Application of radiant strips for cooling

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Abstract

The thesis aims to reduce the energy demand for the cooling of industrial halls in summer thanks to the use of radiant strips, which are typically used for heating in the winter. Given that the use of buildings and their constructional solutions are varied, so we had to occur and to analyze the current condition from which they were intended boundary conditions for the next step. Boundary conditions relate in particular dimensions of the hall (48x18x8m), the percentage of glazing (0 to 5%), building orientation (sides of the hall which are 48 m length are oriented to the east and west) and the use of the hall (storage spaces, shipping warehouses). Another output of the thesis is to identify and optimize the parameters of heat transfer fluid for standard panels in the winter and summer seasons, and appropriate choice of the participation panels into sections. For the new panel with forced convection and condensate drain will be established images of flow and temperature fields in the cooling mode. The new panel is expected to increase cooling capacity.

Key words: radiant strips; radiant panels; cooling; glazing; storage spaces; shipping warehouses; heat loss; heat load

1. Introduction

Constantly rising energy prices and investment costs are forcing manufacturers and experts to optimize the existing device providing functions such as heating and cooling of industrial halls or general quality of the work environment.

This article addresses and offers an alternative to classical cooling of buildings (halls). Under the classical cooling of the halls you can imagine for example the air conditioning system, heat pump air/air on the roof, ventilation unit and etc. This system requires necessarily cold source, distribution of the cold water and the cold air. Classical methods are most commonly used and undoubtedly have their advantages. But why not use for the halls where are installed radiant panels for heating these panels for summer cooling? For summer cooling with radiant panels will be also need a source of cold, but appropriate choice of sources such as reversible air/water heat pump we can cover the requirements for cooling and heating. We have only one system for heating and cooling, but then it will be necessary to specify how it will look with the use of radiant panels for cooling, which can take away heat load and whether this alternative is combat-ready on the market. Most of these issues correspond to the following text, in which are solved designs of radiant strips for heating or cooling mode, the appropriate involvement of the panels with respect to the limits (dew point temperature, maximum usable area for panels, etc.). All calculations and designs are applied to model hall, which represents the common dimensional line.

Therefore it would be appropriate for newly constructed buildings (halls) to solve it complexly and learn from the current situation.

2. Current condition of the issue

2.1. Radiant panels (strips)

2.1.1. Characteristic and construction of radiant panel

Radiant panels form the heating surface of the distribution pipes around which are lamellas. Heat is transferred mainly to the surrounding area by radiation. Panels are mostly hanging from the ceiling of the hall. The advantage of radiant passports (panel) is the possibility of involvement in series or in parallel, enabling us to operate any flow to different parts of the panels. The height of the suspension is by the use of the heating medium and the construction from 4 up to 20m [1].

2.1.2. Typical construction of the radiant panel
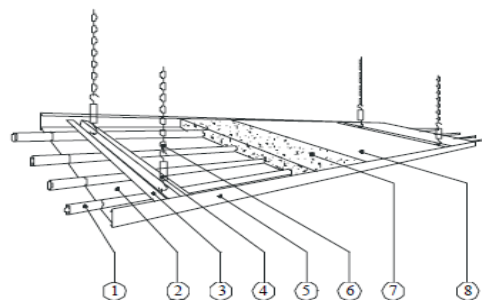
1 -pipe register, 2 - metal lamella, 3 - main crossbeam, 4 – screw, 5 – sidewall, 6 –chainlet, 7 - reflective aluminum foil

