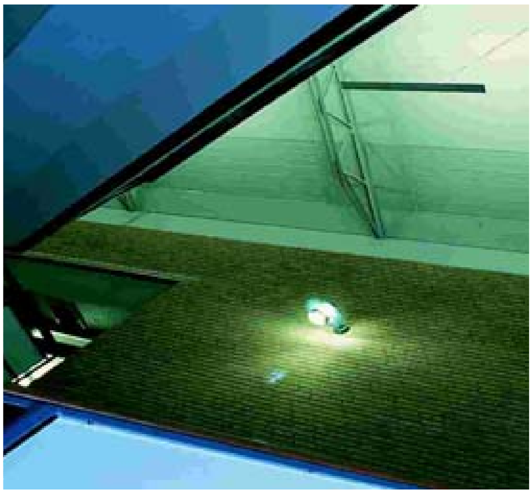
the future of space conditioning

Ceiling heating guide

questions & answers



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FRENGER systems

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Introduction

At Frenger Systems we are frequently asked not only about our own products, but also about ceiling heating as a system and heating principles. Unfortunately, ceiling heating is sometimes misconceived as a heating form. On the contrary it is a very good form of heating; too good to be left to its own destiny.

We have produced this Guide to provide our customers and other interested parties with more information about ceiling heating. We hope that it will be useful to both project managers and purchasers, who can find information quickly as well as to the ambitious designer who wishes to learn more about the subject.

In the Guide, which is based on a large number of Swedish and International references, the experience and measurements of purchasers and consultants as well as our own calculations and measurements, we will show that:

- Ceiling heating heats the room's surfaces via radiant heating. In turn, the surfaces heat the air.
- Due to this fact, ceiling heating gives a very good thermal indoor climate.
- With ceiling heating it is not too cold under the table, to hot on the head, or draughty from windows, which many believe.
- Ceiling heating functions in virtually all types of buildings, from large warehouses to small daycare centres.
- The ceiling heating system can be easily modified when the activities in the building change, you do not need to think about the heating system if you change the walls or floor.
- Ceiling heating can be combined with any type of ventilation system.
- Ceiling heating is one of the most economical heating systems seen from an energy point of view.
- Ceiling heating has a low investment cost compared with other systems. Combined with low energy consumption it is an economic system, both in the short and long term.
- Frenger Systems ceiling heaters are 100% recyclable. Together with low energy consumption it is good for coming generations.

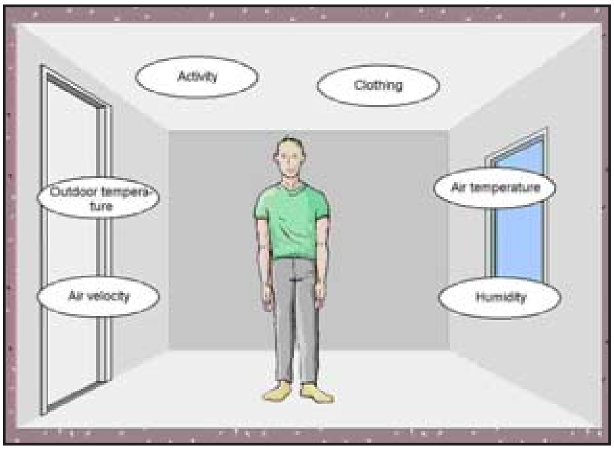
What other heating system has all these benefits?

The Ceiling Heating Guide is divided into three sections:

- The first, Questions and Answers, gives a brief and sometimes simplified answers to well defined questions for those who do not wish to delve too deep.
- The second, in-depth, gives as the name implies a little more to chew on. Knowledge corresponding to a HVAC engineer is required at times here.
- The third, Dimensioning key, provides a quick and easy tool for those planning a ceiling heating system.

What affects the thermal climate experience?

How we experience the thermal indoor climate depends primarily on our overall heat exchange with the surroundings. Heat exchange is affected by physical activity, our clothing and the ambient thermal climate in the room. The thermal climate can be described through the air's temperature velocity and humidity and heat radiation exchange with the surrounding surfaces.

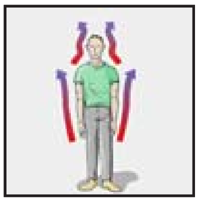


Factors that affect the thermal climate in the room

Heat transfer

Heat can be transferred in four different ways: radiation, conduction, convection and phase transformation. Heat radiation is, for example, what you feel from the sun or from a hot plate. Heat transfer through conduction is experienced when you walk b are foot on a cold stone floor. Convection is felt when you walk without a hat on a windy winter's day. Finally, you feel phase transformation when moisture evaporates for the body, ie. passes from a fluid stage to the gas phase and the skin is chilled.

However, heat is also ways transferred when there is a temperature difference between two bodies. A human body, for example, radiates heat continually to its surroundings. A hand or a face (approx. +33^{O}C) continuously gives off heat through radiation to the walls and furnishings (approx. +22^{O}C) without you directly feeling it. Heat is also given off through convection against the skin, when air is heated close to the body and n rises.



Heat is always given off by the body.

Thermal Comfort

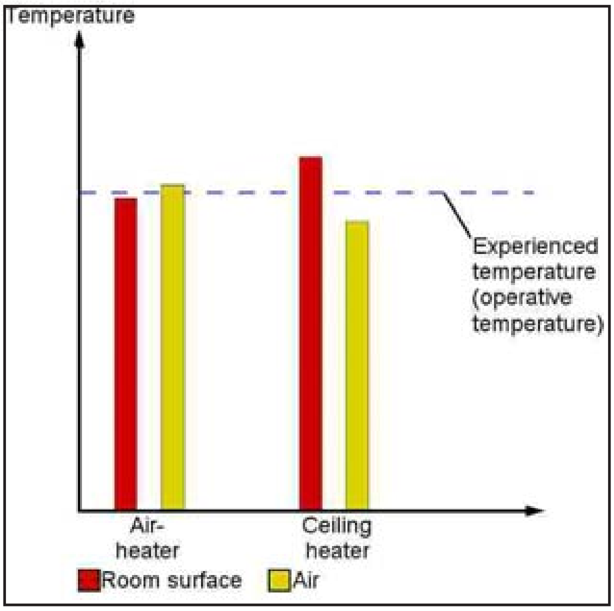
Thermal comfort means that a person feels and finds themselves in a thermal balance, ie. they are neither too hot not too cold. In addition, thermal comfort presupposes that there does not occur unwanted heating or cooling of individual body parts, for example, draughts in the neck or a floor that is too warm.

A person's heat balance and a feeling of comfort is primarily affected indoors by:

- convection directly to the surrounding air via the skin and lungs.
- radiation exchange with surrounding surfaces.

These two methods of transferring heat are approximately equal with normal air movement in a room. Therefore, we are affected just as much by the room's surface temperatures as the air temperature.

If the temperature of the room's surface is increased, fully or in part, the air temperature can be lowered by an amount corresponding to the increase in the room surface's mean temperature. If, for example, we heat a room with a ceiling heater we gain an increase in the mean temperature of the room's surfaces. People then give off less heat through radiation to their surroundings. To avoid being too hot, the body can compensate through increased convective heat transfer to colder room air. This is the background as to why it is possible to have a lower air temperature with radiant heating, compared with conventional heating, at



Ceiling heating gives warm room surfaces and therefore allows a lower air temperature

Section 2

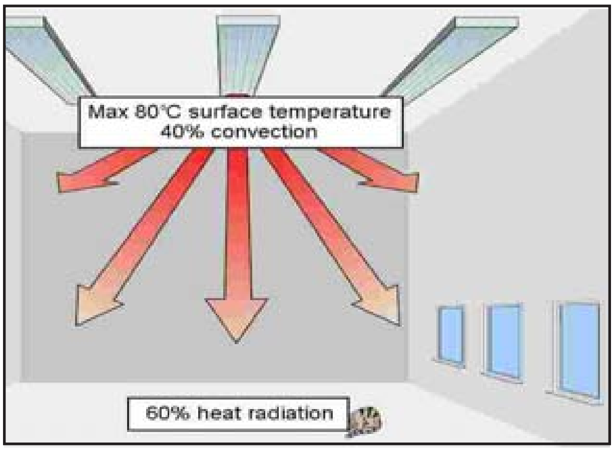
How does ceiling heating work?

Hot air rises, so why put the "element" in the ceiling? This is the normal reaction from people that are uncertain about ceiling heating. In this section we will try to explain how ceiling heating works and why it becomes warm in the entire room and not only the ceiling.

The heating system gives off heat to the surroundings through a mixture of convection and heat radiation. Convection heats up the air in the vicinity of a heater while heat radiation is distributed in all directions in the room. The convectively heated air rises in the room while the heat rays "travel" straight out from the heater until they meet the surrounding surfaces.

The ceiling heating system is based on a high share of heat radiation and a low share of convection. Typical values are approx. 60% radiation and approx. 40% convection. Frenger System's ceiling heating system is waterborne and based on heat radiation at low temperatures (30-80ºC). This means that you do not experience the heat radiation as intensively as from, eg. the sun or an electric infra-heater. The share of convection for a ceiling heating system (approx. 40%) corresponds approximately to the share of heat losses through the building' climate shell such as those made up by roofs heat losses. Accordingly, the other parts of the building directly benefit from the remainder of energy from a ceiling heater, ie. the radiation share.

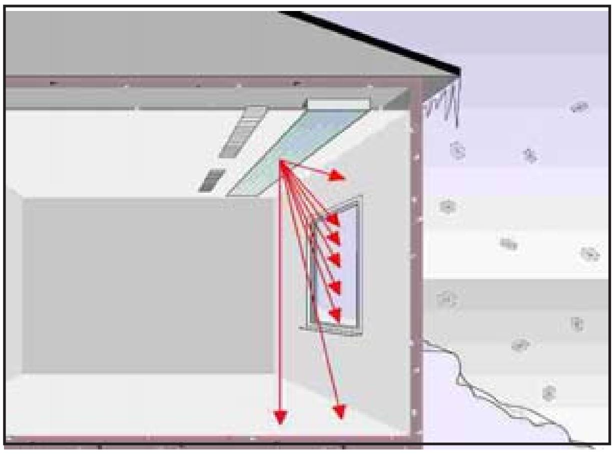
You can compare heat radiation with a normal light. It is distributed and reflected in much the same way. Thus, heat is radiated from the ceiling heater towards all the surfaces it can "see". This also means that surfaces shaded from the heat rays will be heated as a part of the heat rays, just as with visible light, will be reflected towards all surfaces and partly through a radiation exchange between room surfaces that have different temperatures. Therefore the temperature differences in the room and on different surfaces will continuously attempt to even out themselves. This results in the room having a very even temperature spread between the ceiling and the floor.

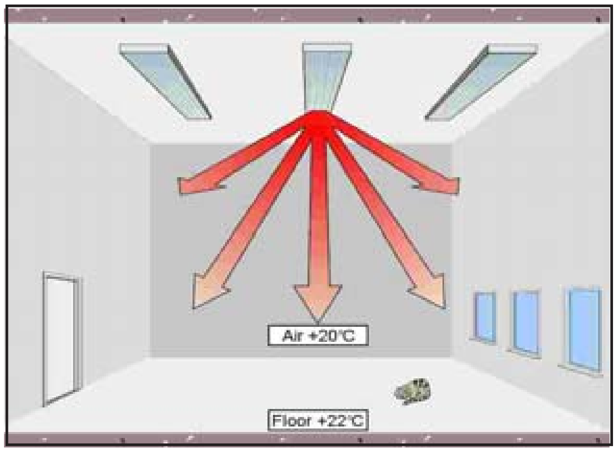


Share of radiation and convection for Frenger System's ceiling heater.

The surfaces to which the radiant heat is transferred will be heated to a temperature greater than if you had used conventional heating. Normally, inner walls for example, would have a surface temperature just above the room's air temperature. An advantage of radiant heat from the ceiling very rarely considered is the fact it heats the floor! The floor temperature is usually approx. 2-3oC above the room temperature at ankle height. It is not difficult to have satisfied tenants with ceiling heating installed. Accordingly, the heat that the ceiling heater produces, and which a person experiences, comes primarily from the indirect heat from surrounding surfaces. Only a very small part comes directly from the ceiling heater panel. The experience of the thermal climate is due to the human body losing less heat to the surroundings when the surfaces are warmer. Thus, it is not sufficient with just the air around being warm! Also see section 1.

A big advantage with radiant heat is that the colder a surrounding surface is the more heat energy it will "attract" to itself. This means that radiant heat will automatically divide itself so that colder surfaces, eg. windows or badly insulated wall sections, will receive a greater share of the heat, ie. heat comes where it is best needed.





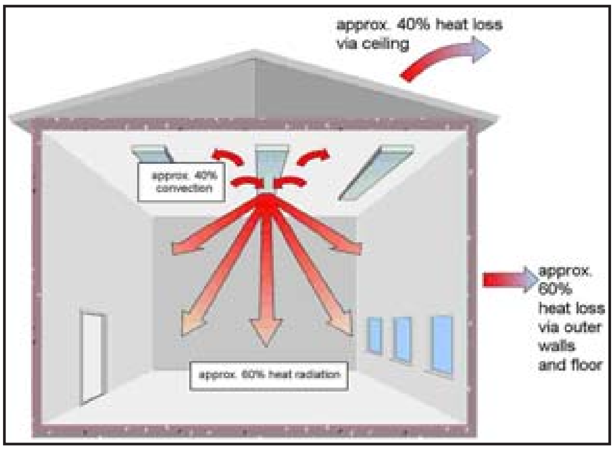
Section 3

When can you use ceiling heating?

Ceiling heating has a very broad application area, broader than most other forms of heating. Generally, you can say that ceiling heating can be used to heat all types of buildings. Ceiling heating is used in a wide variety of buildings such as sports halls, workshops, industrial buildings, warehouses and shopping centres. Ceiling heating also gives excellent results in buildings such as daycare centres, nursing homes, homes, schools and laboratories. A ceiling heaters output is approximately 40% convective (heat the ceiling) and approximately 60% radiant (heat downwards). A building normally shows the same division of heat losses through the walls, ceiling and floor ie. approximately 40% heat is lost through the ceiling and 60% is lost through the remainder of the building. This shows that ceiling heating is, combined with its other advantages, ideal for heating virtually all types of buildings. Homes are an area where ceiling heating is rarely installed. A major reason for this is probably that home heating is based on strong traditions. However, it has been shown in investigations that ceiling heating panels, In a trial, ceiling heating panels were fitted directly above the window in a bedroom. Outdoor air was taken in via a grille in the outer wall and was preheated between the ceiling and the ceiling panel. In summary it was established that:

- Supply air was heated in average to 15.5oC with an outdoor temperature of –2oC.
- The operative temperature was on average approx. 1.1°C higher that for a corresponding reference room with panel radiators.

No draught could be established (the window was heated by the ceiling heater, see section 9).



