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Using large radiant panels for indoor climate conditioning

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Abstract

Large panels are used to control the indoor temperature, by cooling as well as by heating, in several types of buildings. The panels are made out of two corrugated stainless steel foils, seam welded on the perimeter and spot welded at many places on the area. Water at controlled temperature circulates in this cushion. These panels are either installed as conditioning ceilings or on walls. In well-insulated buildings, the power required to control indoor temperature is rather low, and a small temperature difference between the panel and the indoor environment suffice to deliver or absorb the required heat. The paper presents the panel itself and its use in residential and non-residential buildings, as well as some industrial and research implementations.

Keywords: Heating; Cooling; Radiation

1. Introduction

At a given volume flow rate, water is about 4000 times more efficient for heat transport than air. Therefore, water-heating systems are very common in Europe, and hydronic cooling systems progressively replace air conditioning.

In hydronic climate conditioning systems, heat exchangers are used to transmit the heat from water to indoor environment, or vice versa. This occurs partly by radiation to (or from) neighbouring surfaces, partly by convection to (or from) indoor air. Depending on the dominant process, these heat exchangers are called either radiators or convectors.

Most cooling ceiling panels are usually built from elements, which consist of a plate to which a water-cooled tube is attached. This configuration adds a thermal resistance between the tube and the plate surface, thus limiting the heat transfer from the water to the environment.

This paper presents a type of flat plate radiator avoiding this inconvenience, and which is used for both cooling and heating.

2. The radiant panels

The panels are made out of 0.6-mm thick, 860 mm wide, stainless steel sheet (AISI 304). The panel is similar to a thin cushion, where the water is in direct contact with more than 98% of the area. There are two standard lengths: 1520 and 2360 mm. Other lengths and even widths are available on request.

The foil is first stamped in a press especially developed for that purpose (Fig. 1), to obtain regularly spaced square bumps, about 2 mm deep. Front and back sheet have different patterns, to obtain the water flow paths shown on Fig. 2. Two or four 3/8″ connecting pipes are press welded at the corners of the back sheet.

Front and back sheets are then spot welded between each bump to obtain the resistance to pressure, and seam-welded on the periphery to ensure water tightness (Fig. 3). Each panel is tested for leaks and pressure resistance in a water bath at 6 bar air pressure. Service pressure is given at 3.5 bar.

The original surface has a glossy metallic aspect. It is not convenient for radiant heating and cooling, since polished stainless steel has a low emissivity (< 10%). For conditioning purposes, the panel is custom coated with a transparent, white, or colour paint.

These panels, electroplated with black chrome selective layer, are also used as flat plate hot water solar collectors. They are either installed naked, as roofing, for low temper-

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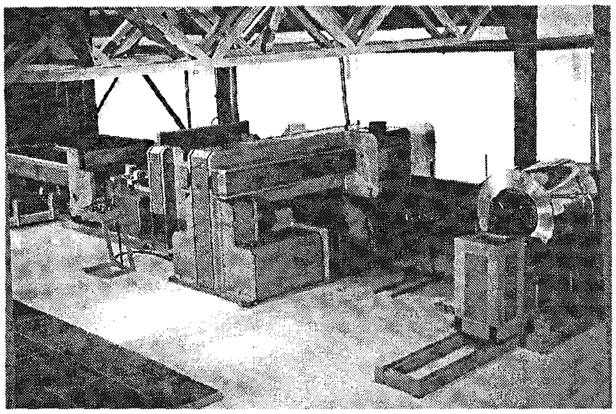

Fig. 1. Stamping press. On the right, the coil of stainless steel sheet.

ature applications, or packed in an insulating box with a glass cover for higher temperature requirements.

3. Performances

3.1. Hydraulic properties

The structure of the panel results in very good heat transfer efficiency between the water and the panel sur-