Fig. 1. *Typical construction of the radiant panel [1]*

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2.1.3. Deployment of panels

When placing radiant strips usually follows the rule that the distance between the passports should be equal to the height of hanging passports. In extreme passports with the rule changes and respects the rule, at least half the height of hanging passports. But not always the rules are feasible.
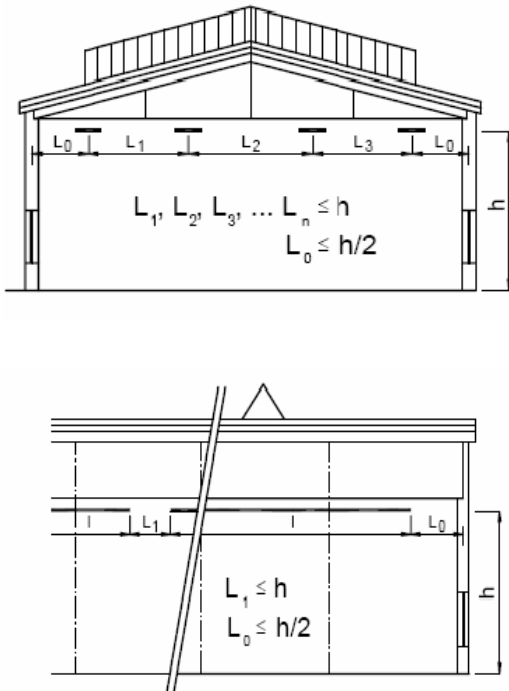

Fig. 2. *The optimum spacing of hanging radiant strips [1]*

2.1.4. Radiant efficiency

By definition, the radiant efficiency of radiant panel by dividing a shared heat output into the surroundings by radiation, and the entire heat output transmitted to the surroundings.
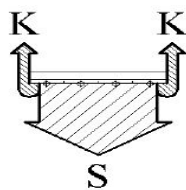

Fig. 3. *Distribution of radiant and convection part [1]*

$$\eta_s = \frac{Q_S}{Q_S + Q_K} \qquad (1)$$

2.2. Halls

For spacing of columns are in 90% of cases using multiples of 6m, up to 30m. Multiples spacing are the same for width and length. The only parameter that isn´t "modulated" is the height of the hall [2].

Location of the halls mostly has no "deeper meaning" in terms of position in relation to the orientation (points of the compass). One of the priorities for the location of halls in the landscape is transport links to the main road. Industrial buildings are built either in industrial zones, which are predetermined land acreage, so the project engineer or investor is not able to somehow change the position of the hall.

2.3. Heating in existing halls

2.3.1. Hot water radiant panels

Radiant panels are currently installed mainly in industrial buildings, warehouses; however we will find the installation of sports halls and houses. But we can say that the main application is still installed in industrial buildings and warehouses. As a heating medium is used hot water (110°C), hot water (160°C max. pressure 1.6MPa) or steam (180°C max. pressure 1.6MPa).

2.3.2. Hot-air heating

Hot-air units heat the air and distribute it to space through air ducts and elements. In this case, not heated directly building structures and objects in the spaces through radiation. For heat transfer and thermal comfort is used heated air.

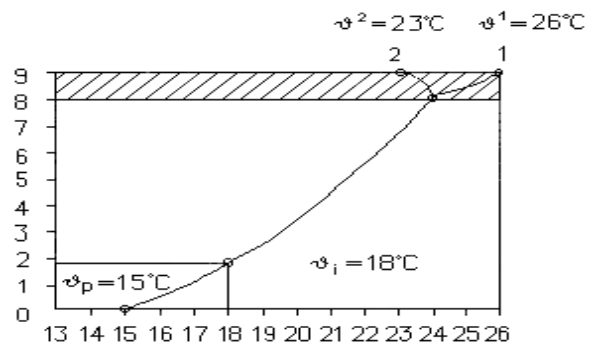### 2.3.3. Differences between hot-air heating and radiant panels

Fig. 4. *The height temperature gradient – hot-air heating [4]*
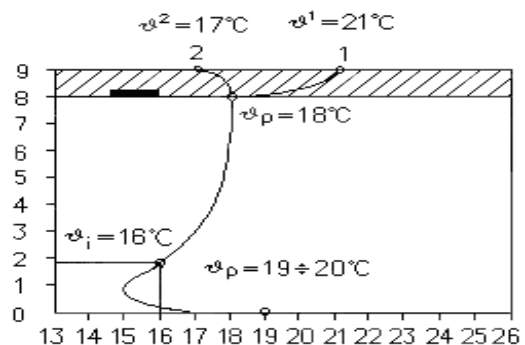

Fig. 5. *The height temperature gradient – radiant panels [4]*

The main advantage of radiant panels is lower heat consumption compared to hot-air heating up to 40%, in use reheat the ventilation air by heat recovery, we save up to 60%.

