# Zonal method for radiant heating design in large space buildings

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## Introduction

Designers of HVAC systems for industrial and other large space buildings tackle these days with the same pressure for energy consumption reductions as in residential area. However especially for large space buildings there was at least in Europe lack of a design methodology that is not directly connected to any particular manufacturer and offers potential of significant energy consumption reductions when followed. This spring was published a new REHVA Guidebook (No. 15) that addresses exactly the topic and offers completely new approach for design of various heating systems used in large space buildings. In this paper the basics of the methodology are shown on a simple example - heating of a 3-bay industrial hall with radiant panels. Details of the methodology including evaluation procedure for the most broadly used heating systems can be found in the guidebook.

## Zonal approach from history to present

The major development in radiant heating systems in Czech Republic had come after 1952, when Mr. Cihelka from Czech Academy of Sciences formulated, based on extensive experimental work, first methodology for radiant panel's design. His work was first published in 1957 and republished in 1961 in even today very often cited book called Radiant Heating (Sálavé vytápění) [1]. The concept of creating the thermal zones in larger spaces had first appeared in Czech Republic already in 1958, when Mr. Kotrbatý had published paper on that issue related with view factors calculations done by Mr. Cihelka. During time this concept was further improved and appeared also later in 1980s in Germany in work done by prof. Glück [2]. The problem of this methodology was the fact that designers and manufacturers didn't accept it in larger scale and therefore it went slowly forgotten. The change has come after turnover in Czech Republic in 1991 when Mr. Kotrbatý had founded a company firstly designing and importing, but soon after also manufacturing and assembling heating systems for large space buildings and started to use the thermal zones methodology for all products (plaque and tube gas radiant heaters and radiant panels). During recent years the methodology was proved on real assemblies, corrected and improved in cooperation with Czech Technical University in Prague (prof. Bašta, prof. Kabele), Slovak University of Technology in Bratislava (prof. Petráš) and Cologne University of Applied Science (prof. Sommer). Later on the methodology was discussed on Clima 2010 congress in special workshop initiated for that purpose [3]. The work was summarized in creation of a universal methodology, applicable to most of the heating systems used for large spaces. The methodology was published IN REHVA Guidebook No. 15 [4].

## Standard approach - Uniform distribution of heating surfaces in large space

The difference between standard methodology and the zonal method is at best observable from particular example. At the **Figure 1** there can be found the most frequently used approach for design of heating systems in large space buildings. There is a typical 3-bay industrial hall with dimensions 60 x 18 x 7 m per each bay. At the front side there is an annexed office building. The hall building is normally insulated with standard windows and skylights. From the figure it is obvious that placement of radiant panels is completely uniform. At first sight everything is ok, installed power output perfectly covers heat losses and hence there is no indication of any problem. However in reality there are two variants of operation. Let's consider for example bay A:

a) The globe temperature control sensor is placed either in zone 1 or 2 or 3;
b) The globe temperature sensor is placed in zone 4.