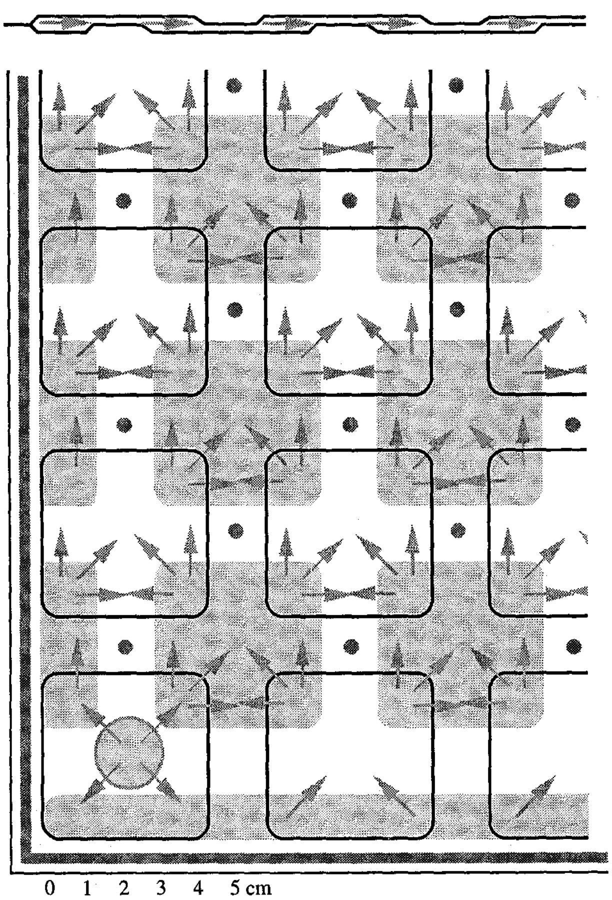

Fig. 2. Structure of the panel and water circulation, plan view of one corner. Grey squares are on the back sheet, dark grey line and dots represent welded perimeter and spots.

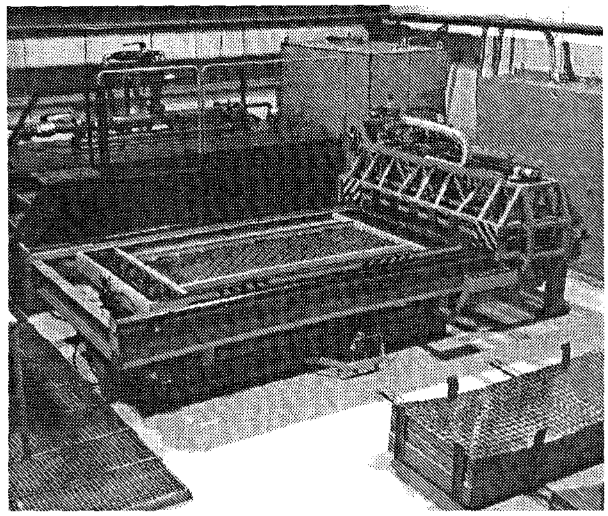

Fig. 3. Spot welding machine. The chariot on the right holds the low-voltage transformer and four electrodes. It moves automatically over the sheets hold in the frame.

face, which temperature is very close to that of the water. The required water flow rate depends directly on the heat flow rate, ϕ, and on the inlet–outlet temperature difference ΔT:

$$\dot{V} = \frac{\Phi}{\rho c \Delta T} \quad (1)$$

where ρ is the density of water and c its heat capacity. Typical water flow rate is 50 $1/(\text{h m}^2)$. This corresponds to a temperature difference of less than 2 K at 100 W/m^2 heat flow rate. Lower water flow rates may be used, but the water distribution becomes less homogeneous below 20 $1/(\text{h m}^2)$, and dead zones may appear in corners distant from connecting pipes.

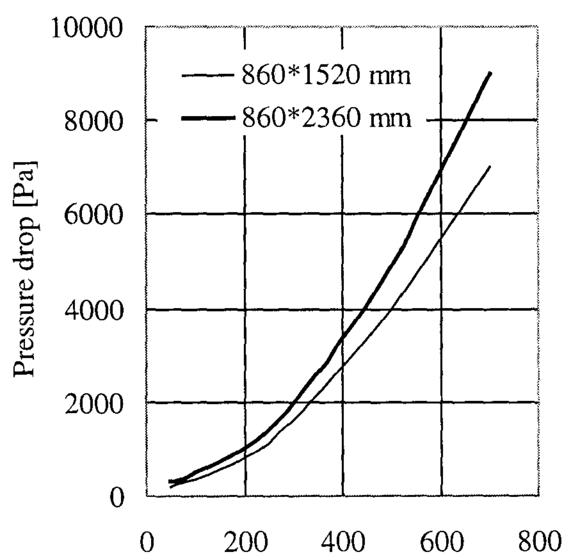

Fig. 4. Pressure drop in standard radiant panels. The two curves correspond to the two panel dimensions given in the legend (width * length).