2.4. Cooling in existing halls

2.4.1. Air conditioning units

The existing buildings are mostly cooling from air conditioning units for supply and exhaust air. Airflow is determined by the dissipation of thermal load, air exchange rate or according to the requirements for minimum hygienic minimum for one person, technology. Therefore, cooling is performed by air-conditioning unit, which has a cooler. This cooler needs a source of cold.

2.4.2. Adiabatic cooling and ventilation units

Another technical solution is the use of adiabatic cooling and ventilation units mounted on the roof. By supplying air through special filters moisturizing cools down water evaporation. The resulting humidified and cooled air is blown into the space. Devalued warm air is extracted fans also mounted on the roof of the hall.

2.4.3. Heat pumps air/air

Another solution is to use a heat pump air/air, which is placed on the roof. Heat pumps air/air take energy from the outside air and transmit energy to the air, which is distributed to the hall through ventilation ducting and ventilation elements.

2.4.4. Summary for cooling

Ventilation in existing halls is insufficient or not addressed at all.

All the above options solves both the possibility of heating and cooling in one or more devices, but it is always a cooling/heating systems, which are achieved the required parameters hot/cold air. I focus on the use of radiant panels for cooling.

3. Intermediate goals

- Analysis of projects (realizations) halls using radiant ceiling panels.
- Optimization of design proposals with regard to the issue of the dew point => suitable choice of of temperature supply and return water.
- Optimization of design proposals with regard to hydraulic arrangement panels/strips => suitable choice of the involvement.
- Creating a new type of panel that will forcibly blowing and will have a ensure condensate drain, used for all applications (ensure thermal comfort).

4. Existing halls - mapping

Analysis of projects (realizations) halls using radiant ceiling panels (strips) for heating in Czech Republic, Germany, Slovakia and other countries in the Central European zone. It analyzed about 80 projects, from which have been obtained the value for further calculations. Heat losses from these realizations are 150-250W/m^2 or 20-30W/m^3 and more recurring size is 18x48x18m. Can say that in most cases they are applications where it will be heated storage spaces or shipping warehouses. Minimum number of applications has substantial internal heat load => can eliminate internal heat gains from the technology. Evaluation in terms of thermal and construction properties, various orientation and glazing is very varied. Analysis projects serve to correct election boundary conditions.

5. Calculations - preconditions

The use of halls is very varied, from the storage area to production halls. For further calculations are solved only storage spaces or shipping warehouses. Size is 18x48x18m. Calculation was considered for glazing individual structures (walls, roof) from 0% to 5% of the total area of the structure (in accordance with the requirement of natural lighting). Source of heat and cold is reversible heat pump air/water, it means use of only one source.

Hall is reflected as a single space without walls by extension, other areas with different temperatures. For further calculations determines the temperature in storage spaces to 20°C because into this temperature is stored most foods, everything is seen from the next table. Draft of temperature and relative humidity (selection) for food storage is in accordance with Czech legislation (Vyhláška č. 110/97 Sb.).