Share of heat production from the ceiling heater and from a building

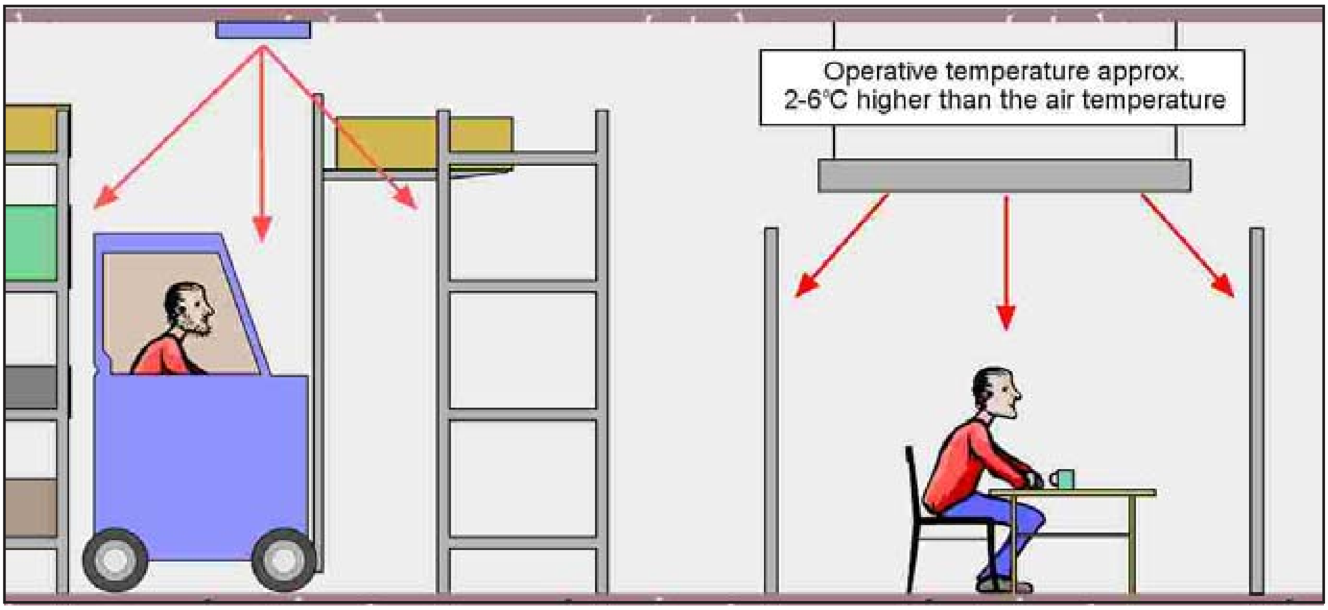
Ceiling heating works just as well in buildings where people sit with concentrated work as in buildings where people stand up or move about. The ceiling height has practically no importance either upwards or downwards to give a warm climate in the occupied zone (also see sections 5 and 7).

Zone heating

Ceiling heating also provides excellent results if only a part of the room need to be heated, ie. zone heating. It can, for example, be a permanent work place in a building where activities demand a low temperature. Radiant heat can then contribute to increase the experienced temperature (operative temperature) by locally increasing the temperature degree, the air temperature, and in this way create a more tolerable working environment.

Other advantages of ceiling heating:

A big advantage of ceiling heating is that the heaters are "out-of-the-way". The placement of furnishings, machines or other equipment do not usually need to be taken into consideration and the ceiling heating panels take upon space one the walls or floor.
Ceiling heating panels and heating strips are also easy to move if the building should be used for other activities or if the walls are moved. In schools and public buildings for example the heaters are not accessible for interference. (In depth study see chapters III and chapter VI).



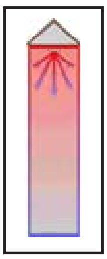
Zone heating gives a higher operative temperature in part of building

Section 4

When is ceiling heating not suitable?

There are not many situations where ceiling heating does not work, but every technique has its limitations. The following example can show the ceiling heatings limitations:
Ceiling heating works no better than other heating systems in preventing air loss with an open door. The floor, walls and any furnishings next to the door are heated, but ceiling heating does not prevent air loss through an open door. However, ceiling heating contributes towards creating the best possible thermal climate in the zone around the door by keeping the

Ceiling heating also gives inferior results in a high tower, eg. a lighthouse, as very little of the radiant heat reaches the floor and occupied zone. However, not due to the long distance to the floor, but due to the relatively small area of the total area "seen" by the ceiling heater. A large part of the heat radiation will be taken up by the walls.



Ceiling heating gives poorer results in high, narrow areas.

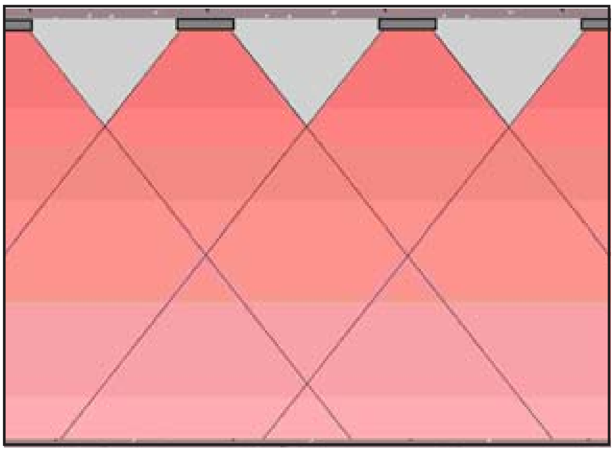
Questions and Answers

Section 5

At what height should ceiling heaters be installed?

As long as the air in the building is normally clean there are no limitations, other that the building itself, at what height the ceiling panels can be installed. The radiant height is not obstructed by the air and is distributed towards the floor, walls and furnishings irrespective of the installation height and the surface temperature of the ceiling heaters. However, there is a limitation downwards for how low the ceiling heaters can be installed. The greatest factor for the ceiling heater's lowest installation height is the surface temperature of the ceiling heaters, followed by factors such as the length and width ratio and whether the people in the room are sitting or standing. The hotter the surfaces the greater the heaters installation height so that the building's occupants do not feel uncomfortable. The limitations for the lowest installation height are however modest, see section 7.

An example can be shown here:
A ceiling heating panel, 3.6 x 0.6m and a maximum surface temperature of 50°C (55/45°C system) can be installed as low as 2.1m(!). If the surface temperature is increased to 70°C (80/60°C system) the lowest installation height is then 2.8m. It is important in connection to this to point out that w are speaking about dimensioned water temperatures that, statistically, only occur on a few days per year. During the greater part of the year the heating temperature in the system is lower. (In depth study see chapters II and IV)



Ceiling heights do not matter, all radiant height reaches the walls and floor. It is only the intensity that diminishes with height.

Section 6

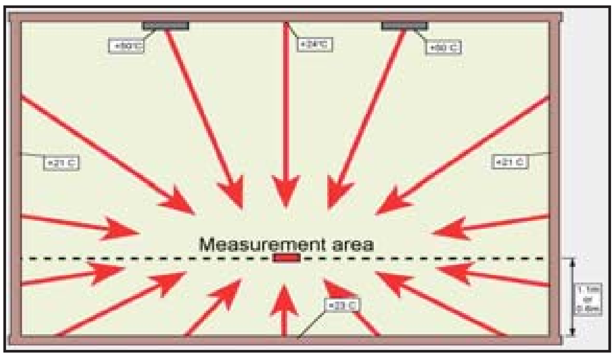
Does ceiling heating affect the ventilation?

Ceiling heating in itself does not cause air movement that can affect any form of ventilation. This means that it is perfect in buildings where there are high demands over the control of the air flow in the building. This means you have a free hand to choose the type of ventilation system in combination with ceiling heating when planning new development or the renovation of buildings and rooms. (In depth studies see chapter V).

Section 7

Will it be hot on the head?

The radiant temperature asymmetry (RTA) is an expression used to define low large temperature differences on different surround surfaces a person can accept without experiencing discomfort. RTA is noticed if, for example, you turn one side of your face towards a fire and the other towards a cold window. RTA is measured over a small plane at either a height of 0.6m, which corresponds to a sitting person or 1.1m, which corresponds to a standing person. RTA is the difference between heat radiation on each side of the measurement plane.
As previously mentioned in section 2, heat radiation from the ceiling heater heats the surrounding surfaces especially the floor. This means that RTA will be balanced out. An important factor for RTA to lie in acceptable limits is, however, that the ceiling heater is dimensioned correctly bearing in mind these maximum temperatures. If this condition is met, RTA will ie within the limits for a comfortable



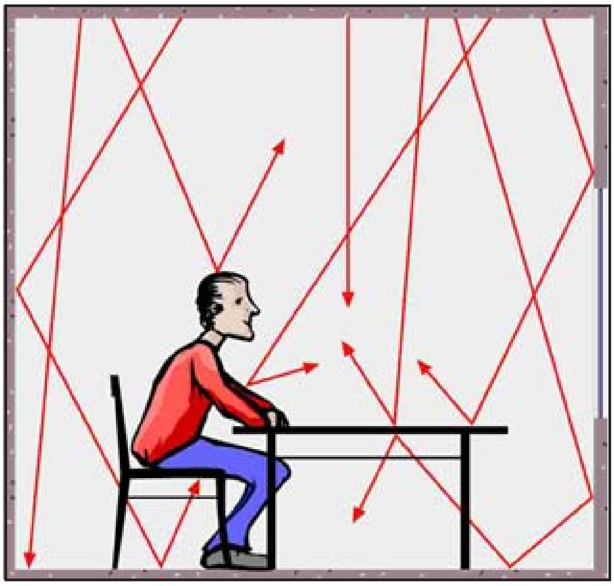
Example of how radiant temperature asymmetry (RTA) is measured. RTA is the difference between the heat radiation on each side of the measured surface. The temperatures are only stated as an example.

An example:
A ceiling heater panel 3.6 x 0.6m and maximum outdoor temperatures of 50°C (55/45°C system) can be installed as low as 2.1m from the floor(!) calculated for a person sitting (measurement plane 0.6m above the floor according to ISO7730). Consequently it will not be on the head! (In depth studies see chapters I and IV)

Section 8

Will it be cold under the table?

It is a widespread misconception that it will be cold under the table and any other horizontal surfaces when using ceiling heating as the heating system. The chances of it being cold under a table are the same as it being dark under a table when the light is on.
Heat radiation, as light rays from the ceiling, spreads to surrounding areas. These areas absorb most of the heat energy, but also reflect a small part. This part of the heat radiation "bounces" around to all the room's different surfaces and heats surrounding surfaces including the floor under the table. Even the top and under sides of the table will be warm through direct and indirect heat radiation. This means the difference in air temperature or radiant temperature is extremely small under the table compared with next to the table. (In depth study see chapter II)

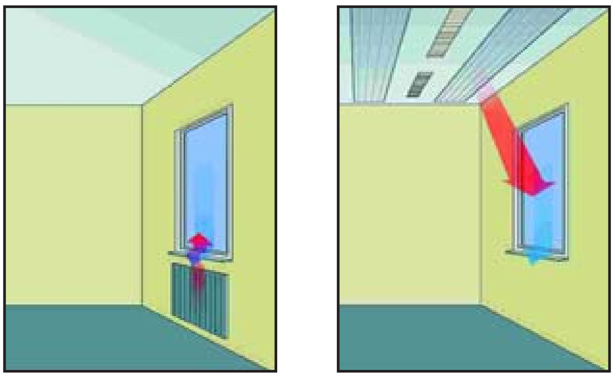


Heat radiation is partly reflected and equalises the difference in temperature.

Section 9

Will there be draughts by the window?

With double or triple glazing there can be a risk of draughts (ie. air movement caused by air being chilled against a cold surface) if there is no form of heat source by the window that counteracts the downward air flow. However, the heat source does not need to be located under the window. A radiator under a window results in warm upward air movement that should counteract the draught from the window. On the other hand, ceiling heating prevents draughts at source, ie. the window's cold surface. The ceiling heaters namely heat the window's surface so the risk of draught is minimized. Accordingly, the ceiling heating through heat radiation will directly heat the cold surfaces. As mentioned in section 2, heat radiation is distributed to the room's surfaces in proportion to its surface temperature. More heating output goes to colder surfaces. Heat radiation from the ceiling will therefore partly heat the window and window frame and partly heat the window sill. In this way the draughts will be eliminated directly at "source" partly due to the warm window surface and partly due to the heating effect of the window frame and window sill. Those at the greatest risk from draughts are persons with sedentary work, dressed in light indoor clothing and with their work places close to outer windows and without a heat source to counteract draughts. With standing work and work demanding movement away from an outer window the risk is nonexistent especially in newer buildings with triple glazing. (In depth study see chapter II)

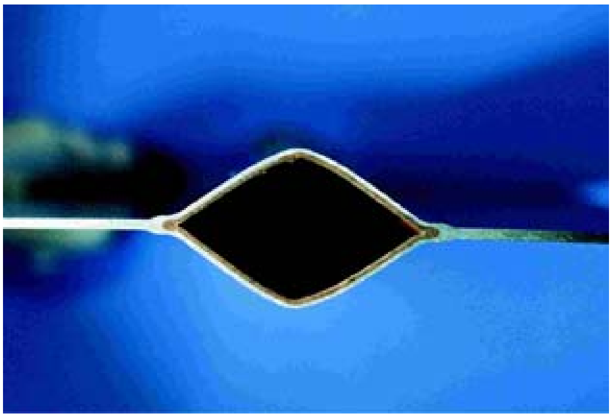


The ceiling heater prevents draughts by heating the window surface.

Section 10

How long will Frenger Systems' ceiling heaters last?

Frenger Systems' base element, our world patent, is used in heating and cooling systems as well as in solar collectors throughout the world, where temperature are up to 250oC. At the National Swedish Institute for Materials Testing they have had surfaces over 200oC and then shock tested these with 10 degree water. They have also had components outdoors, to then take then in after several years and test them again. They have also pressure tested components at a pressure of 10-11 bar – 16000 times! None of these test have effected the quality or performance of the product. We do not know of a product on the market tested so comprehensively as those from Frenger Systems. We therefore dare to say that Frenger Systems' ceiling heater can function as long as the building it is installed in. (In-



The water channel from Frenger Systems' ceiling heater in cross-section

Section 11

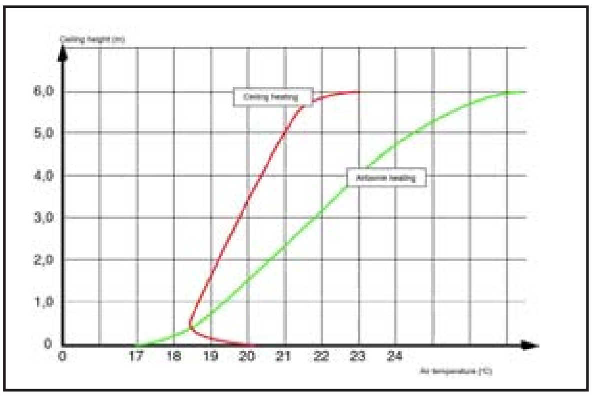
Can a ceiling heating installation be changed with changed activities?

Today it is common for a building and its insides to undergo immense changes during its service life. If is therefore essential that both the walls and installations can be changed and moved without too much expense. In this respect ceiling heating offers large advantages. The pipe system is often routed visibly or in a suspended ceiling, which is easy to dismantle, making it simple to demolish or rebuild. If the ceiling heaters are installed in a suspended cassette ceiling, they can easily change places with the cassette in other places. If they use drop rods they can also be easily dismantled and moved to another position. You can also find benefits here with just Frenger Systems' ceiling products. They have the markets lowest weight, especially at high ceiling heights, are extremely easy. Property owners/managers are not tied to e special type of tenant. They can change between a manufacturing industry, dance study or warehouse. They do not need to take the heating system into consideration when removing the floor or walls.