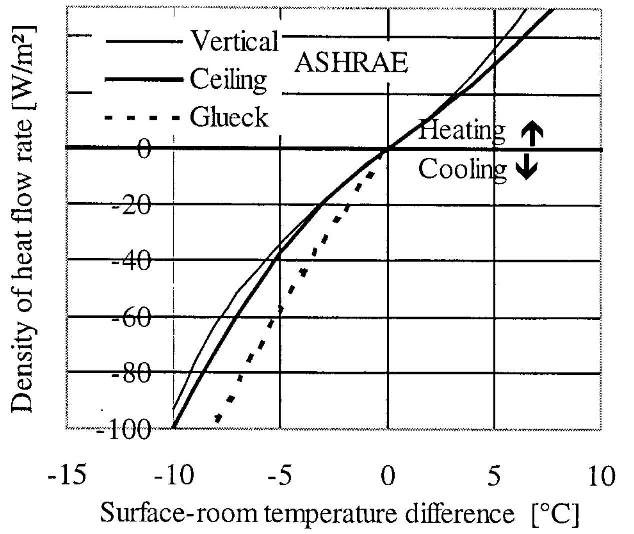

Fig. 5. Density of heat flow rate of flat plates at 20°C ambient temperature, according to ASHRAE [1] and Glueck [2].

The pressure drop for the two standard panels is given on Fig. 4. For a 2 m^2 panel, it is 300 Pa at 50 l/h, and 500 Pa at 100 l/h. This low pressure drop allows for mounting up to five panels together in series.

3.2. Surface heat transfer coefficient

This coefficient depends on the position of the panel (horizontal or vertical), on the direction of heat flow, and on temperature difference between the panel surface and the environment. Since the panel behaves like a thermally homogeneous plane, usual formulas to compute the heat transfer coefficient of plane plates can be used (see for example, Ref. [1]).

These formulas however take only one side of the plate into account, and are based on measurements made on relatively small plates. Other empirical relationship, measured on real cooling ceilings, give larger heat flow rate [2]. This results from exchanges on the side of the panel facing the ceiling, which may cool the room if the air contained between the panels and the ceilings is mixed with the air in the room.

Fig. 5 shows the density of heat flow rate versus surface temperatures in an environment at 20°C. Curves according to [1] are given for wall and ceiling panels, and for heating and cooling. In addition, Glueck's curve is given for cooling ceilings. The actual heat flow rate for side-by-side panels will be closer to ASHRAE values, while Glueck's values are probably more accurate for cooling fins, profiles, ducts or separated panels.

4. Domain of application

Any system has its limitations. Those for radiant heating and cooling are not harder than for other systems, but they should be known to avoid troubles.

4.1. Cooling

In many applications, condensation on the panels limits the temperature difference between room air and panel surface, thus limiting the cooling power. In continental climates however, the design dew point temperature is often far below the design dry bulb temperature, and clearly below the summer comfort temperature [3]. In Switzerland for example, cooling systems are designed assuming 100 W/m^2 cooling power, that is about 10 K temperature difference between dry bulb temperature and dew point.

In some cases however, this is not a limiting factor or even an advantage. Cooling panels were installed in wine and cheese cellars, where condensation on the panels simply drops on the gravel floor. The relative humidity is then kept at the high level required in such cellars.

On the other hand, hydronic cooling is an efficient way to transport heat where large airflow rates are not required for indoor air quality. Fitzner [4] attributes particular domains to cooling systems in the two-dimensional space internal heat load–airflow rate (Fig. 6). This shows that there is a domain where cooling ceilings only can be applied.

For example, in clean office buildings, 7 m^3/(h m^2 floor area) should suffice to provide excellent indoor air quality [5]. Such an airflow rate cannot transport more heat than 12 W/m^2 floor area, if an air temperature increase as high as 10 K is accepted. If more heat is needed for heating or cooling, the energy should be transported by means of water rather than by increasing the airflow rate artificially.

