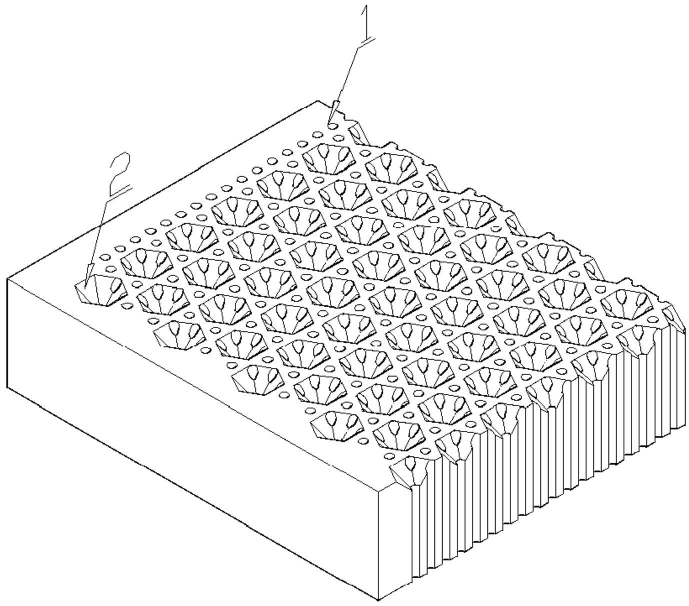


*Fig. 3 Detail of luminous heater's burner – ceramic plaque*

**Results**

Results are displayed in the figure 4 and 5. Firstly, it should be mentioned that they are in very good agreement with previous studies. It is clear that the radiant intensity maximum does not lay right below the luminous heater but rather it is shifted a bit to the side. Although there are results depended just on y direction, x-axis dependency looks very similar. Shortly, right below the heater there is a local minimum of radiant heat flux. The second remark is related to the influence of the reflector on the position of radiant intensity maximum. The results from the measurement without reflector (fig. 4 sphere mark) show, that the dislocation is actually not just a function of the shape of the reflector but also the shape of the burner. It can be noticed that attaching the reflector itself doesn´t cause the radiant intensity maximum's dislocation. The main influence has the shape of the burner. For the reflector with just one side tilted (fig. 4 triangle mark) there is a slight increase in radiant efficiency but otherwise the trend of both lines is similar. In case of the reflector with both sides tilted (fig. 4 rotated square mark) radiant efficiency is again higher, however the trend of the line is different. This implies that there must be at least some influence on the absolute value and the position of the radiant intensity maximum.