Section 12

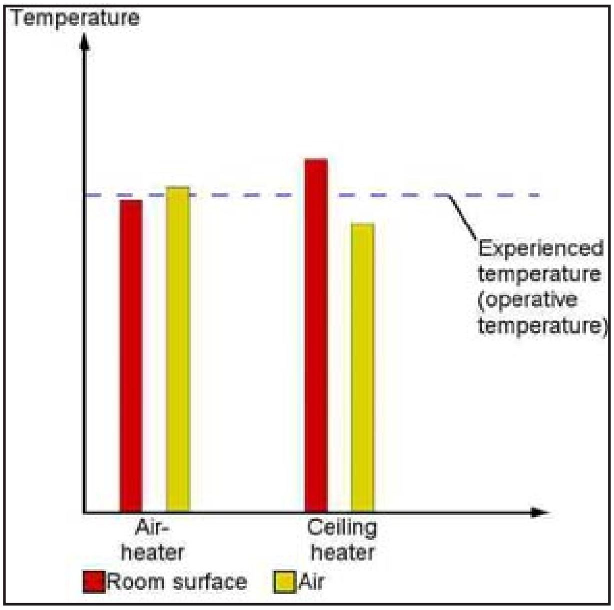
What output should be installed?

When calculating the design heating output requirement, the buildings different elements are calculated first with regard to the area and total heat transfer coefficient (U-value). This is calculated as standard in accordance with applicable building regulations and Swedish standard. In addition, the indoor temperature is determined and the design outdoor temperature, DOT. The latter is normally calculated according to Swedish standard. Therefore a calculation of the design heating output for the building can be made. However, during calculations you should consider that there is a temperature difference between the ceiling and floor (temperature gradient). The temperature gradient can also give large differences in the temperature between the walls and floor and ceiling with high ceiling heights. One of the advantages of ceiling heating is that the temperature gradient, relative to other heating systems, is small, approx. 0.5oC/m. This condition gives small differences in temperature between the ceiling and floor. Heating with, e.g. a hot ai fan gives a temperature gradient of approx. 2oC/m. Of course, a small temperature



Example of the temperature distribution in air in a building with different heating systems

In addition to the low temperature gradient, you also normally count on approx. one to two degrees lower indoor temperature with new construction, due to the radiant supplement from surrounding surfaces (see sections 1 and 2), and thereby lower the installed heating output. However, with rebuilding and renovation a more accurate analysis should be made to see weather the building's standard after the work and the activities in it permit calculating with a lower indoor temperature.



Ceiling heating gives warm room surfaces and therefore allows a lower air temperature, resulting in a lower heating output requirement

An example can explain the difference in output requirement due to a lower indoor temperature and less temperature gradient; assume a newly built hall of 1000m^2 with a ceiling height of 5m and normal wall, ceiling and floor constructions. The window area is equal to 10% of the floor area. The requisite heating effect for transmission and unintentional ventilation will be for two different heating systems as follows heating output for ventilation not included):

Heating system	Temp.in occup. zone/gradient	Heat output
Hot air fan (aerotemper)	20 °C/ 2 °C/m	71.3 kW
Ceiling heating	18 °C/ 0.5 °C/m	58.5 kW

Thus, the ceiling heating system requires in this example only 82% of the heating output compared to a system with hot air fans. It should be stressed that the difference should be less in buildings with lower ceiling heights. (In-depth study see chapter VII).

Section 13

Does the ceiling heating system save energy?

In most cases you can answer yes to this question when making comparisons with other conventional heating systems. The ceiling heating saves energy depends partly on the ability to maintain a lower air temperature in the occupied zone (approx. 1-2°C) without the experienced (operative) temperature being lowered and partly as the difference between the ceiling and floor temperature (temperature gradient) being less (see sections 1 and 12). The latter results in a smaller hot air cushion on the ceiling, which could give large heat losses through the roof. How large the energy saving will be depends on the type of property and any previous heating system. For buildings with a ceiling height between 2-3 metres you can count on a saving of between 2-7%. For buildings with higher ceiling heights the energy savings can be even greater, especially if the building is old, leaks or has large doors or openings that give a large proportion of air leakage (unintentional ventilation). Savings up to 30% have been documented in Swedish and overseas research reports. (In depth study see chapter VII.)

Section 14

What does it cost?

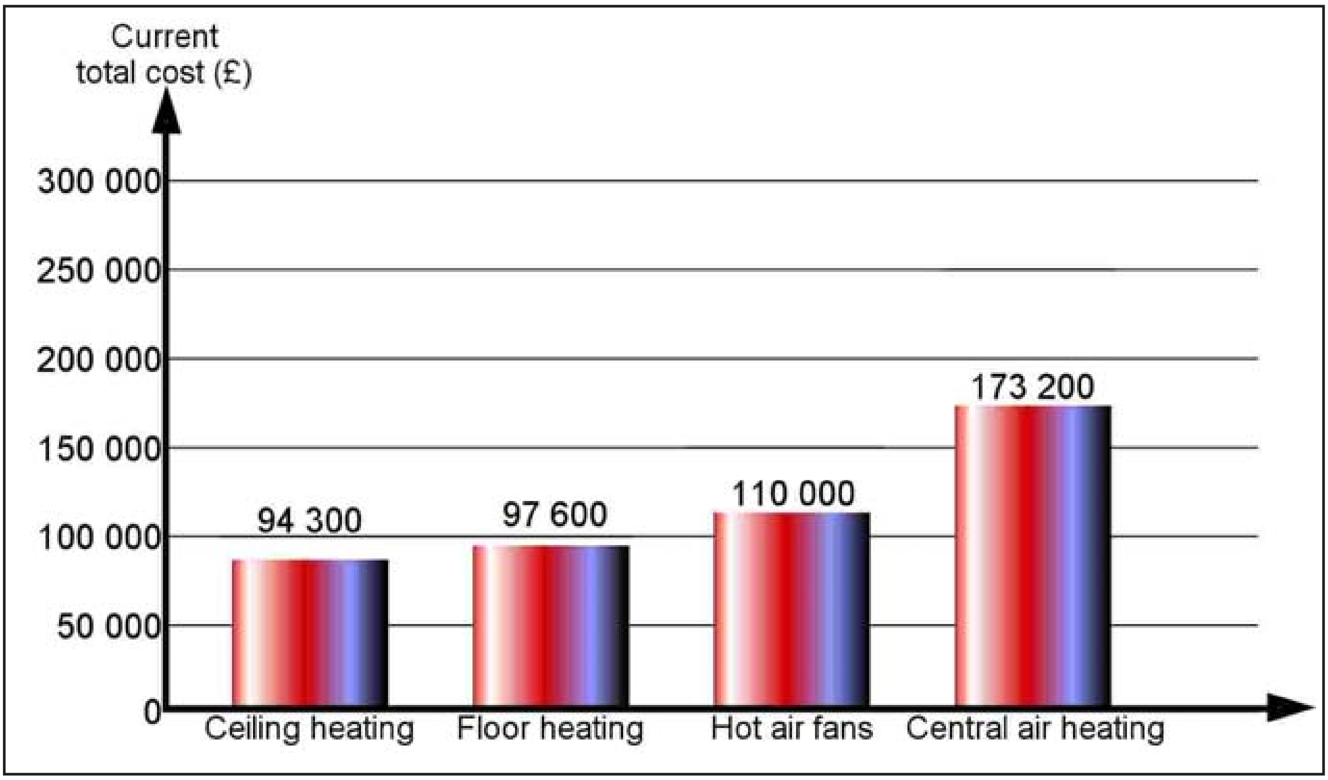
The answer to this question is different depending on the time perspective you assume and the costs to be included. We have chosen a long term perspective, in this case 15 years, when the overall picture of costs I most cases is more interesting for the manager or property owner. If you only look at the investment costs then ceiling heating is second cheapest in the example. The example shows the calculated overall costs for four heating systems. The four systems are ceiling heating, floor heating, hot air fans (aerotemper) and air heating. the conditions for the calculation are also documented and are based on an assumed newly constructed industrial hall, 60 x 40m with a ceiling height of 8m, located in Gothenburg, Sweden. It Is assumed that the hall is connected to Gothenburg's district heating system. The investment costs for the different heating systems including ceiling heating system have been calculated by an independent firm of consultants.

Annual operating and maintenance costs (O&M) are calculated as a percentage of the investment including electricity, maintenance and repair costs. For ceiling and floor heating it is assumed to be 0.5% and for hot air fan and air heating to be 2% of the investment cost. Energy consumption for the different heating systems, which includes the heating energy requirement for transmission and unintentional ventilation, has been calculated using the conditions set out below. The energy requirement for ventilation is not included as it is assumed to be the equal for each heating system. The overall cost for respective systems includes the investment cost, operating and maintenance costs and energy costs. The overall cost is documented partly as a present value and partly as annuity.

Common conditions:	
Calculation Interest:	10%
Economic service life:	15 years
Energy price:	£20/MWh
Energy price increase:	2% per annum

Heating system	Investment (£)	O&M (£/year)	Energy consump. (MWh/year)	Overall costs Present (£)	Overall costs Annuity (£/year)
Ceiling heating	37,300	186	386	94,300	12,400
Floor heating	42,000	210	375	97,600	12,800
Hot air fan	34,500	690	488	110,000	14,500
Central air heating	96,500	1,929	431	173,200	22,800

Costs for different heating systems. Investment costs have been calculated by an independent firm of consultants



Present value of overall cost for four different heating systems.

Calculation conditions:

U-value	roof:	0.2 W/m^2, °C
	walls:	0.2 W/m^2, °C
	floor inner zone:	0.3 W/m^2, °C
	floor outer zone:	0.3 W/m^2, °C
	windows:	2.0 W/m^2, °C
Area	roof:	2400 m^2
	walls:	1400 m^2
	floor inner zone	1000 m^2
	floor outer zone:	200 m^2
	windows:	200 m^2

Ceiling height: 8m

	Ceiling heating	Floor heating	Hot air fan	Air heating
Indoor temp. occupied zone (°C)	19[1)]	19[1)]	20	20
Temperature gradient (°C/m^2)	0.7	0.5	2.0	1.0[3)]

Other conditions:

1) Ceiling heating and floor heating require a lower air temperature, 19°C, to maintain a determined operative temperature, which in this case is assumed to be 20°C.
2) The stated temperature gradiant applies with the design outdoor temperature. With other outdoor temperatures it is assumed to drop linear to be zero when there is no heat requirement.
3) Temperature gradient the air heating applies when tropic fans are installed.

Section 15

Can Frenger Systems' products be recycled?

Life cycle assessment (LCA) that have been performed for aluminium products show many common features. The material's manufacturing stage (mining, enrichment and production) receive a relatively high input loading factor for energy and the environment. In the product utilization stage a reversed situation is obtained compared with other materials. The load that aluminium products give during the production stage is compensated many times over by the low environmental impact in the utilization stage. In addition, if aluminium is recycled even more the environmental impact from the manufacturing stage will decrease by an equivalent degree. Frenger Systems' ceiling heating system consists solely of copper, aluminium, a sheet of expanded polystyrene insulation and a small amount of lead solder. All component materials excluding the insulation are 100% recyclable. All production waste already goes for recycling.

All metal components can be recycled to 100% when demolishing a building where Frenger Systems' ceiling heating products have been installed. Aluminium and copper are of course metallically bonded in the manufacturing process and cannot be separated, but recycling is still possible. The ceiling heaters are pressed in a package of approx. 20 x 20cm and are used within the metal industry as alloy additives in different qualities of aluminium. In each package the share of copper is well defined as each centimetre of panel contains a equal percentage of copper. (In depth study see chapter VIII.)

Chapter I

How people experience the thermal

Heat exchange

A person's heat exchange with his surroundings depends on activity, amount of clothing and how much heat is transferred to the surroundings via primarily convection and radiation. Some heat is given off in the form of latent heat as water vapour. Normally this heat is not supplied to the room, but is given off outdoors through condensation.

Activity

Metabolic activity determines how much heat is produced by the body and is expressed in the unit met (1 met=58W/m^2). Man's degree of activity varies usually between 0.8 met (sleeping) to 7 met (hard physical work). Common values with normal office activity is between 1.1-2.2 met. How high metabolism a person has with a given task is also determined by individual factors such as age, weight, sex, health, etc.

Amount of clothing

The amount of clothing is a measure of heat insulation of the human body and is expressed in the unit clo (1 clo = 0.155^{o}C m^2/W). This varies between 0 clo when naked and approx. 3 clo under thick bedding. Normal indoor clothing lies somewhere within the interval 0.7 to 1.2 clo.

A person's heat exchange

A person's heat exchange normally takes place through convection and radiation. These are basically similar to small air movement. When air flows past the skin at a speed greater than approx. 0.1 m/s the convective heat transfer gradually increases. If the person becomes too hot and starts to perspirea significant part of the heat is given off through moisture evaporating from the body (phase transformation). With thermal comfort the production of perspiration is extremely small and the moisture which nevertheless evaporates from the skin is counted with the convective heat given off. The air humidity affects the amount of moisture that evaporates from the skin and mucous membranes.

Convection

The convection that a person is exposed to consists partly of convection by gravitation, which occurs due to people heating the air next to the body, which then rises and causes air movement, and partly forced convection, which is external air movement from, eg. ventilation or draughts. The limit for unpleasant air velocity varies primarily with surrounding temperatures and therefore the normal limit indoors is 0.15m/s in winter and 0.2-0.4m/s during the summer [8], see page 4:35. The higher value during the summer is due to the room temperature being frequently higher so the limit for unpleasant air velocity is increased.

Radiation

Radiation takes place as a net exchange between two bodies/surfaces and in most cases goes from a person to colder surroundings. The size of heat transfer via radiation depends on the person's activity, amount of clothing and the ambient temperature.

Temperature

When it concerns the temperature of the air and surrounding surfaces there are a number of different temperatures defined to describe the effects on people. The most common are presented below. In addition to the air temperature there are:

Vertical temperature gradient (^{o}C/m): a measurement of how much the air temperature changes at different heights above the floor. Normally defined as the temperature difference between heights of 0.1m and 1.1m. The temperature gradient should be less then 2-3^{o}C/m to avoid discomfort. The low value is used when it's a question of sedentary work. However, it should be pointed out that a temperature gradient of 2-3^{o}C brings about a significant layering of the air and consequently large energy losses at ceiling level. The temperature gradient for Frenger Systems' ceiling heater is normally approx. 0.4-0.5^{o}C/m, which results in energy losses at ceiling level dropping significantly. Also see chapter VII.

Plane radiation temperature (^{o}C): is used to determine the radiation exchange for a plane surface (skin section) that faces a specific direction. Radiation exchange is dependent on the surface temperature and the angle factor from respective sub-surfaces that can be "seen" by the plane surface. The plane radiation temperature is calculated by means of the measured surface temperatures and the angle factors or measured with a radiation temperature meter.