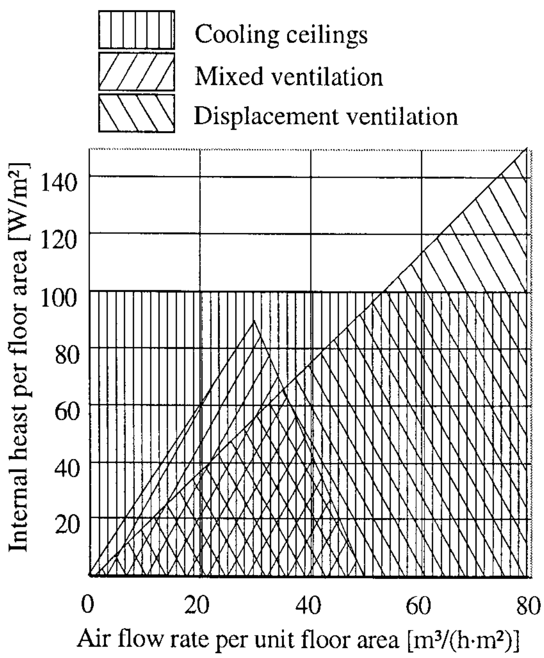

Fig. 6. Utilisation domains of various cooling systems (from Fitzner [4]).

4.2. Interaction between cooling ceilings and other systems

Passive ventilation cooling [6] is a strategy consisting first in avoiding heat sources as much as possible. Then, by using large openings, ventilation is strongly increased, when external temperature is lower than internal temperature; and maintained at a minimum otherwise. This cools down the building structure, which, when massive enough, takes a long time to be reheated during the warm period. Cooling ceilings are compatible with passive cooling, as long as the panels do not insulate the massive ceilings from the indoor air. Radiant panels can assist passive cooling and absorb peak cooling loads.

Cooling ceiling panels may disturb the buoyant piston flow expected in displacement ventilation systems [7], and induces a partial mixing. From this point of view, continuous ceilings, made of joint panels, disturbs the flow pattern less than discontinuous cooling ceilings, where panels or pipes are separated by an air gap.

4.3. Heating

Temperature as high as 90°C can be used in radiators installed on walls, and radiant panels may in principle be used instead of conventional water heaters. Radiant panels are however intended to heat with low temperature sources, such as heat pumps or active solar systems. Therefore, temperature in vertical panels is often lower than 50°C.

A lower limit appears when ceiling is used for heating. As shown by Fanger et al. [8], the radiant temperature asymmetry resulting from heated ceiling should not exceed 4 K to limit the percentage of dissatisfied to 5% (besides the usual 5% in ideal comfort conditions), or 6 K for 10% dissatisfied.

Let us take for example a very unfavourable case, which is the infinitely broad and long room. In such a room, the radiant temperature asymmetry equals the difference between ceiling and floor temperatures.

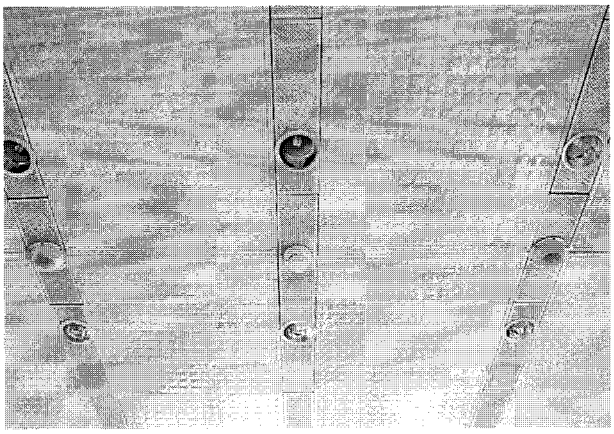

Fig. 7. Example of combination of radiant panels with acoustic tiles, lighting and smoke detectors.

Table 1
Panel area delivered by a factory among main types an use

Type and use	Area [m^2]
Cooling office buildings	3515
Heating and cooling office buildings	1992
Thermal comfort in a hotel	74
Thermal comfort in dwellings	20
Cheese cellar conditioning	82
Mushroom cellar conditioning	104
Cooling of electronic microscope	50
Face plate temperature control	15
Workshop and office cooling	74
Workshop heating and cooling	1850

To limit the number of dissatisfied at a reasonable value, Fig. 5 shows that, at 5 K above ambient temperature, the panel cannot deliver more than 30 W/m^2. Note that the panel temperature could be higher and its areal heating power larger if the ceiling were only partly covered.

However, this limited power is large enough to heat any enclosure designed and built according to energy saving regulations. Applying heating ceiling to poorly insulated buildings will however certainly result in great thermal discomfort.

4.4. Acoustics

Radiant metallic panels reflect sound waves: sound absorption of a panel is 6% on the average, and less than 10% at any audible frequency. Therefore, care should be taken to manage other absorbing areas in the room in order to maintain the reverberation time between comfortable limits. Combination of radiant panels, acoustic tiles, lighting devices, and other devices such as loudspeakers and fire safety systems can easily be arranged (Fig. 7).