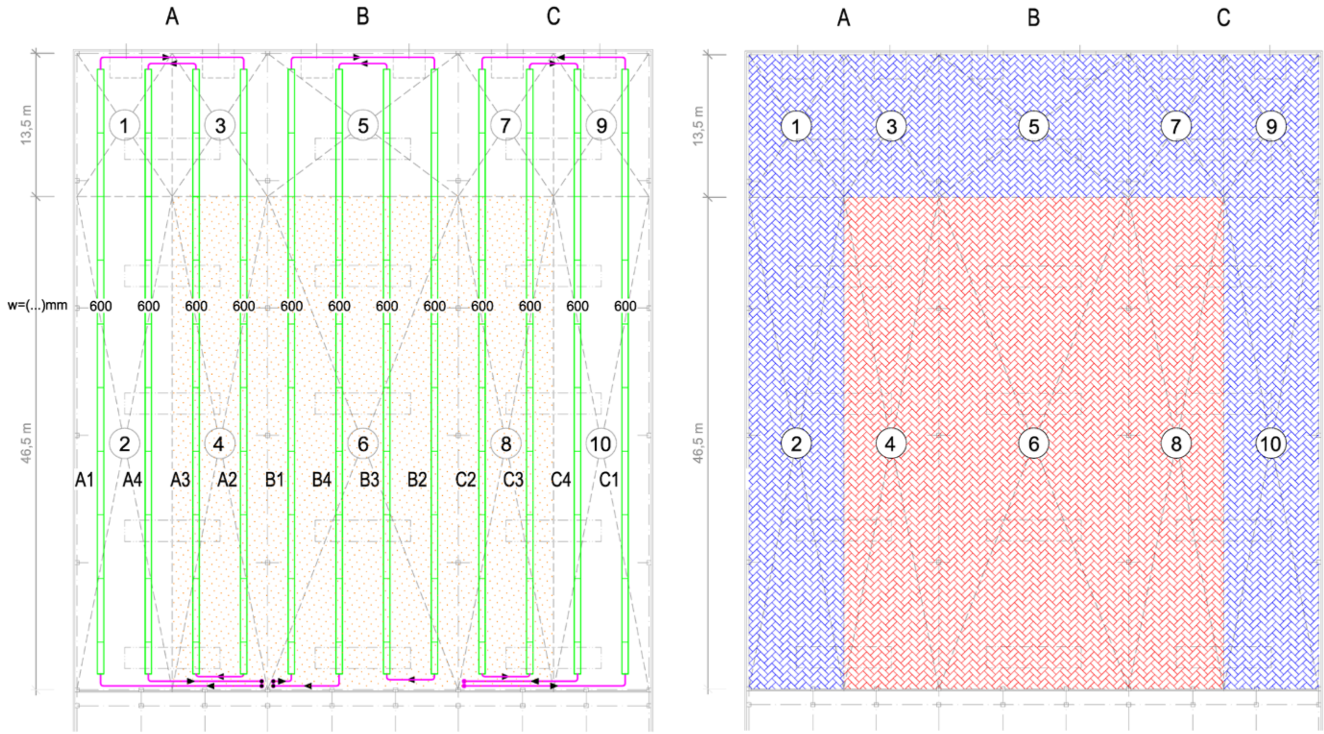


**Figure 1 Uniform location and connection of radiant strips related with resulting temperature distribution at nominal conditions.**

It results in general in two possible operation statuses:

a) If the design was done with sufficient reserve there is significant **overheating** in zone 4. However, if the design was done to the edge, the desired temperature in zones 1, 2 and 3 **will never be reached** (when external temperature is at design value);

b) Zones 1, 2 and 3 will be heated **insufficiently**;

Particular values of design heat losses $\Phi_i$ and installed power outputs of radiant panels $\Phi_{HL,i}$ are shown in **Table 1** for each zone of the hall. Visually, it is easier to observe results at **Figure 1** on the right hand side. For example in zone no. 1 installed radiant panels deliver at nominal conditions of about 30.3% less heat than needed. On the other hand in zone no. 4, and 8 radiant panels deliver 41.3% more heat than needed. That means that however the heating surface is designed uniformly, the thermal comfort conditions will not be uniform at all.

**Table 1.** Ratio r between installed power output $\Phi_{HL,i}$ and total heat losses $\Phi_i$ in every zone in case of uniform design.

| Zone no. | $\Phi_i$ [W] | $l$ [m] | $\Phi_{HL,i}$ [W] | r [%] |
|---|---|---|---|---|
| 1 | 17 280 | 24 | 12 036 | 69.7 |
| 2 | 56 340 | 90 | 45 270 | 80.4 |
| 3 | 12 729 | 24 | 12 024 | 94.5 |
| 4 | 31 871 | 90 | 45 045 | 141.3 |
| 5 | 25 458 | 48 | 24 060 | 94.5 |
| 6 | 63 742 | 180 | 90 315 | 141.7 |
| 7 | 12 729 | 24 | 12 024 | 94.5 |
| 8 | 31 871 | 90 | 45 045 | 141.3 |
| 9 | 17 280 | 24 | 12 036 | 69.7 |
| 10 | 56 340 | 90 | 45 270 | 80.4 |
| Σ | 325 640 | 684 | 343 125 | |

*l* ... length of radiant strips in a zone.

Resulting statement is simple: **In order to obtain uniform thermal comfort conditions all over the considered space, it is necessary to design heating system non-uniformly.**

## Zonal method - Adapted sizes of heating surfaces

To be able to satisfy different heat delivery demands in each zone, the heating surfaces have to be designed differently. Because the length of radiant panels is given by space requirements, the parameter that can be adapted is the width of the heating surface (in case of radiant panels). In the design process suitable sizes (widths) of radiant panels have to be adapted in all zones according to the thermal requirements and simultaneously connection of radiant strips plays also the role. From the **Figure 2** it is obvious that the whole building has in different places (thermal zones) different requirements on heat delivery. However also in such situation it is necessary to keep whole heating system as simple as possible at least for the control and maintenance. Hence, the system was divided in three separately controllable sections. After initial concept was done, thermal zones had to be determined. The rules for boundary setting are described later on. Finally, it resulted in two sections lengthwise and in total five sections crosswise (two per marginal bays plus one per inner bay).