Table 1. *Information about storage temperature of individual goods*

foods	storage temperature [°C]	relative humidity [%]	dew point temperature [°C]
vegetable fats and oils	to +20	80	16.42
mustard	from +1 to 20	80	16.42
bread and pastries	to + 35	80	31.01
sugar	to +30	70	23.9
chocolate	to + 25	70	19.11

The calculation was performed for the above model hall with recommended values (ČSN 73 0540-2:2011) of heat transfer coefficients by individual constructions. For glass is a value $U=1.2W/m^2K$ for the walls is $U=0.2W/m^2K$ roof has $U=0.16W/m^2K$ and the floor has $U=0.3W/m^2K$.

6. Heat loss – ČSN EN 12 831

The calculation was performed for the above model hall with recommended values of heat transfer coefficients individual constructions. Outside design temperature is selected to -15°C and the internal is 20°C in the winter.

6.1. Heat loss – transmission

The calculation was included linear thermal bridges and penetration into the soil by detailed method. Heat loss by transmission is from 16.9 to 20.9 kW.

6.2. Heat loss – ventilation

For calculating, I will consider a higher value of heat loss by infiltration and heat loss of the ventilation air.

6.2.1. Infiltration

Infiltration through the cladding to get to the heat loss of 19.4kW, shading factor e=0.02.

6.2.2. Ventilation air

I am considering air exchange rate $n=1h^{-1}$ for forced ventilation with heat recovery efficiency of 75%. Forced air exchange is considering to the entire volume of the hall. Total heat loss of the ventilation air is 20.5kW.

6.3. Total heat loss

Total heat loss is composed of the heat loss by ventilation and transmission.
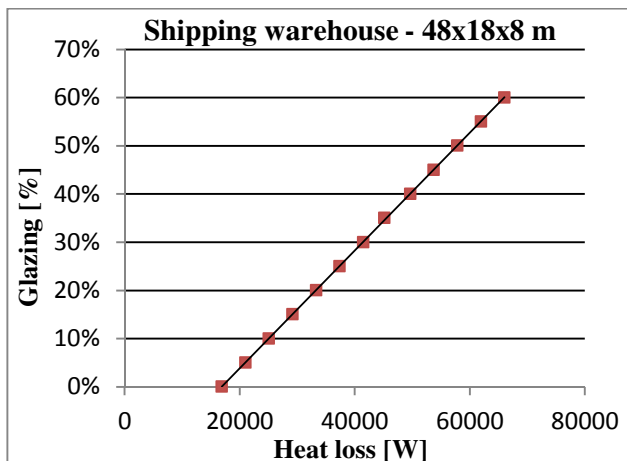

Fig. 6. *Total heat loss for shipping warehouse*

7. Heat load – ČSN 730548

The calculation was performed for the above model hall with recommended values of heat transfer coefficients individual constructions. Outside design temperature is selected to 32°C and the internal is 20°C in the summer. Relative humidity in hall is maximal 70%.

7.1. External heat load

Solar constant was considered $I_o=1350W/m^2$, the contamination factor =0.5 and the construction was chosen as moderate. Operating hours of the device was elected on the 24. Calculation was carried out for spans from May to September. Thermal load by the ventilation air is not solved. Orientation on different sides of the world is very important for the calculation because of heat gains through windows. From the calculations was found optimal position, the orientation of the side 48m to the east and west. On this site is the minimum external thermal load. The following graph plots orientation of east and west.

Fig. 7. *External heat load for shipping warehouse*

7.2. Internal heat load

Internal heat gains are considered only from light ($15W/m^2$). Total internal heat gains are 13kW for lighting all over the hall, with a minimal amount of natural light.

7.3. Total heat load

Total heat load is composed of the heat load internal and external.

8. Parameters - recommendations

Temperature parameters in heating and cooling mode are determined with respect to the selected reversible heat pump air/water.

8.1. Only for heating

The selections of parameters for heating are based on the calculated heat loss. For the calculation is considering heat recovery, and therefore neglecting the ventilation heat loss. Everything is done for two conditions (0% and 5% glazing).