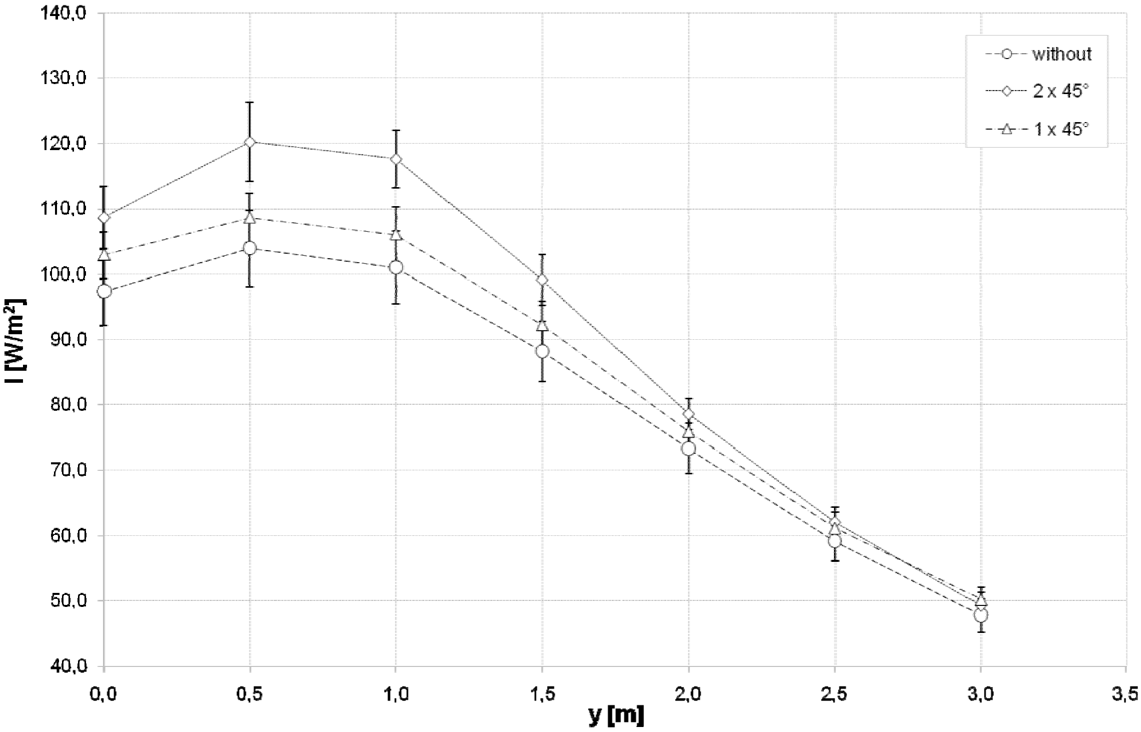


*Fig. 4 Distribution of radiant heat flux on the plane 3 m below the radiant heater - three variants of the reflector*

In fig. 5 there are summary data obtained both from the mathematical model and from the experimental measurement. In order to reduce uncertainty in mathematical model as much as possible the variant without reflector was chosen. It is clear, that both compared cases are in good agreement as all the points are within the uncertainty ranges. The shape of model curve (crosses) underlines what already has been written in paragraphs above. The dislocation of radiant intensity maximum is proven also by detail mathematical analysis of radiation heat transfer below the radiant heater's burner. During the construction of the model, it was found that incorporating the cylindrical holes to the burner's surface actually causes the dislocation of the radiant intensity maximum. This finding would not be without such a detail theoretical analysis possible.