Radiation temperature asymmetry (°C): Radiation temperature asymmetry (RTA) is defined as the difference in plane radiation temperature on each side of a small flat surface. RTA is measured in a place 0.6m above floor with sitting activities or 1.1m above the floor with standing activities. RTA should be a maximum of 5°C in cases where the heat radiation comes from the ceiling. Also see chapter VI.

Mean radiation temperature (°C): is a measurement to determine the body's total radiation exchange with the surrounding surfaces. The mean radiation temperature refers to the average value of the radiation exchange in all directions.

Operative temperature (°C): describes the combined effect of the air temperature and the mean radiation temperature on a person's heat balance. Frequently the operative temperature is assumed to be the average value of the air temperature and the mean radiation temperature.

Directed operative temperature (°C): expression in Swedish building regulations used to describe the heat exchange for a small section of skin. Defined for a specific measurement point and direction in the room as the average temperature of the air temperature and the plane radiation temperature.

Equivalent temperature (°C): is a measurement to describe the combined effect of the air temperature, radiation temperature and the air velocity on a person's heat balance. The relation is also affected by the person's activity and clothing.

Thermal comfort

The indoor climate conditions that give thermal comfort differ from individual to individual. Trials, performed by Professor P O Fanger [21], where large groups of people were exposed to different climatical effects, show that the majority of people react to the indoor climate in a similar way. The trials resulted in criteria for thermal comfort based on climate conditions where a majority of the large group of people considered the climate to be neutral. the degree of thermal comfort can be calculated using a PMV-index (Predicted Mean Vote) with the above mentioned climate factors. The value defines a statistically based prediction of how a large group of people would rate the degree of comfort for a specific climate with given activity and clothing. Based on the PMV index you can then calculate a PPD-index (Predicted Percentage of Dissatisfied), which defines how many of a large group of people find a specific indoor climate uncomfortable.

$$\mathbf{PMV = (0.303 * e^{-0.0036M} + 0.028) [(M+W) - 3.05 * 10^3 \{5733 - 6.99(M-W) - p_a\} - 0.42\{(M-W) - 58.15\} - 1.7 * 10^{-5} * M(5867-p_a) - 0.0014 M (34 - t_a) - 3.96 * 10^{-8} f_{cl}\{t_{cl} + 273)^4 - (tr + 273)^4\} - f_{cl}h_c(t_{cl}-t_a)}$$

where:

$$\mathbf{t_{cl} = 35.7 - 0.028(M-W) - 0.155I_{cl}[3.96 * 10^{-8} f_{cl}\{(t_{cl} + 273)^4 - (tr + 273)^4\} - f_{cl}h_c(t_{cl} - t_a)]}$$

$$h_c = \begin{cases} 2.38(t_{cl} - t_a)0.25 & \text{for } 2.38(t_{cl} - t_a)^{0.25} > 12.1(v_r)^{0.5} \\ 12.1(v_r)^{0.5} & \text{for } 2.38(t_{cl} - t_a)^{0.25} < 12.1(v_r)^{0.5} \end{cases}$$

$$f_{cl} = \begin{cases} 1.00 + 0.2I_{cl} & \text{for } I_{cl} < 0.5 \text{ clo} \\ 1.05 + 0.1Icl & \text{for } I_{cl} > 0.5 \text{ clo} \end{cases}$$

Key:

M = Metabolism (W)
W = External labour (W)
I_{cl} = Degree of clothing (clo)
pa = Water vapour's partial pressure (Pa)
f_{cl} = Clothing's surface factor, i.e. the relation between naked skin and clothed skin
t_{cl} = Clothing's surface temperature (oC)
h_c = Convective heat transmission rate (W/m2 oC)
t_r = Mean radiation temperature (oC)
t_a = Room air temperature (oC)
v_r = Relative air velocity (m/s) = v + 0.005(M-58)
v = Average velocity of the room air

When PMV- index is known, the PPD-index can be calculated:
$PPD=100-95*_e-(0.03553PMV4+0.02179PMV^2)$

This is how ceiling heating works

Frenger Systems' ceiling heating products utilize heat radiation as the primary method to transmit heat (approx. 60% of the total heat output). In this chapter we discuss the basics of heat radiation.

Heat radiation

Heat radiation is electromagnetic radiation, where the wave length lies at approx. 9-15mm with a surface temperature of 30-70^{o}C. The wave length becomes shorter the greater the temperature of a surface and longer the colder the surface. Heat radiation is invisible to the eye at these temperatures. It is only when the temperature approaches 600-800^{o}C that heat radiation becomes visible to the eye.

Heat radiation is transmitted from all bodies that are warmer than absolute zero (-273.16^{o}C). It is seldom that the absolute heat radiation of a body is of interest. On the other hand, the net exchange of the radiation energy between two bodies or surfaces is of interest in order to make technical calculations.

Heat transmission through radiation

Heat transmission (net exchange) with radiation depends on the temperature difference between surfaces, their geometrical relation and the character of the surfaces. The heat flow, Ps, between two surfaces is formulated in the following formula:

$$P_s \sigma = F_{12} A_1 (T_1^4 - T_2^4) \text{ (W)}$$

where $$F_{12} = \frac{1}{\frac{1}{f_{12}} + \frac{1}{\varepsilon_{12}} - 1 + \frac{A_1}{A_2}\frac{1}{\varepsilon_2} - 1}$$

Here F_{12} is a function of the geometrical relation between the surfaces A_1 and A_2 and is known as the angle factor. The angle factor can be calculated or read off from diagrams in heat transmission guides. It is always the projected area of a surface that is used when calculating the heat radiation. Accordingly, the net exchange of heat radiation does not increase from a folded or ribbed surface compared with a smooth surface.

s = 5.67*10^{-8}W/m^{2}K4
(Stefan-Boltzmann's constant)
e_1 = The heat radiating surface's emission factor
e_2 = The receiving surface's emission factor
A_1 = The heat radiating surface's projected area (m^2)
A_2 = The receiving surface's projected area (m^2)

T_1 = The heat radiating surface's temperature
(K = Kelvin which is T^{o}C +273)
T_2 = The receiving surface's temperature (K)

It is important to remember that the radiation exchange between two surfaces (eg. a ceiling heater and a floor) does not diminish over distance as long as the air that the radiation passes through is normally clean. This is due to the air's absorption of heat radiation is negligible, see below. However, the radiation intensity (output per surface unit) diminishes, and thereby the transmitted energy, to a given surface if the distance increases or the surface is tilted. This affects the angle factor, which is included in the factor F12 and depends on the distance and angle between surfaces and the size and temperature of the surfaces. A well-known example of variation in radiation intensity is solar radiation's intensity throughout the day and even throughout the year ie. to the earth and partly by the angle of the earth.

The surface with the lower temperature will be the recipient of the net exchange of heat radiation. In ceiling heating it is always the surrounding room surfaces that are the recipient of heat radiation. Subsequently, with radiant heating the surround surfaces that have a lower temperature than the radiation heater will absorb the heat radiation and thereby increase their temperature, normally a few degrees above the room's air temperature.

The air's significance

When heat radiation passes through the air virtually no radiation is absorbed at all. However, the gases carbon dioxide (CO_2) and water vapour (H_2O) absorb and emit heat radiation while elementary gases (gas where the atoms are of one kind) e.g. O_2, N_2 and H_2 are transparent to heat radiation. As the air is composed of different gases, where CO_2 (0.05 weight%) and H_2O (0.7 weight%) have very low concentrations and O_2 (21%) and N_2 (79%) have high concentrations, it can be regarded as completely transparent to heat radiation at normal air layer thickness (<20m). However, an abnormally high particle content in the air has less significance for the heat exchange between the ceiling heating and surrounding surfaces.

Emission factor

The emission factor, e, defines how much energy a surface radiates compared with a perfect radiant surface, aka a black body. The emission factor is equal to 1 for a black body and between 0 and 1 for all other material. The higher the emission factor the better the surface acts as a heat radiator and a heat recipient. The emission factors square to the surface for some materials at normal room temperature are shown below:

Aluminium, rolled bright:	0.04
Copper, polished:	0.03
Glass:	0.94
Wood (beech):	0.94
Brick, plaster:	0.93
Concrete:	0.88
White enamel:	0.95 (Frenger Systems heater)
Matt black enamel:	0.97

As can be seen from the table all surfaces except the metal surfaces are good heat radiators/heat recipients. The values show that a white enamelled surface is nearly as good as a matt black enamelled surface. It is for this reason, among others, why Frenger Systems ceiling heater panels are enamelled white on the underside but not on the top side. The top surface of the ceiling heater is normal oxidized aluminium which in itself has a higher emission factor than rolled bright aluminium but a great deal less than a white enamelled surface. In this way the radiant energy can be “guided” to the underside of the heater where it is best needed. To further guide the heat radiation downwards it is also insulated.

It is worth noting that glass has a relatively high emission factor, lying on a level with some common building and furnishing materials. With regard to glass, no low temperature radiation can pass through the glass, all such radiation is either absorbed (approx. 88%) or reflected (approx.12%). Solar radiation, with its significantly higher temperature and consequently shorter wave length, is however let through. This condition is the background to the expression “greenhouse” in just greenhouses and other buildings with large glassed areas.

Thermal comfort with heat radiation

People are, in relation to their surroundings, a warm body and therefore also radiate some heat excess to the surroundings. When the surrounding surfaces have a hotter temperature than normal, which is the case with radiant heating. The radiation from the body is less. In a building with radiant heating a person will experience the surroundings as warmer as its radiation to the surroundings is less than with conventional heating at the same air temperature. Due to this, it is possible to lower the air temperature with radiant heating yet still maintain

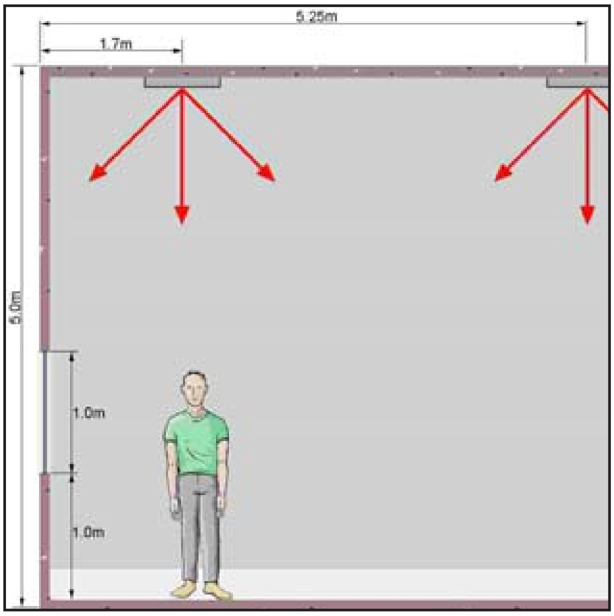
same air temperature. Due to this, it is possible to lower the air temperature with radiant heating yet still maintain the same operative temperature. In normal cases its possible to lower the air temperature by 1-2T [4] and still maintain the requisite operative temperature. Heat radiation in a room is either absorbed or reflected. With absorption of radiant heat the surface temperatures are increased. With normal furnishings and building materials the reflected proportion of the radiation is only approx. 5-10%, which means that most of the heat radiation is absorbed. This is the primary reason why the surface temperature of the underside of a table [1] is a few degrees above the air temperature. All surfaces, including all furnishings and furniture, absorb heat radiation and become hotter than the ambient air temperature. This means that the air temperature and the operative temperature will be balanced even in parts of the room which the ceiling heater does not directly “see”.

In [1] the difference between the air temperature under to the side of a table is stated to be between 0-0.9°c depending on the instance. This shows that the table is heated by the heat radiation from the ceiling. In [2] a difference in air temperature under and to the side of a school was recorded to be a maximum of 0.3°C. The difference in radiant temperature is defined here as a maximum of 1.6°C. According to our own measurements made in different environments, e.g. day-care centres, offices, schools and industries, the difference in operative temperature lies at approx. 0.2-0.4°c under respective next to a table.

Draughts

There are many factors that effect whether, and how much you will experience the draught from a window. Among the most important are the windows U-value, the design of the window ventilation method, placement of the air terminal, characteristics of the air terminal, the heating system, the persons clothing and activity, the rooms geometry and furnishing, infiltration and outdoor temperature [5] [6] [7]. Accordingly it is not just a question of whether the heating is positioned under the window or on the ceiling. An air terminal with rear edge air supply with a long throw and low air supply temperature can also be a reason for draughts to occur. With radiators under the window, furnishings can be a critical factor if, e.g. a table is placed close to the window. The upward moving hot air flow is then screened from the radiator under the table and the draught “runs” over the table and then down on to the floor [7].

In [1] [2] and [3] increased surface temperatures on the inside of the window were recorded due to the glass surfaces absorbing heat radiation. A common result for all three is that radiant heat is distributed differently across the window surface. The window has a higher surface temperature on the upper part and a somewhat lower temperature on the lower part. An increase of approx. 2-10°c is noted depending on the measurement point and instance. It is important to point out that in all cases it was a question of double glazing. In modern houses with triple glazing the temperature increase will be even higher. Our own surface temperature measurements on windows, heated by a ceiling heater, indicate that double glazing has a surface temperature of 12-17°C and triple glazing 17-20°C with an outdoor temperature of between 0°C and –5°C. In [2] it was noted that a building with window sills had a favourable effect on the draught from a window. This is because the window sill is heated by the ceiling heater and that it deflects the downward air flow and in doing so mixes in the warmer room air.



The assumed room for the calculation example.

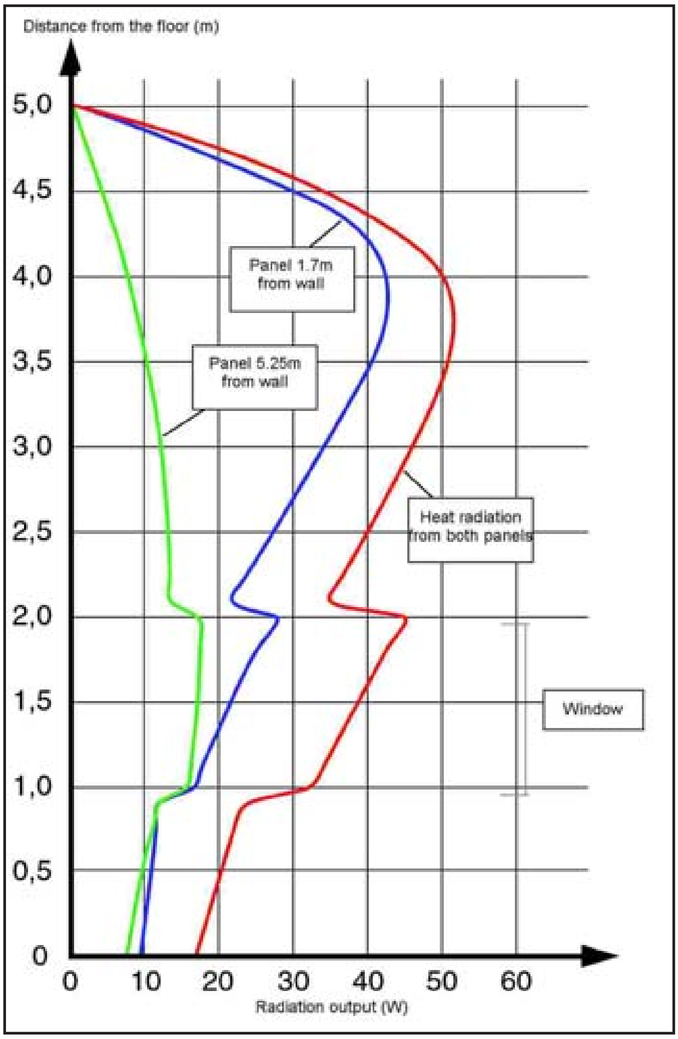
Calculation example

The formula for radiant heat transmission says the temperature difference between two surfaces are relatively important, especially if the temperature is stated in Kelvin and raised to the power of four. The formula also says that more heat radiation automatically goes to colder surfaces than to warmer surfaces, and it is this condition that is ideal for a heating system. The diagram here shows how the heat radiation spreads across a wall. The calculation of the heat exchange between the ceiling heaters and the wall has been made for each decimetre of wall according to the formula in chapter II and the formula for the angle factor. Two ceiling heaters are mounted on the ceiling parallel to the wall at 1.7m respective 5.25m from the wall. These measurements have been obtained from the diagram describing the placement of the ceiling heaters in chapter V. Conditions during a cold winter's day are assumed to apply.