8.1.1. 1st status

Designing of radiant strips were performed using the calculation program of the company Kotrbatý for heat loss (transmission) a value of 16.9kW (0% glazing). Radiant strips will be 4 thanks to the recommendations set out in section 2.1.3., where it is recommended to keep the distance between passports h/2. When the suspension height 7m and is based on four passports. Panels are connected in series, the total flow rate flows through every pipe - the so called wiring "Snake". Strips are 44 m long. The width of the strip is 450mm. Temperature gradient is 50/40°C.

8.1.2. 2nd status

Design of radiant strips is the same, the only change is in heat loss (20.9kW for 5% glazing) and the width of the panel for the second status it is 600mm.

8.2. Primary for heating using for cooling

The selection of parameters for cooling based on the calculated heat load. When selecting a temperature gradient is necessary to take into account the dew point temperature. The relative humidity of the internal environment is taken 70%, at 20°C => tr = 14.33°C, for calculating I choose 15°C. For the realization of cooling using radiant panels will be placed in the room air humidity sensor which will appropriately adjust the supply water temperature in the room with a safety margin from 0.5 to 1°C. Temperature gradient is 15/20°C.

8.2.1. 1st status

Radiant strips were performed using graphs from Kotrbatý heat load 19.6kW, number of panel and length are based on the design for heating. With panels designed primarily for heating, remove the maximum thermal load on value 2.2kW, which amounts to only 11% of the total heat load, t_i is 29°C. 2nd status I will not mention. We need a larger number of panels or other temperature gradient. Because we are limited by the dew point, we can only change the number, length and width panels. Here we are limited by the dimensions of the hall.

8.3. Only for cooling

Everything is done for one conditions 0% glazing. For cooling, we need the largest possible number of radiant panels because of the temperature gradient is 15/20°C

8.3.1. 1st status

Radiant strips were performed using graphs from Kotrbatý heat load 19.6kW. Radiant strips will be 6. Panels are connected in series, the total flow rate flows through every pipe. Strips are 46m long. The width of the strip is 1500mm. Temperature gradient is 15/20°C.

We will take the summer heat load on value 9.9kW, which is 50% of the total heat load (maximum quantity of panels), t_i is 25°C, the rest the heat load must be borne by another device. Another option is to invent a new construction of the panel.

8.4. Conclusion on the parameters

If we want to heat and cool by radiant panels, primarily we design the panels for cooling. How will it be involvement will be shown in the next chapter?

9. Hydraulic connection

At this moment it is apparent that to cover the heat loss will be needed the use of less panels/strips and for cooling will be necessary to add installed panels additional sections.
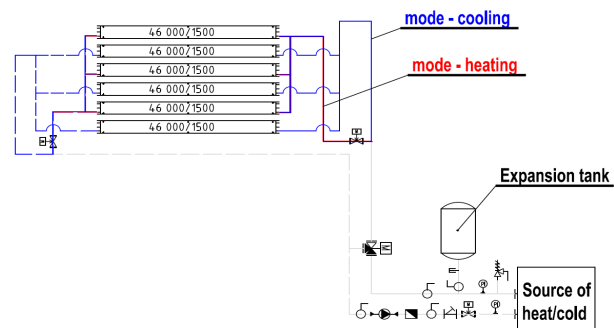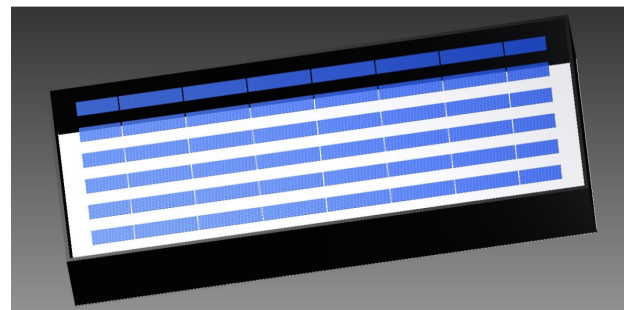