5. Examples of uses

Radiant panels may be installed in various types of buildings. Table 1 and Fig. 8 show the distribution of panel area delivered by a factory among main uses.

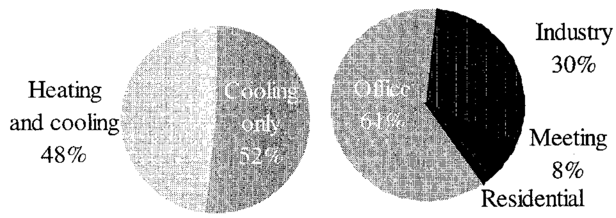

Fig. 8. Uses of radiant panels. Percentages are related to surface area of panels.

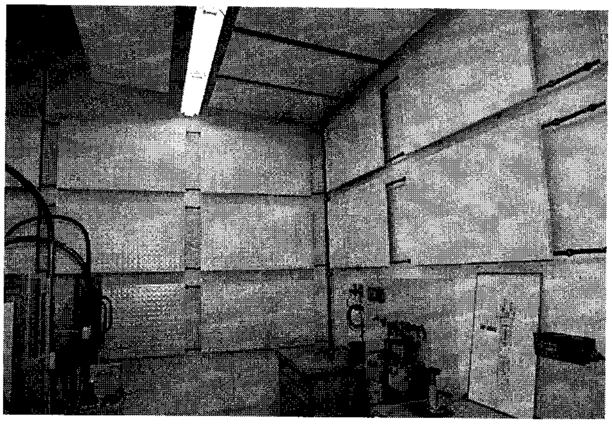

Fig. 9. Cooling high resolution electronic microscopes.

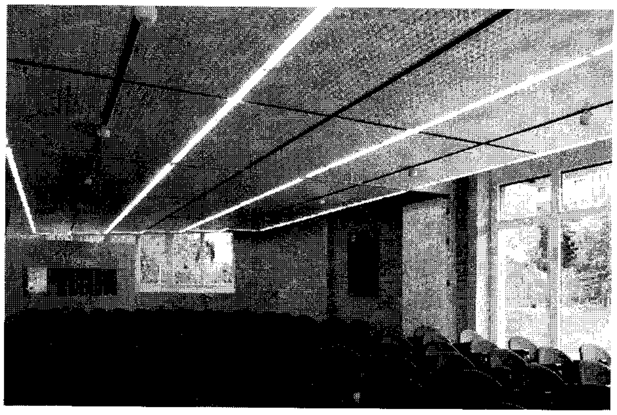

Fig. 11. Heating and cooling ceiling in a meeting room.

5.1. *Office rooms*

Cooling ceilings in offices is a common use of radiant panels. Most of installed panel area is used for this purpose. Some offices are also heated by the ceiling. In this case, controlling the temperature of the water circulating in the ceiling ensures the thermal comfort. The heat source and sink is in many cases a reversible heat pump. However, natural gas, oil, or solar energy (with seasonal storage) is also used for heating, and ground or surface water provides cooling in several cases.

5.2. *Workshops, laboratories, and industry*

A building for arts and crafts is equipped with 450 m^2 ceiling panels, used for heating and cooling. This building hosts, among others, a printing company, a graphic designer and a broadcasting studio.

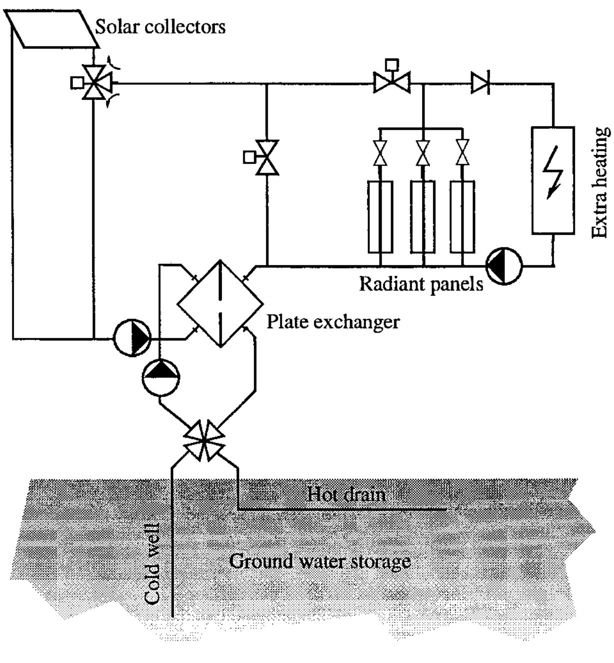

Fig. 10. Schematics of the solar heating and storage cooling system.