It is a very lengthy process to manually calculate the PPD-index for a given instance using these formulae. It is significantly easier to use climate simulation software that gives the PPD-index or other climatical indexes as a result of simulating condition in a room. Frenger Systems' climate simulation software, TeknoSim, gives the air temperature, operative temperature and PPD-index as results. According to Fanger's formula, a maximum of 95% can be satisfied with a given indoor climate, that is at least five per cent will always experience the indoor climate as uncomfortable (PPD = 5% and PMV = 0 defines the best possible thermal comfort). In the Swedish Indoor Climate Institute's publication R1 [8] the defined classes for thermal indoor climate are based on the PPD-index, which runs from, 10% dissatisfied for the highest class to 20% dissatisfied for the lowest class.

It is interesting to note that the two panels heat radiation have their maximum levels on different parts of the wall. This is due to the geometric relationship, i.e. the angle factor, being different for the two heater panels in relation to the wall. It is also clear that the window receives a large share of the heat radiation compared with the wall next to the window. The reason for this, as mentioned above is due to the window surface being colder and "attracts" more heat radiation. This means the window surface will be heated considerably more than if the room heat source was solely convective, e.g. a hot air fan heater. That the window surface is heated to approx. +15°c means that the risk of draughts is significantly reduced. In summarising we can establish the following applies for ceiling heating applications in building and rooms:

- The emission factor for indoor surfaces is relatively equal, approximately 00.88-0.95.
- The ceiling height has no importance for the transmission of heat radiation from the ceiling heater to other surfaces.
- Transmission of radiant heat is automatically greater if the recipient surface has a lower surface temperature.
- The air temperature can normally be lowered by1-2T, with maintained operative temperature, thanks to the surrounding surfaces being heated by the ceiling heating system.
- There are very small differences in air temperature and operative temperature under respective to the side of a table using ceiling heating.
- Radiant heat from the ceiling panel heats the inside of a window, minimizing the risk of draughts.



The diagram shows how the transmitted heat output from two panels is distributed on a facade wall with a window

The following input data has been assumed:

Wall:	- height: 5m - width: 10m - emission factor: 0.9 - surface temperature: 22°C	Ceiling heater:	- width: 1m - length: 10m - emission factor: 0.95 - surface temperatures: 40°C - installation height: 5m
Window:	- height to window: 1m - window height: 1m - emission factor: 0.94 - surface temperature: 15°C		

Where does a ceiling heater work well?

Ceiling heating has a very broad application area broader than most forms of heating. Generally you can say that ceiling heating can be used in virtually all types of building. Ceiling heating is preliminary used in premises such as sports halls, workshops, industrial halls, warehouses and shopping centres. Ceiling heating also works well in day-care centres, nursing homes, homes, schools and laboratories.
A ceiling heaters output is approx. 40% conductive and approx. 60% radioactive. The convective heat is given off to the air at the ceiling and contributes towards covering transmission losses through the roof. The proportion of heat transmitted through radiation mainly goes to the floors and walls. Heat loss via transmission through the wall, roof and the floor in a building is divided approx. 40% of heat through the roof and approx. 60% through the remainder of the building. Therefore ceiling heating combined with all its other benefits is an excellent choice for heating all types of buildings. Below a transmission calculation of a building is presented, and the result shows that the division of transmission loss is as described above.

Input data:

DOT10:		20oC
Annual mean temp.:		6oC
U-value	Ceiling:	0.2 W/m^2, ^{o}C
	Wall:	0.2 W/m^2, ^{o}C
	Floor, inner:	0.3 W/m^2, ^{o}C
	Window:	2.0 W/m^2, ^{o}C
Area	Ceiling:	800m^2
	Walls:	600m^2
	Floor, I:	680m^2
	Floor, o:	120m^2
	Window:	30m^2
Temperature gradient		0.7^{o}C/m
Ceiling height (mean):		5.0m
Length:		40m
Width:		20m
% Window area:		5% of wall area
Indoor temp.	Occupied zone:	18^{o}C
Mean:	20^{o}C	
Ceiling:	22^{o}C	

Output data:

Output requirement:	Ceiling:	6640 W	38%
(transmission)	Walls:	4770 W	28%
	Floor, I:	2448 W	14%
	Floor, o:	2448 W	7%
	Window:	2280 W	13%
	Total:	17278 W	100%

Chapter IV

Design requirements for a ceiling heater

The design and technical solutions for a ceiling heater differ from manufacturer to manufacturer. Demands on a well-working ceiling heater are however the same and are based on the physical laws as that control heat transmission.

Basic demands on a ceiling heater

One of the essential demands that should be made on a ceiling heater is an equal temperature across its surfaces. This gives maximum output per unit area. If you have a water temperature on a heating system of, e.g. 55-45oC or 60-40oC, i.e. a mean water temperature of 50o (55+45/2), then the desired temperature on the products entire surface should also reach 50oC. However, this is a practical and even theoretical impossibility (it would demand infinite heat conductivity) as heat loss would occur from the water in the pipe to the product surfaces. Therefore the aim is to reduce these heat losses as far as possible. Below we intended to review how this aim can be optimised and how other demands can be met.

What symbolises a well-designed ceiling heater?

There are several ways to assess the quality, operation and service life of a ceiling heater. These are:

1. Choice of material?
2. How effective is the bonding/contact between the pipe and flange?
3. Optimisation of the ceiling heater: heat output/cost?
4. How well the product has been tested?
5. How easy is the product to install?
6. Flexibility?
7. Finish?
8. Structure of the product?

The basic principle for all waterborne ceiling heating products is completely identical. This is based on a water bearing pipe and a radiant surface (flange). The pipe shall then be joined to the flange in such a manner that the heat from the water is led through the pipe wall to the flange. See diagram 1. The temperature of the flange increases, and heat radiation from the product is achieved. To attain the intended output in the building the ceiling heater is insulated on top to prevent unnecessary heat radiation from reaching the ceiling surface.

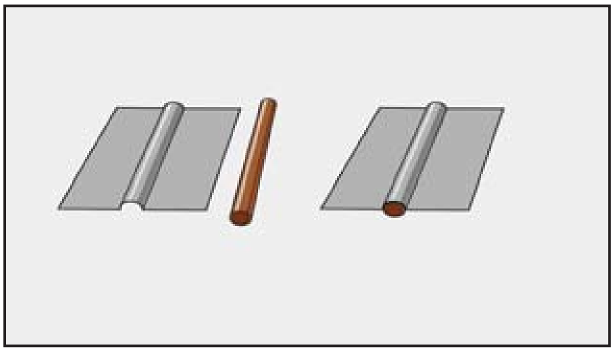


Diagram 1. Basic elements in a ceiling heater.

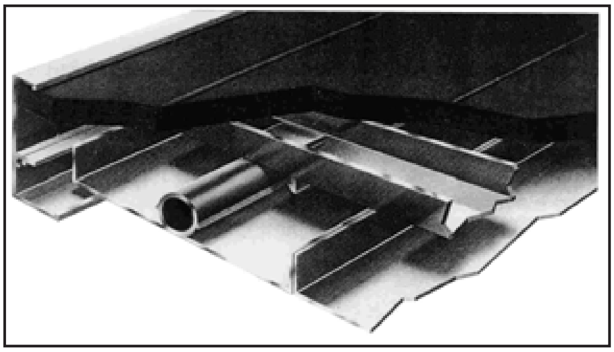


Diagram 2. The pipe expanded in an aluminium section.

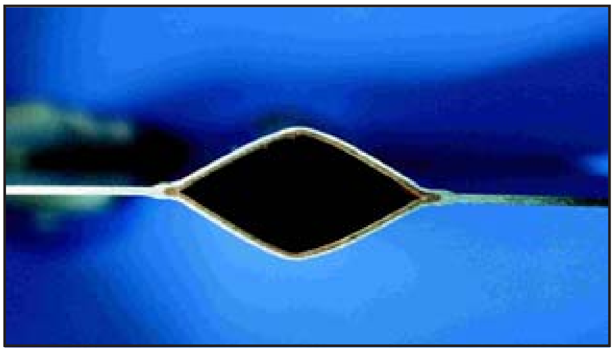


Diagram 3. Cross-section of Frenger Systems' basic element. The copper pipe and aluminium flange are metallurgically bonded using Frenger Systems' world patent.

1. Choice of material

The choice of material is decisive for the heat output and the service life of the product. In Scandinavia today only aluminium is used as the flange material. This is because aluminium conducts heat efficiently and the product weight is low. The pipe material can either consist of steel or copper. The advantages of using copper pipe are many:

- The corrosion risk is significantly lower compared to steel pipe
- The weight of the product is less and material expansion (see next page) is equal.
- Installation is far easier using copper pipe.

2.Bonding the pipe and flange

When the choice of materials has been made, the pipe and flange must be joined to obtain the best possible contact/connection between these. The quality of the connection between the pipe and flange has a significant effect on how well a heat radiator will work. Currently there are three methods for making this joint.

1. Through different methods to screw, weld, clamp or snap together the different surfaces with each other. *See diagram 1 on the previous page.*
2. A normal copper pipe is inserted into an aluminium profile, shaped as a pipe and flange in a single unit. The pipe is then expanded in to the profile to gain good contact between the different materials. *See diagram 2 on the previous page.*
3. Here a copper pipe and an aluminium flange are rolled together under high pressure (approx. 50 tonnes) to form a single unit. The copper pipe is then blown up and takes on a rhombic form. *See diagram 3 on the previous page.*

The pipe and flange connection on the first two methods is purely mechanical. It is not hard to imagine that a mechanically made joint does not give optimal heat transmission. Numerous experiments on this type of solution [14] indicate considerable effect losses especially after a long period of use. The last method provides a metallurgical connection (the materials are partly mixed through molecular bonding)

If you intend to determine the quality of these methods , you could say the last two named methods constitute a good design if done correctly. The first method has a significantly inferior design due to several reasons. Primarily this is all to do with the fact that different materials expand by different amounts when exposed to heat. The expansion difference between steel and aluminium is far greater than the expansion difference between copper and aluminium. What happens is that the aluminium sheet "lifts" itself from the steel pipe, resulting in impaired contact between the pipe and flange, or – the heat output from the product decreases. In addition, these types of design are sensitive to how the product is handled in production, delivery and assembly. Contact between the pipe and flange can even here decrease with handling.

A metallurgical joint (design no. 3) gives the mot advantages. Material expansion is completely equal, the risk of corrosion minimized and it's no possible to impair the contact between the pipe and flange, due to handling during production, transport or assembly.

Expansion coefficients for different materials:

Aluminium	24
Copper	16
Steel	12

This shows that it is technically wrong to join the different metals using a mechanical method as this results in output losses from the product – this is under the condition that point contact between the pipe and the flange is not infinite, seen from the number of point contacts. If the point contact connection is made using too much spacing, the aluminium sheet (radiant surface) will rise from the steel or copper pipe, which in turn causes output losses. To mechanically join a steel pipe with aluminium sheet gives the worst thermal contact.

Example:

Conditions: A steel pipe is joined mechanically (at points) every meter with an aluminium flange.

WS: 80/60°C
Room: 20°C

Result: The aluminium flange will lift 0.6mm from the steel pipe, i.e. contact will only be made at points, and these are the only places on the product where efficient heat transmission will take place.

Galvanic corrosion

This problems becomes more relevant for cooling when using a chilled panel where there is a risk for condensation during specific times of the year. However, it can also be relevant for heating where there is a high humidity level in the building or where products are washed down, especially when these are not exposed to the effects of heating. To discover how great the risk is, refer to the table on the next page.

	Standard potential series relative to standard hydrogen electrode		Galvanic series in 3 per cent NaCl relative to standard hydrogen electrode
	Me/Me^{n+}	Me/Me_xZ_y,pH7	
Pt/Pt^{2+}	+1.20V	+0.57(Pt/PtO)	Pt +0.47V
Ag/Ag^{+}	+0.80V	+0.22(Ag/AgC1)	Ti +0.37V
Cu/Cu^{2+}	+0.34V	+0.05(Cu/Cu2O)	Ag +0.30V
H^2/H^+	0.00V	-0.414(H_2/H_2O)	Cu +0.04V
Pb/Pb^{2+}	-0.13V	-0.27($Pb/PbCl_2$)	Ni -0.03V
Ni/Ni^{2+}	-0.25V	-0.30(Ni/NiO)	Pb -0.27V
Fe/Fe^{2+}	-0.44V	-0.46(Fe/FeO)	Fe -0.40V
Zn/Zn^{2+}	-0.76V	-0.83(Zn/ZnO)	Al -0.53V
Ti/Ti^{2+}	-1.63V	-0.50($Ti_2/O_3/TiO_2$)	Zn -0.76V
Al/Al^{3+}	-1.67V	-1.90(Al/Al2O3)	

Standard potential series (electrochemical voltage series and galvanic series for some common metals.

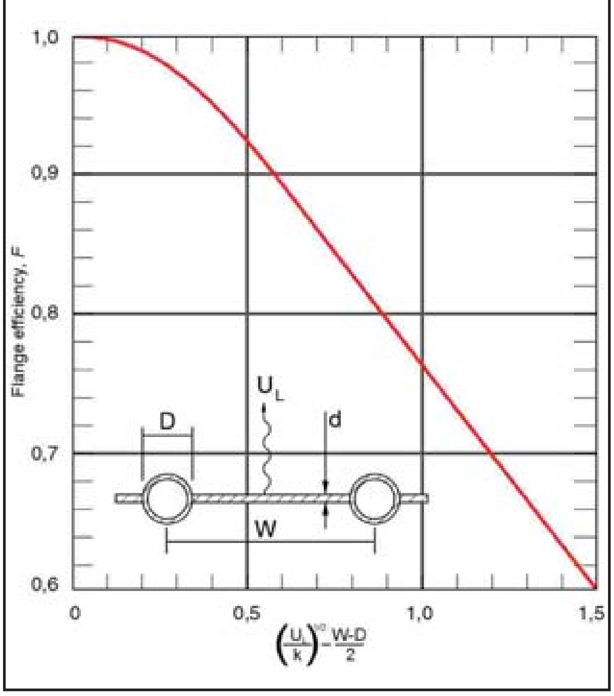
Galvanic corrosion occurs due to the interconnection of two metals with different electrode potential. What happens is that aluminium hydroxide (looks like flour) deposits on the aluminium next to the pipe. This coating then prevents effective heating from reaching the flange (radiant surface) from pipe, which in turn causes output loss from the ceiling heater. A condition for this process is that moisture successfully penetrates between the different metals. It is evident from the table that you should definitely avoid mechanical connections between coper and aluminium, but also between steel and aluminium.