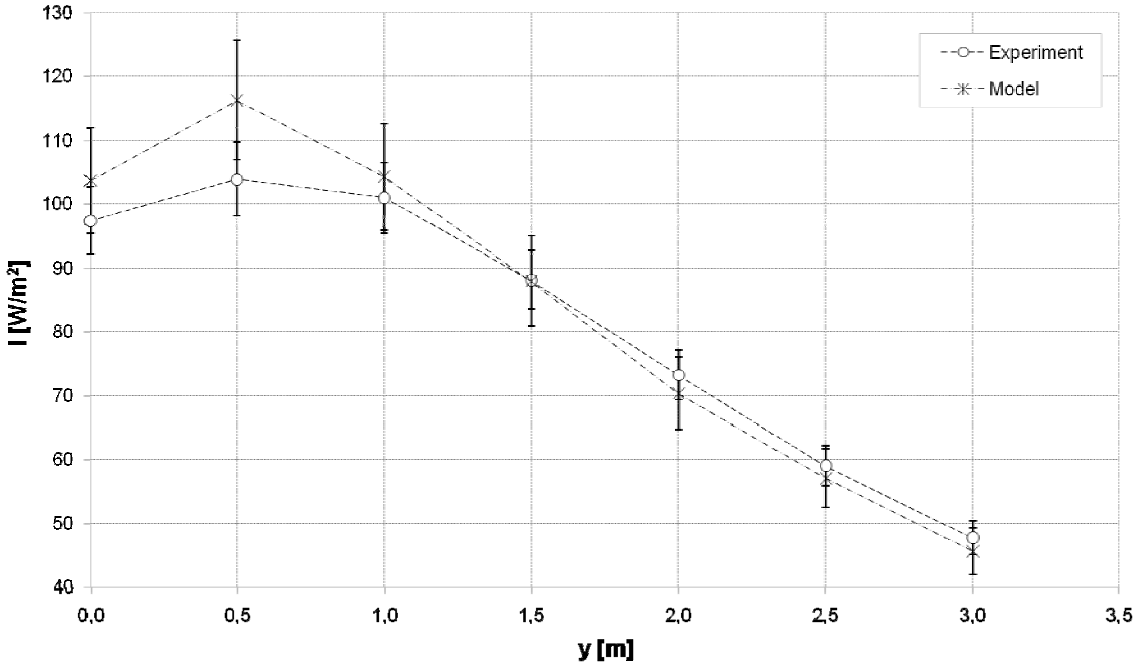


*Fig. 5 Distribution of radiant heat flux on the plane 3 m below the radiant heater without reflector - experiment vs. model*

From the measured data can be also evaluated $I_y / I_0$ ratio for all variants. Because of the measurement methodology, this type of ratio was preferred against the angular one. The results can be also recalculated, but it would add to the values another uncertainty. Results are in tab. 1. Maximum $I_y / I_n$ ratio is about 1.107 that is 10.7 % difference between the radiant intensity right below the heater and 0.5 meters to the side. Generally, it was observed that the radiant intensity maximum can be found approximately at $\alpha_{max}$ = 10 °.

*Tab 1. Values of $I_y / I_n$ ratio for all measured variants*

| **y** | **0.0** | **0.5** | **1.0** | **1.5** | **2.0** | **2.5** | **3.0** |
|---|---|---|---|---|---|---|---|
| **without** | 1.000 | 1.067 | 1.037 | 0.905 | 0.752 | 0.607 | 0.490 |
| **1 x 45** | 1.000 | 1.055 | 1.031 | 0.896 | 0.737 | 0.594 | 0.488 |
| **2 x 45** | 1.000 | 1.107 | 1.083 | 0.913 | 0.723 | 0.571 | 0.454 |

**Discussion**

At the beginning, a question should be asked: what is the explanation for such a distribution of radiant heat flux? The answer is logical. Simply, right below the heater, the radiating surface (and therefore radiant heat flux) is smaller because of missing radiating area of the cylindrical holes. However as soon as the position is a bit different, radiating surface is larger and hence radiant intensity is higher. Anyway receding from the midpoint radiant intensity firstly increases because of an enlargement of the radiating surface area and then gradually decreases because the distance plays also significant role.

Apart from small cylindrical holes (fig. 3 - 1) that are designated for even distribution of air-gas mixture to the burner's surface, there are also small polyhedral cavities (fig. 3 - 2) originally designed for improving of the burning process. During creation of the mathematical model, it was found that these cavities plays also important role in radiant heat transfer and therefore there occurred a question whether the burner itself could not be designed also from a radiant heat transfer point of view.

## Conclusions

The contribution is in general aimed on analyzing the influence of two significant parts of gas burning overhead luminous heater on the distribution of radiant intensity. Analyzed parts are a metal reflector and a ceramic burner. Results prove that instead of reflectors' geometry, very complicated shape of gas luminous heater's burner plays the most significant role in radiant heat transfer from the luminous heater. The burner itself, respectively small cylindrical holes and polyhedral cavities in it cause that the radiant intensity is not maximal at normal direction but rather it is shifted to the side. It was evaluated that the position of the maximum is around 10° from the radiating surface's normal direction. Anyway, the dislocation causes that the heat flux delivered to the occupancy zone is more uniform within the heated area. This finding can open future discussion if it is possible to optimize the burner also from the heat distribution to the occupancy zone point of view.

Besides this conclusion, it is also apparent that adding the reflector actually increases summary radiant heat flux to the desired zone and therefore radiant efficiency increases. It is also clear that varying the reflector shape, different improvement of the efficiency can be expected.

## Acknowledgement

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