High-resolution electronic microscopes require an environment without vibrations, and a high temperature stability, but release several kilowatts of heat into the room. To provide cooling, air conditioning with expensive noise absorbers was installed in an electronic microscopy room at the EPFL. However, it was found impossible to decrease the vibrations generated by air conditioning below an acceptable level (35 dB without filter). Therefore, the system was replaced by radiative panels, which maintain the room temperature at 23 ± 1°C without any trouble (Fig. 9).

Interesting is the system built at the panel factory itself (Fig. 10). The roof of the building is covered with solar panels, that is the same panels coated with selective black chrome layer. These solar collectors are linked, through heat exchangers, on one hand to ground water seasonal heat storage located under the building, and on the other hand to radiant panels on the wall of the office room.

In summertime, water heated by the sun is injected at the top of the ground storage at about 40°C, while cold water, at 10 to 15°C is extracted from the bottom. This cold water is used to cool the radiant panels.

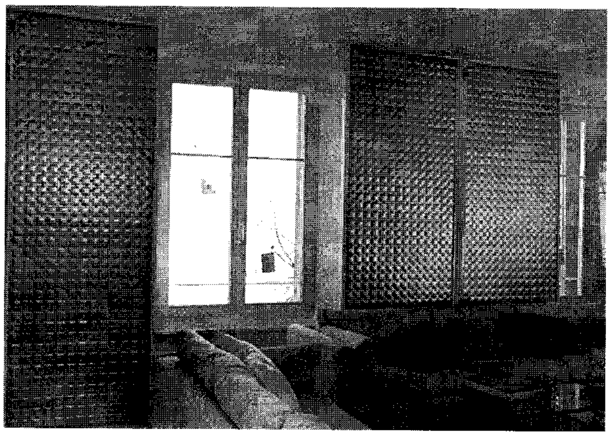

Fig. 12. Heating and cooling panels in a living room.

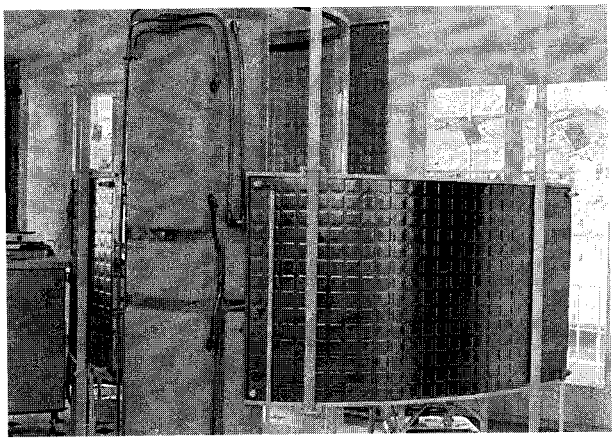

Fig. 13. A curved panel around the shower protects surroundings against splash and provides soft heat.

In winter, the warm water from heat storage heats radiant panels, as long as there is some useful stored heat. An extra heater provides the complement when required. When the storage temperature is below 15°C, the remaining heat is sent to the roof collectors, providing an active thermal insulation.

Other special industrial applications include accurate temperature control of a faceplate in a micro-mechanics workshop, and the already mentioned wine or cheese cellar cooling.

5.3. Meeting rooms

Radiant panels react very fast to changes in heat load. They are therefore well suited to rooms with intermittent occupancy (Fig. 11).

5.4. Residential applications

The home of an architect is equipped with radiant panels, heated at low temperature by a heat pump taking heat in a neighbouring spring, or cooled directly by the water of the spring. In this case, panels are mounted vertically on the walls (Fig. 12). An interesting feature is the shower, which is installed in a larger room, and surrounded by a curved panel (Fig. 13).

6. Conclusions

Radiant ceilings are mostly used for cooling. However, they are also used to fully control the indoor temperature, that is to heat and cool, in various types of buildings. On the other hand, wall radiators are mostly used for heating, but can be and are also used for cooling. In some cases, when severe criteria for vibrations, noise, and temperature stability should be fulfilled, radiant panels are also the most efficient and cheapest way to control the temperature.

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