In some types of buildings where a high degree of moisture is expected during specific periods, or in cases where for reasons of hygiene the products are rinsed, you should avoid using products with a mechanical connection (design 1). If moisture succeeds in penetrating between the copper pipe/steel pipe and the aluminium flange there is a risk of galvanic corrosion.

3.Optimising the ceiling heater

How good heat transmission between the pipe and flange is and how well the flange can conduct the heat can be described with the expression flange efficiency. Flange efficiency is a measurement described as: *The loss in heat transmission in a flange due to unevenness in the output distribution across the flange surface.*

In theory flange efficiency can be calculated. This then allows the flange thickness, c/c spacing between pipe, component materials and pipe diameters to be optimised. Note! The diagram applies with perfect (homogeneous) contact between the pipe and flange.



Flange efficiency for the pipe and flange in homogeneous contact.

Key:
D: Pipe, outside diameter
d: Flange thickness
W: c/c spacing between pipes
UL: Heat load total per surface unit W/m2 oC – is approx. 11 with suspended installation
k:Thermal conductivity (coefficient of thermal conductivity)

It is evident from the formula that increased flange efficiency can be achieved by:

1. Using material offering high thermal conductivity.
2. Thicker flanges.
3. Increasing the pipe diameter (however, the expression for flange efficiency does not consider that an increase in pipe diameter lowers the Reynolds number and increases the risk of switching to laminar flow, which would significantly impair the heat transmission between the water and the pipe wall).
4. To reduce the c/c spacing between pipes.

Thermal conductivity

To answer point 1 in the previous section you need to know the thermal conductivity of the metals that can come into question.

Material	Thermal conductivity (W/m K)
Aluminium	218
Copper	385
Steel	84
Silver	420
Gold	300
Tin	65
Nickel	85

Some of these metals can be eliminated directly due to cost. Those metals that can come into question for the flange are as previously mentioned – aluminium, copper or steel. The reason for choosing aluminium is evident

Material/ Property	Cost	Weight	Strength
Aluminium	£0.07	1 kg*	1 N/m^2
Copper	£0.13	2 kg	0.6 N/m^2
Steel	£0.07	4 kg*	6 N/m^2

**) Index = 1 for Al. The table applies to achieve the same flange efficiency, i.e. with compensated flange thichness*

A few examples:

What effect does the thickness of the flange have if you use copper or steel instead of a aluminium and does the flange efficiency remain constant?

Copper: Flange thickness can virtually be halved to achieve the same degree of efficiency.

Steel: The flange thickness needs to increase by a factor of 2.5.

Pipe spacing

Pipe spacing has a significance for the heat output produced by the product. The closer the pipe spacing the more even the surface temperature and by that the higher the output, or if you like, the smaller the heat surface needed to be installed in the building. In other words, the most optimal situation would be to install hot pipes in the ceiling. This is not feasible due to reasons of cost, material + installation. Instead, it is a question of calculating the optimal pipe spacing without loosing too much heating output.

4. How well tested are the products?

In those cases where the product is tested by an independent test institute you can get true evidence of the products quality and service life. Frenger Systems ceiling heaters have undergone many extreme tests: Here follows a selection of these:

1. The products have been kept unprotected outdoors for a period of ten years (in the form of a solar collector) to establish corrosion risks.
2. Expansion tests. On numerous occasions the surfaces have been exposed to temperatures of 200°C and then the surface s are shocked using 10°C water to see whether the expansion between the copper pipe and aluminium flange affect the product.
3. Pressure tests. The products have been pressure tested during 5,000 cycles at a pressure of 10-12 bar to ascertain martial fatigue and to discover crack formation in the design.

The last two mentioned tests are carried out by the National Swedish Institute for Materials Testing. Not in any of the cases has it been possible to discover any quality impairment in the product.

5. Ease of installation

if you can manufacture a product with a low weight at the same time as it has a stable design, you will have lower overall costs (product price + installation costs) compared with any other option. Again, material selection is decisive for a good result, however, even the products construction and composition are significant factors. A low weight also gives benefits in the form of lower loads on the ceiling structure.

6. Flexibility

By flexibility e mean how well the product can be adapted to meet new circumstances in the building. Flexibility can have great importance for the property owner, who during the buildings lifetime, will rent it out to numerous tenants or where changes to the buildings layout will take place. The climate system should not limit the type of activities to be carried out in the building. If the building has been used as a warehouse, the climate system should not prevent it from being changes to a house manufacturing industry where, for example, there is a need to anchor machines to the floor. The products should be easy to move on the ceiling or relocated to areas where they are needed more. A prerequisite fort his is prefabricated units that are easy to connect and interconnect.

7. Product finish

Regarding finish, it is the surface finish that is essential. Automated production with well-implemented preparatory work combined with stove enamelled surfaces gives a high quality finish.

8. Product structure

To obtain the intended output from the ceiling heater the surfaces should be smooth to prevent unnecessary air movement convection. The share of radiation should be as high as possible to attain the intended output – both from comfort and operating cost points-of-view. Insulation on the top should be so good so that the heat output is concentrated to the underside of the ceiling heater.

Products entirely of aluminium

These types of product where the pipe and flange are of aluminium are rare. This is due to the obvious corrosion risk that occurs when water is led through an aluminium pipe.
The corrosion is called pitting and it always occurs, very quickly, when water is led through aluminium. You can count on the risk of leakage in days. To cancel out this type of corrosion inhibitors are added to the water, i.e. different types of chemicals to slow down the corrosion process. The problem with inhibitors is that they are continuously consumed and must be continuously added to revoke the corrosion risk. If the inhibitor can do more damage than good that is, accelerate corrosion process.

Placing the ceiling heater

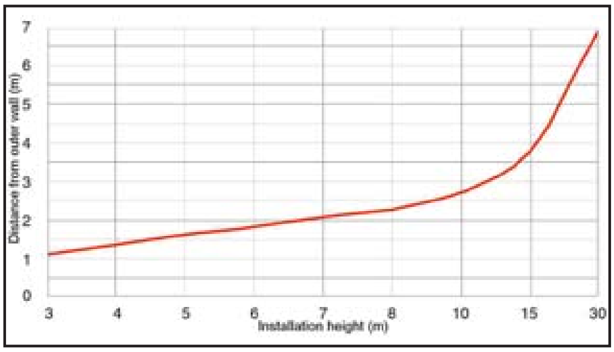
The general rule when positioning ceiling heaters in a room or building is that the ceiling panels should be distributed as evenly as possible. In addition the panels should be placed in relation to the surrounding surfaces heat losses i.e.., a large share of the heat emitting surfaces should be positioned near the facades and window areas to cover heat losses and to heat window areas to counteract any draughts.

When selecting a ventilation system or the placement of the air terminals you do not need to bear in mind the ceiling heating system. The ceiling heater in itself does not cause any air movement. The references [10] and [11] have investigated air movement in a room using ceiling heating. In summary the results showed that only very small air movement was detected in these rooms. It is only close to cold outer walls that air velocity exceeding 0.03 m/s can be registered. The air velocity rates normally occurring in a room, 0.1-0.2m/s are caused by ventilation and convective air movement due to people and hot equipment. Directions are given here for how ideal placement of heating panels should be carried out. However, in reality there are usually obstacles preventing ideal placement of heating panels. It can be a question of ceiling beams or other structures in the ceiling, light fittings or other installations that are in the way. Furthermore, you can save on pipe laying cost by simplifying distribution of the heating panels and by that not attain perfect placement. It is important to point out that the directions below are recommended values. If it is not possible to reach these recommended values, and deviations from these is large, you should get in touch with us to ensure that there will not be any problems. If the deviations are smaller the results will probably be okay in most cases. People are not so sensitive in experiencing discomfort with the small differences that would occur if the recommended distribution cannot be attained. You should attempt to realise the following rule of thumb to obtain as balanced heat radiation distribution as possible.

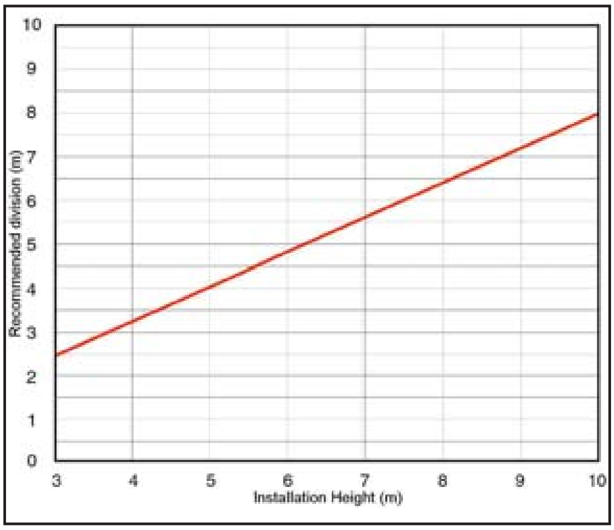
Against outer wall without windows panels closest to the wall are placed according to the following: With the stated distance from the outer wall at different ceiling heights distribution of heat radiation is approx. 60-70% against the outer wall and approx. 30-40% towards the floor, which corresponds generally with the distribution of transmission losses along the outer wall and the outer and inner edge zone on the floor which are covered by the ceiling hater panels/heating strips. Strips or panels do not normally need to be angled to direct the heat radiation towards, e.g. the outer wall. Normal spacing between ceiling heaters in accordance with the below presupposed.

Against an outer wall with window: if the outer wall contains standard or large glass surfaces the panels can be placed closer to the walls. A concentration of the heating effect should be made to reduce the risk of draughts and to reach the requisite values for the operative temperature. Concentration really needs to be performed with smaller windows. A rule of thumb is hard to give in these cases as variations in window sizes and building shapes are immense.

Spacing between panel/strips: is evident from the diagrams below. The recommended spacing between panels/strips is presented as a function of the installation height. At the recommended spacing, heat radiation is obtained that is equal in size between the ceiling heaters as well as directly under them, i.e. radioactive heat is distributed as equally as possible.



Recommended distance between the ceiling heaters closest to the outer wall and outer wall (without windows).

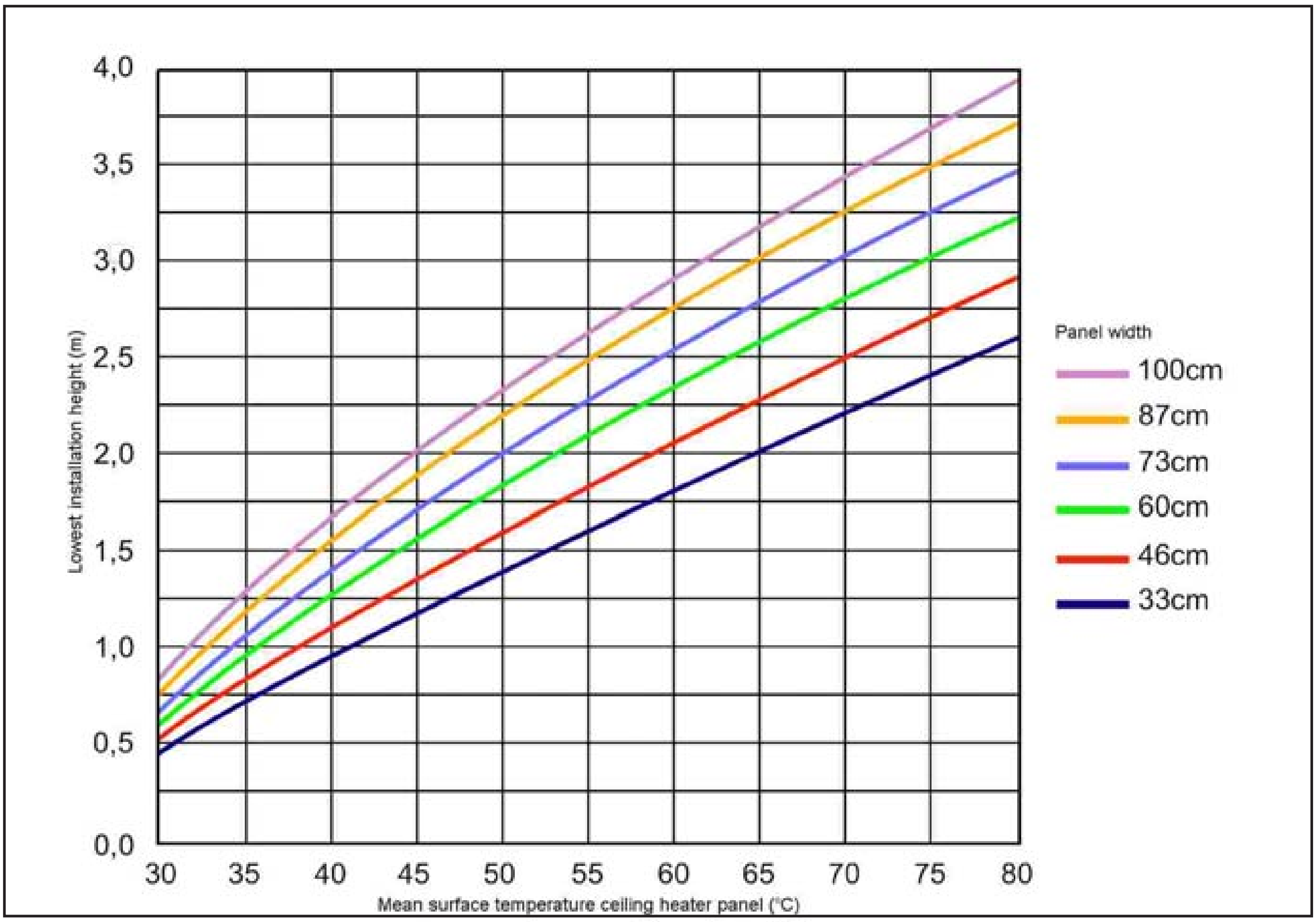


Recommended spacings between panels with ceiling heating.

Temperature and the requisite installation height

The temperature on the ceiling heaters, i.e. the temperature in the heating system, affects the effect emission, which we discussed in chapter VII, however it also effects the heat experience from the ceiling heaters. The question “will it be too warm on my head?” is common. In this chapter we deal with the conditions for how the ceiling heaters temperature and installation height affect the climatically experience.
It is the buildings installations and heat source, the number and size of ceiling panels, ceiling height, radiant temperature asymmetry and the operative temperature that are affected by or affect the temperature level. In this context it is important to point out that a higher temperature in the heating system is not required the higher the ceiling height. The reason for this is documented in chapter II. Usually you use a selected temperature level and then decide, exactly as with a conventional heating system the number and size of the ceiling heater panels to cover the dimensioned heating effect requirement (see chapter VII).