Following aspects are significantly influencing effectiveness and efficiency of whole heating system:

a) Connection of radiant strips into water circuits (the warmest inlet connected first to the marginal strips – this aspect has already been discussed in detail in [5]);
b) Increase of heat delivery in lengthwise marginal zones by means of wider radiant strips;
c) Increase of heat delivery in crosswise marginal zones by means of wider radiant panels at the end of each strip.

## Connection of radiant strips into water circuits

In the bay A, the connection order starts from the very side strip and goes inward one after another. As the distance from the external wall increases the heat delivery needed to achieve thermal comfort for occupants is decreasing.

The bay C is vice-versa.

In the bay B there are different requirements. There is a need to supply heat uniformly and therefore the connection order is different. First the heat is delivered to the side strip at one side (strip B1), but then the connection leads to the opposite side of the bay (strip B2). Just after that the inner strips (B3 and B4) are connected. This way, uniform mean water temperature in a cross-cut is achieved.

## Increase of heat delivery in lengthwise marginal zones

The connection itself doesn't always have to be enough. In some cases the difference in heat losses between marginal thermal zone and inner one is so large that in order to maintain uniform thermal comfort there have to be considered also changes in radiant panels' width.

## Increase of heat delivery in crosswise marginal zones

In crosswise direction, there have to be considered also zones in the neighborhood of the front wall. Gates and windows located there can cause significant increase in local heat losses that has to be somehow covered. There is a possibility to make changes in width of strips even along one strip.

**Table 2** shows how the reallocation of heating surfaces can influence thermal conditions in each zone.

**Table 2.** Ratio r between installed power output $\Phi_{HL,i}$ and total heat losses $\Phi_i$ in every zone in case of thermal zones-based design.

| Zone no. | $\Phi_i$ [W] | *l* [m] | $\Phi_{HL,i}$ [W] | *r* [%] |
|---|---|---|---|---|
| 1 | 17 280 | 24 | 19 104 | 110.6 |
| 2 | 56 340 | 90 | 61 335 | 108.9 |
| 3 | 12 729 | 24 | 13 728 | 107.9 |
| 4 | 31 871 | 90 | 36 315 | 113.9 |
| 5 | 25 458 | 48 | 29 208 | 114.7 |
| 6 | 63 742 | 180 | 70 290 | 110.3 |
| 7 | 12 729 | 24 | 13 728 | 107.9 |
| 8 | 31 871 | 90 | 36 315 | 113.9 |
| 9 | 17 280 | 24 | 19 104 | 110.6 |
| 10 | 56 340 | 90 | 61 335 | 108.9 |
| Σ | 325 640 | 684 | 360 462 | |

*l* … length of radiant strips in a zone.

It can be easily seen that the situation is significantly better, because the heat delivery much more follows the demands of the space. The highest overheating is about 14.7% and wherever the temperature sensor might be placed there will be almost no zone with lack in heat delivery. The difference among zones is not higher than 6.8%.

## How to determine boundaries of the thermal zones

The only question remains, where are the boundaries of outer and inner thermal zones? The answer is in the way how heat is delivered to the considered space. In case of convective systems it is difficult to separate thermal zones within the space because as the amount of delivered air increases the mixing causes hardly separable conditions. On the other hand radiant heating systems are for these purposes ideal. In case of smaller local sources (electric or gas radiant heaters) it can be easily considered so, that to every heating source can be assigned a specific thermal zone. In case of larger systems (low temperature & long tube gas radiant heaters and water/steam radiant panels) the situation is a little bit more difficult. It is obvious that as the distance from the external wall increases, the total irradiation from different heating surfaces increases as well. This can be mathematically expressed by summary view factor calculation from all the heating surfaces. The view factor can be presented on a graph as a function of distance from the external wall. As we follow the curve shape from the beginning, it rises significantly and, at some certain point, the view factor reaches its maximum. From that point on it fluctuates around a mean value. So ideally the boundary of the marginal thermal zone can be set at the point where the curve changes from rising towards constant value. In reality the curve may have various shapes (depending on the location and sizes of heating surfaces) and therefore there is a necessity of designers' decision.