Fig. 8. Connection diagram

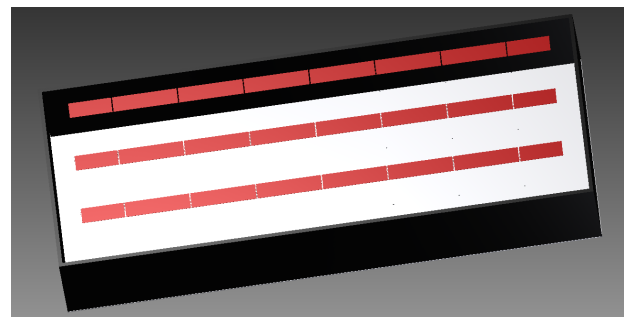*Fig. 9. Ground plan is switched on panels for cooling*

Fig. 10. Ground plan is switched on panels for heating

10. New construction of the panel

From the existing panels we are able to take away heat load around 50% of the total heat load. So there is possibility to choose the way of the new panel construction. New panel will be using forced convection

and will have a condensate drain. Therefore we will go below the dew point temperature. This panel will reduce energy costs for cooling. This new panel will be used for all applications (halls, building etc.) in cooling and heating mode. It will need monitoring of temperature and velocity fields by using simulation (CFD). Cooling capacity will be verified with the measured data. But what will be the price and traffic? It will be compared with other types of cooling halls.

11. Summary of the contribution

Calculations are solved only storage space or shipping warehouses with dimensions 18x48x8m. Glazing is from 0% to 5% for walls, roof from the total area the construction. Constructions have recommended values from the standards ČSN 73 0540-2:2011.

11.1. Optimal parameters of the hall

From the calculations was found optimal position, the orientation the longer side of the hall to the east and west. A small percentage of glazing, whether that enables hygienic standards, it depends on the use of the hall.

11.2. Parameters and proposing strips

Designing strips mainly for cooling with monitoring the dew point in space. Temperature gradient for cooling is 15/20°C, for heating is 50/40°C, with regard to the use of one cold/heat source (heat pump air/water). We will take the summer heat load with value 9.9 kW, which is 50% of the total heat load for glazing 0%. The rest the heat load must be borne by another device, but we will save another source of cold energy consumption by simply switching strips to cold water. Hydraulic connection is to sections for heating and cooling.

11.3. Make a new type of panel

From the new panel, we expect more cooling performance, at this moment it is only in the planning stage of development.

Thanks

I would like to thank Prof. Ing. Jiří Bašta, Ph.D. for patiently answering my questions and provided consulting hours.

List of symbols

e is shading factor (-);
h is height of hall (m);
n is air exchange rate (h^{-1});
t_i is interior temperature (°C);
I_o is solar constant (W/m²);
Q_S is radiation part of power (W);
Q_K is convection part of power (W);

U is heat transfer coefficient (W/m²K).

Literature

[1] Bašta, J., Hojer, O.: Sálavé a průmyslové vytápění pro IB. Praha 2009. 121 s.
[2] Hojer, O.: Disertační práce „Optimalizace radiační geometrie světlých zářičů". 2008.
[3] Hojer, O.: Sálavé a průmyslové vytápění – učební texty.
[4] Topenářská příručka. 2001, Praha: GAS. 2 500. 80-86176-82-7

Used standards:
ČSN 73 0540-2:2007 Tepelná ochrana budov – Část 2: Požadavky
ČSN 73 0540-2:2011 Tepelná ochrana budov – Část 2: Požadavky
ČSN 73 0542 Tepelně technické vlastnosti stavebních konstrukcí a budov
ČSN 73 0548 Výpočet tepelné zátěže klimatizovaných prostor
ČSN EN 12 831 Výpočet tepelného výkonu

Czech legislation:
Vyhláška č.110/97 Sb.

Company data:
Kotrbatý D.I.Z., s.r.o., Praha 10, www.kotrbaty.cz