The number and size shall be combined so that the ceiling heater panels are distributed across the buildings area (see chapter v). In addition the radiant temperature asymmetry and the directed operative temperature shall be checked to see whether these values are prescribed. When ceiling panels pacing has been done, based on the heating effect requirement, the buildings geometry and the furnishings and other installations have been considered the radiant temperature asymmetry (RTA) should be checked. RTA is the difference in plane radiant temperature on each side of a small plane area (also see chapter I). Plane radiant temperature is calculated by using the measured surface temperatures and angle factors or is measured using a radiant temperature meter. RTA is measured on one plane 0.6m above the floor with sitting activities or 1.1m above the floor with standing activities. The Swedish indoor climate institute [8] and standard 7730 state RTA to be a maximum of 5^{o}C with ceiling heating.



Lowest installation height for ceiling heaters with radiant temperature asymmetry of 5oC. Ceiling heater length 3.6m

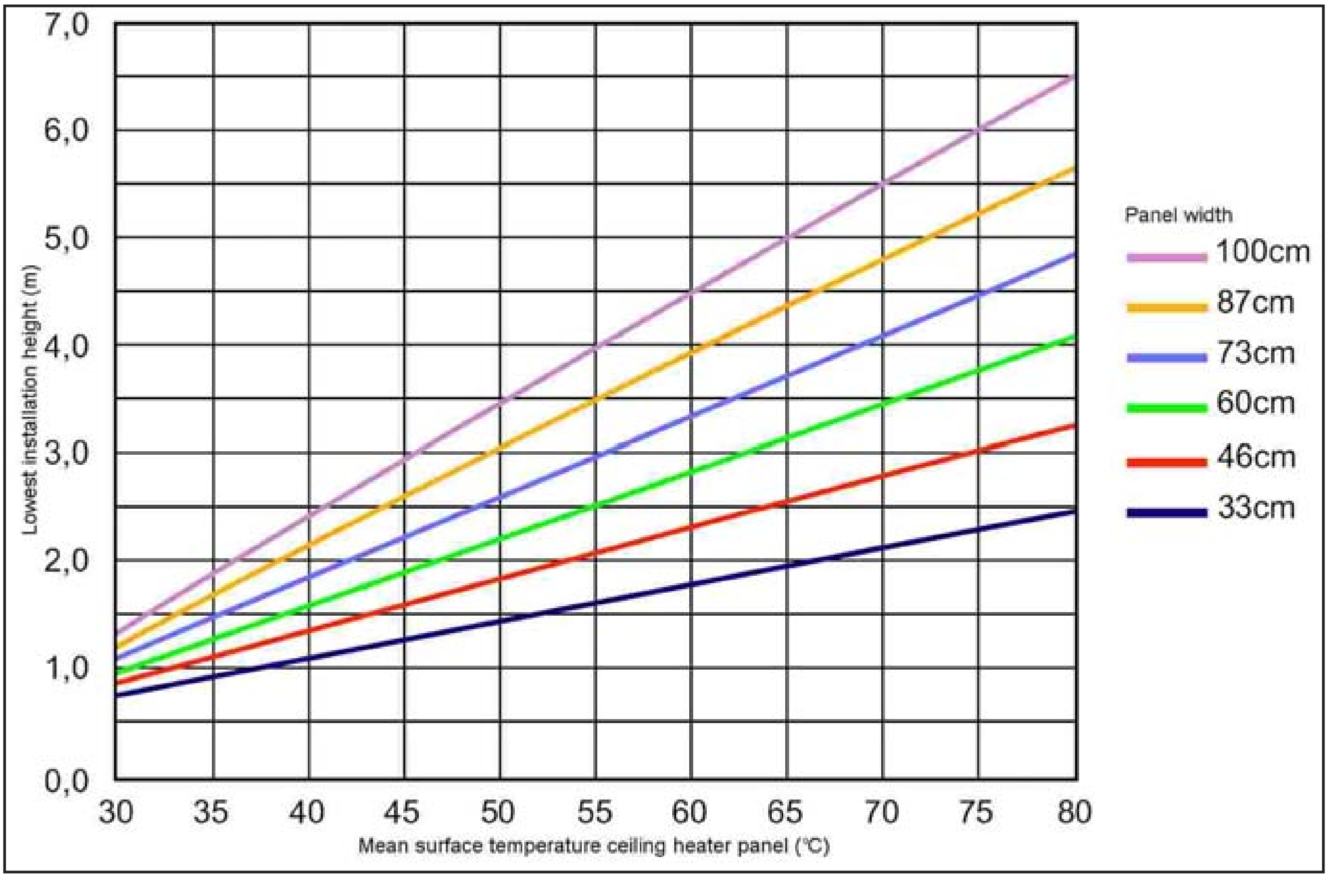
RTA is normally calculated directly under a ceiling heater and depends on the installation height, surface temperature and the size of the ceiling heater as well as the temperature of the other surfaces. To avoid extensive calculations the diagram below is presented which states the lowest permitted installation heights so that RTA does not exceed 5ºC. The curves represent the width of the ceiling panels. The different diagrams apply for different ceiling panel lengths (3.6m and 10m). The presentation of these curves presupposes that all surrounding surface have the same temperature. This is rarely the case in reality. Usually RTA will be more favourable. Normally there are one or more cold windows and floors are normally warmer than surrounding walls with ceiling heating. This means that RTA drops as the window/s are frequently above the measurement plane and compensate for the warm ceiling panels. The warmer floor also contributes to raise the plane radiant temperature under the measurement plane, which reduces RTA. Combined the RTA will be less than 5ºC if the ceiling heaters are installed at the height stated in the diagram. It is important to point out that we are speaking about design heating temperatures that, statistically, only occur on a few individual days per year.

During the major part of the year the RTA with ceiling heating is less than 5ºC.

In summary we can establish that the smaller the surface (shorter and/or narrower) of the panels the lower they can be installed without exceeding the stated radiant temperature asymmetry.

In [1] skin temperature measurements are made and the experienced comfort level of 15 people were registered while in a room with ceiling heating. In summary we can establish that normal differences in skin temperature on the head compared to the rest of the body were recorded. Regarding the comfort experience, there were some small differences in the comfort results between the head and feet. However the differences were no greater than those other heating systems would cause.

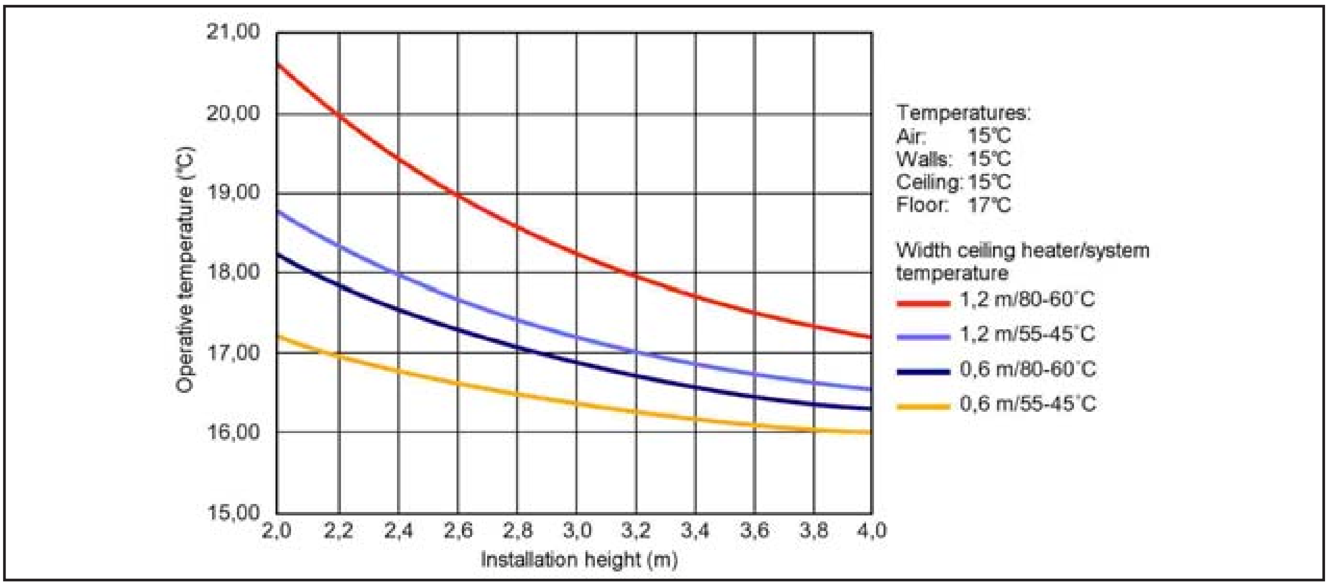
With our own measurements of radiant temperature asymmetry the values have been between 1.0-5.5ºC in different buildings, e.g. schools, day-care centres, garages, offices and industrial buildings. Most values were around 2-3ºC. The highest value (5.5ºC) was measure in a workshop where the door opened frequently and which lowered the floor temperature.

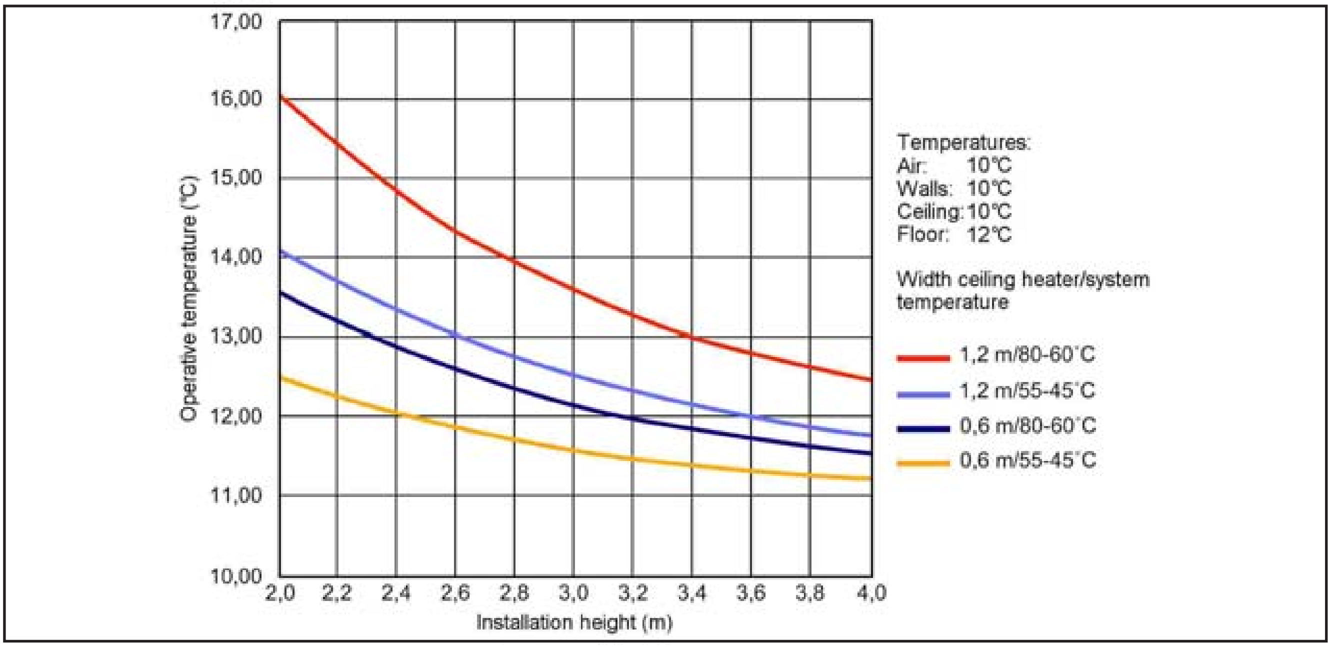


Lowest installation height for ceiling heaters with radiant temperature asymmetry of 5oC. Ceiling heater length > 10m

Zone heating

Ceiling heating has a special advantage when heating a part or a zone in a building. You can maintain a low air temperature in the building and locally increase the operative temperature in those areas where people work/occupy. The higher temperature partly on the ceiling heater and partly the heated floors allows the operative temperature to be increase well above the air temperature. In the diagrams below the operative temperature is shown as a function of the installation height. These show cases with air temperatures of 10 and 15oC. Walls and ceilings are presupposed to have the same temperatures as the air, while the floor is heated to a temperature of approx. 2oC above the air temperature. The different curves represent ceiling heater widths of 0.6m resp 1.2m with two different system temperatures, 55/45 resp 80/60oC.





Effect and energy

When calculating the dimensioned heating effect requirement, as previously mentioned, the different parts of the building with regard to area and thermal transmittance, Up –value, and then Umean are calculated. This is normally calculated in accordance with applicable building regulations BBR 94, heat insulation (Boverket) and Swedish standard (SS 02 42 02 and SS 02 42 30).
When the designed outdoor temperature (DOT) is to be determined the method described in Swedish standard (SS 02 43 10) should be used to prevent the heating system from being over dimensioned. The method is based on considering the rooms/buildings individual time constants, i.e. heat storage ability, and in this way calculate the DOT for each building or room.
When calculating the heat effect requirement in a new building you can usually assume a one to two degree lower indoor temperature for ceiling heating than for the standard value. This reduction is however, only an experience-value and checks should be made during planning on sensitive parts of the building with regard to the operative temperature dependent. The fact that a reduction in temperature is normally possible is due, as mentioned before, to the heat radiation from the ceiling heating up the surrounding surfaces, e.g. the floor, walls and furnishings. People ten experience that heat radiation from the body reduces, and to maintain the correct comfort level the rooms temperature can be educed by a corresponding amount as the surrounding surfaces mean temperature has been increased. This applies under the condition that the other climate factors are kept on a constant level and the air velocity does not exceed 0.15 m/s.
As soon as a heat source is introduced into the room and the temperature is kept above the outdoor temperature a temperature gradient will occur in the room due to the density differences between the hot and cold air . The gradient is not the same size everywhere. The gradient can be non linear especially in the vicinity of the floor and ceiling as will as the outer wall. In other parts of the room the temperature gradient is virtually linear. The size of the temperature gradient varies with its position in the room, the temperature of the rooms surfaces, the rooms ventilation, the size of the room, the number of heaters and their placement, unintentional ventilation, furnishing of the room and the activity in the room [12]. As you can see numerous factors have an effect, however, some of them often have a small or very small effect on the temperature gradient.

$P_{dim}=P_t+P_{ov}+P_v$

where P_t = Effect requirement due to transmission
P_{ov}=Effect requirement due to unintentional ventilation
P_v=Effect requirement due to ventilation

The supplied effect generated internally in the building or room is not normally included in the calculation if it cannot be considered as a constant heat source. The effect requirement due to transmission is calculated according to:

$P_t={}_iU_i*A_i*\ t_i$

A_i=Area for each part of the building (m^2)
U_i=Up value for each part of the building ($W/m^2\ {}^oC$)
t_i=Temperature difference for each part of the building, ie. regard taken to the temperature gradient when calculating each part of the building. You do not need to consider the temperature gradient with low ceiling heights (approx. 2.5-3.5m).