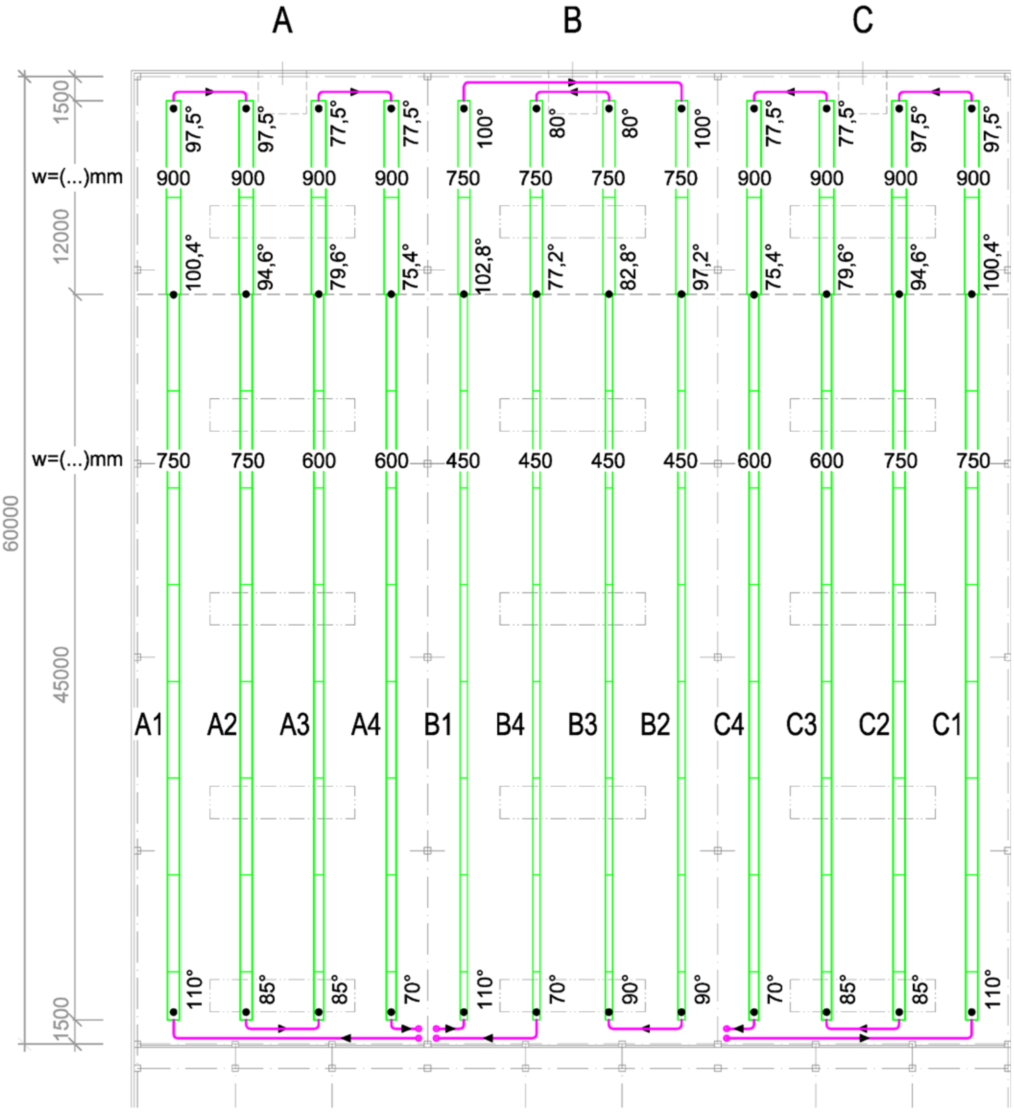


**Figure 2.** Optimal location and connection of radiant strips.

## Conclusion

Proposed design methodology is based on practical experience with many real projects as well as theoretical backgrounds. It was written to be easy to use without complicated mathematical formulas. The methodology is applicable and has similar effects both for the low end and high end products. It provides much more energy efficient heat delivery for large spaces than standard, uniform approach and requires just slightly higher effort from the designers. It covers electric, gas, water and even steam based radiant heating systems. It was proposed for radiant heating systems as they are themselves more efficient than most of the convective heating systems in large (especially high) spaces.

## References

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