Effect requirement due to unintentional ventilation, P_{ov}, is normally assumed to follow the value:

- Older homes: 0.4-0.6 yield/h
- Newer homes 0.2-0.4 yield/h
- Older commercial or public buildings: 0.3-0.5 yield/h
- Newer commercial or public buildings: 0.1-0.3 yield/h

Effect requirement due to ventilation is calculated according to:

$P_v=q*\ *c_p*\ t_v$

where
q = air flow outdoor air (m^3/s)
= the air's density (kg/m^3)
c_p=the air's heating capacitivity
t_v = temperature difference between the outdoor's temperature and the supply temperature.

Calculation of the dimensioned effect requirement for heating is shown in the table.

A ceiling heating systems effect on the temperature is favourable. The surrounding room surfaces are heating by the radiant heat and in turn give off, partly through radiation (secondary) to other surfaces and partly conductively through the air. Together this results in the air being heated extremely evenly against all room surfaces. The result is a relatively very small temperature gradient . As hinted above there are several factors other than the heating system that effect the size of the temperature gradient. Consequently the temperature gradient is different in size from building to building depending on the conditions in the building . In those measurements we have made ourselves the temperature gradient in buildings with ceiling heating and ceiling heights between 2.8m and approx. 7m lies at 0.3-1.0^{o}C/m with a concentration at 0.4-0.5^{o}C/m. In reference [12] the values for other heating systems collected from international literature are:

- radiator systems: 1-2^{o}C/m
- convective systems: 2-3^{o}C/m

As previously mentioned at higher ceiling heights the temperature gradient plays a significant part in the calculation for the dimensioned heating requirement. In rooms with normal ceiling heights (approx. 2.5m) the temperature gradient plays a relatively small part in heat requirement. Examples are shown below of how great an effect the temperature gradient has in different cases with relatively high ceiling heights. The values below are theoretically calculated ad are based on the following: A hall on the Gothenburg area, DOT10= -10oC, with a floor area of 500, 100 resp. 2000m2 and with a window area that is 10% of the floor area.
The Up –value for the walls is 0.2, for the roof 0.2 and for the floor 0.3 w/m2, oC.
The windows Up –value is set to 2.0w/m2, oC. Unintentional ventilation is assumed to be 0.3 yield/h/ The heating requirement refers only to transmission ad unintentional ventilation. The heat requirement for each row is indexed against the case room temp/gradient: 20oC / 0.0oC/m for respective rows. The figures can only be compared with each other on the same row.

Relative heating effect requirement

The energy requirement for heating comes from three factors: transmission, ventilation and unintentional ventilation. The transmission normally represents approx. 20-50% and ventilation including unintentional ventilation between 50-80%. In a building heated to the normal indoor temperature (approx 20oC) it is often said as a guide that you save approx. 5% of the energy consumption per drop in degree in the indoor temperature.

The indoor room temperature can normally be lowered by one to two degrees using a ceiling heating system without the operative temperature falling below that permitted in [4]. Added to this is the effect of the temperature gradient being lower with ceiling heating compared with a conventional heating system. These two factors mean that losses are reduced with transmission (especially through the roof), but especially for ventilation and unintentional ventilation. In [3] it is stated the difference in measured energy consumption between a ceiling heating system and a radiator system is 2-7% in the ceiling heatings favour. In a literature study [4] the measured energy savings in different buildings are said to be 6-30% using ceiling heating. A theoretical comparison of the energy consumption between different systems illustrated as different temperatures and different temperature gradients are accounted on page 4:33. The same building and conditions as used in the comparison with the dimensioned effect requirement above have been used. The energy consumption has been calculated using the degree day method. The stated temperature gradient is presumed to occur with the design outdoor temperature (-10oC) and thereafter drop linearly to zero when the outdoor temperature and the room temperature are equal. The energy requirement for each row is indexed against the case room temp/gradient: 20oC/ 0,0oC/m for respective rows. The figures can only be compared with each other on the same row (see table 1).

Relative heating energy requirement

From the tables you can see that the difference between different heating systems or temperature relation, gives an energy consumption which approximately corresponds to the measured savings that the ceiling heating gives in the references above. The reasons the size of the energy savings vary are obvious and depend on the conditions. Yet, it is clear that ceiling heating systems give lower energy consumption than most other heating systems (see table 2).

Table 1 - Relative heat effect requirement

Area (m^2)	Ceiling height (m)	Room temp./gradient (°C resp. °C/m)				
		20/0.0	20/0.5	20/2.0	18/0.5	18/2.0
500	5	1.00	1.04	1.17	0.96	1.09
	10	1.00	1.08	1.33	1.01	1.26
1000	5	1.00	1.04	1.18	0.97	1.10
	10	1.00	1.08	1.35	1.02	1.28
2000	5	1.00	1.05	1.18	0.97	1.11
	10	1.00	1.09	1.35	1.02	1.29

Table 2 - Relative heat energy requirement

Area (m^2)	Ceiling height (m)	Room temp./gradient (°C resp. °C/m)				
		20/0.0	20/0.5	20/2.0	18/0.5	18/2.0
500	5	1.00	1.04	1.17	0.89	1.01
	10	1.00	1.09	1.34	0.94	1.18
1000	5	1.00	1.04	1.17	0.90	1.01
	10	1.00	1.09	1.34	1.94	1.18
2000	5	1.00	1.04	1.17	0.90	1.01
	10	1.00	1.09	1.34	0.94	1.18

Environment and recycling

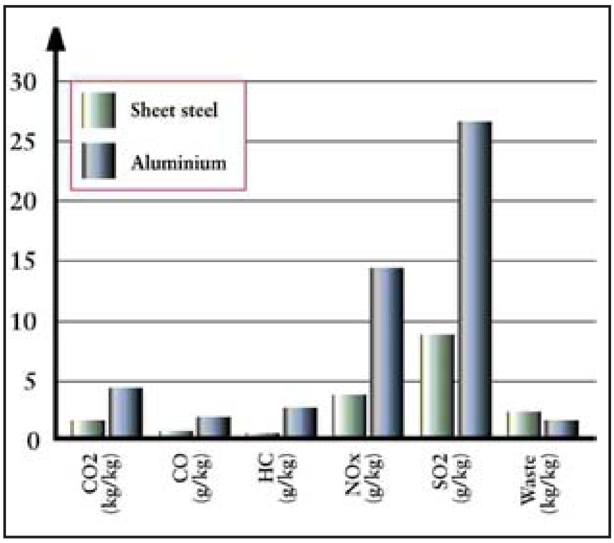
Life cycle assessment (LCA) that have been performed for aluminium products show many common features. The materials manufacturing stage (minimising, enrichment and production) receive a relatively high input loading factor for energy and the environment. In the product utilisation stage a revered situation is obtained compared with other materials. The load that aluminium products give during the production stage is compensated many times over by the low environmental impact in the utilisation stage. In addition, if aluminium is recycled even more the environmental impact from the manufacturing stage will decrease by an equivalent degree.

Frenger Systems ceiling heating system consists solely of copper, aluminium, an sheet of expanded polystyrene insulation and a small amount of lead solder. All component materials excluding the insulation are 100% recyclable. All production waste already goes for recycling. All metal components can be recycled to 100% when demolishing a building where Frenger Systems ceiling heating products have been installed. Aluminium and copper are of course metallically bonded in the manufacturing process and cannot be separated, but recycling is still possible. The ceiling heaters are pressed in a package of approx. 20 x 20cm and are used within the metal industry as alloy additives in different qualities of aluminium. In each package the share of copper is well defined as each centimetre of panel contains a equal percentage of copper.

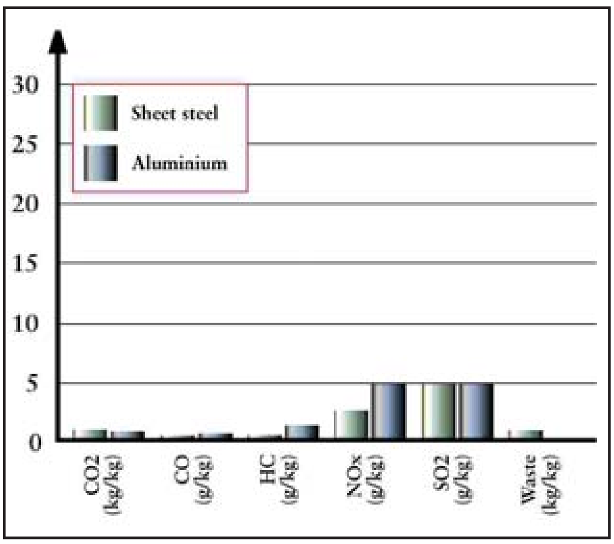
In [20] the life cycle assessment (LCA) for different packaging materials are shown, e.g. aluminium and sheet steel. Below a comparison between these metals is shown, partly without recycling and partly with 7—75% recycling. The accounted values are not translatable Frenger Systems ceiling heating products as a lCA applies only for a specific product and its special conditions during its severe life. Thus the absolute values are not applicable to Frenger Systems products.

What we wish to show with the diagrams on this and the next page is that the load on the environment falls dramatically and that aluminium is, from an environmental aspect, equal to sheet steel with 70-75% recycling. Today recycling is low when a house is demolished, but development within this area will go fast and 70-75% recycling will not be unusual. Bearing this in mind, you can probably assume that Frenger Systems products installed today will be recycled when the building they serve is demolished or rebuilt.

Discharge of different substances

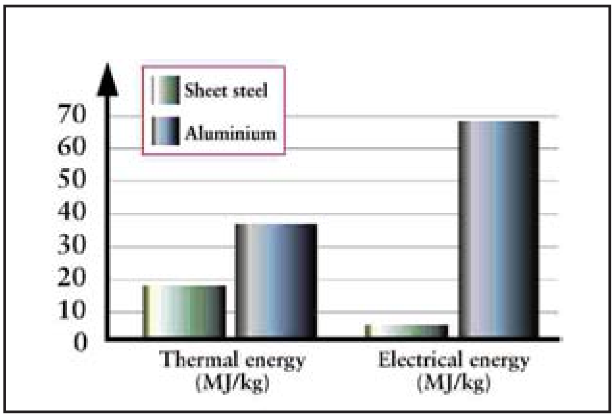


LCA values for packaging without recycling

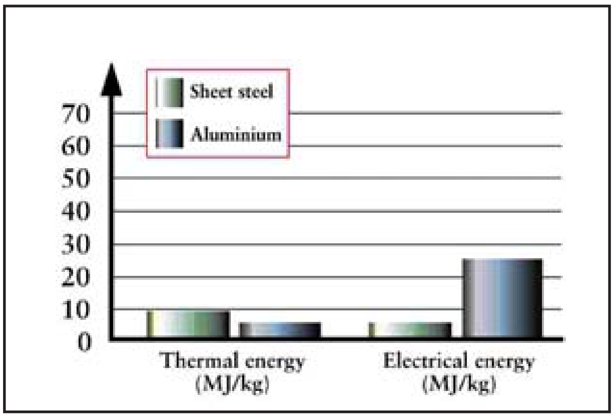


LCA values for packaging with 70-75% recycling

Use of different types of energy



LCA values for packaging without recycling

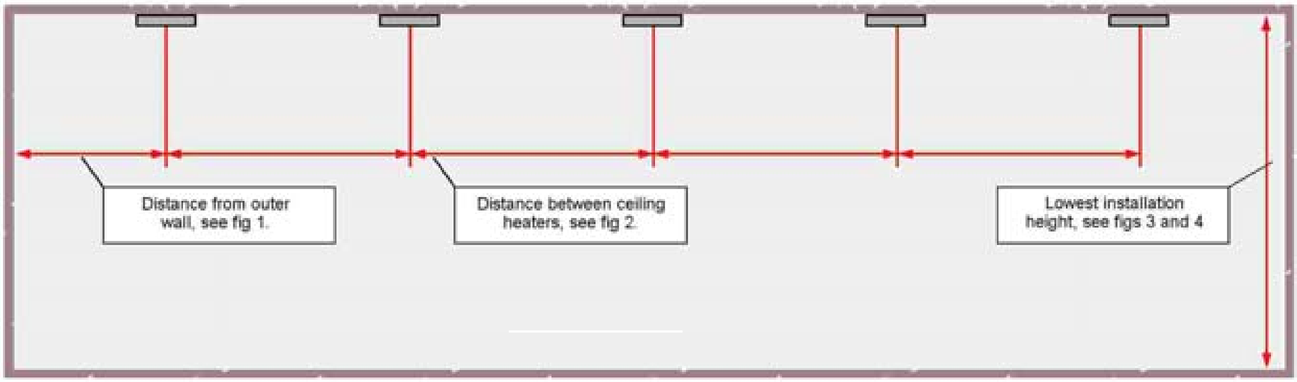


LCA values for packaging with 70-75% recycling

References

[1] Adamsson/Löfstedt: Takvärme, Temperaturfördelning och behaglighet, (Ceiling heating, Temperature distribution and Comfort): The Swedish Institute for Building Research, Report R12: 1971, 1971
[2] Lind/Olsson: Klimatmätningar I skolar med elektrisk takvärme och fläktyrd frånluftsventilation (Climate measurements in schools with electric ceiling heaters and fan controlled exhaust ventilation): The Swedish Institute for Building Research, Report R40:1972, 1972
[3] Johansson/Pettersson: Takvärme – energiförbrukning och inomhusklimat (Ceiling heating – energy consumption and indoor climate): The Swedish Institute for Building Resarch, Report R12:1984, 1984
[4] Brännvall: Takvärme – kritish granskning av olika uppvärmningssystem, litteraturstudie: (Ceiling heating – critical review of different heating systems, literature study) KTH Inst, for Heating and Oven technology, Stockholm 1977
[5] Jacobsson/Lindgren: Kallras vid fönster – en förstudie (Draught by windows – a pilot study): Wahlings installationutveckling AB, Stockholm 1982
[6] Peterson: Kallras vid konvertering (Draught with conversion): KTH Inst. for Heating and Ventilation Technology, A4-series no.140, Stockholm 1991
[7] Al-Bazi: Klimat och byggnader nr 1/1989 (Climate and buildings no 1/1989): KTH Inst. for Heating and Ventilation Technology, Stockholm 1989
[8] SCANVAC, Classified indoor climate systems, guide lines and specifications: Swedish Indoor Climate Institute, Guideline series, R1
[9] Allard/Inard/Simoneau: Experimental study and numerical simulation of natural convection in a room with heated ceiling or floor: ROOMVENT '90 Engineering Aero- and Thermodynamics of Ventilated Room, second international conference, Oslo 1990
[10] Krause: Die konvektie Wärmeabgabe von Heizdecken: Gesundheiz-ingenieur no. 10 and 11, 1959
[11] Müllejans: Uber die Ähnlichkeit der nichtisotermen strömung und den Wärmeübergang in Raümen mit Strahllüftning: Forschungsberichte des landes Nordrein-Westfalen, no. 1656, 1966
[12] Peterson, F: Temperaturgradienter vid olika uppvärmningssystem (Temperature gradients with different heating systems): Technical Notice No. 65, KTH Inst. for Heating and Ventilation Technology, 1975
[13] Pierre, B: Mekanisk Värmeteori fk del 2 (Mechanical Heating Theory part 2) Kompendium, Institution for Mechanical Heating Theory and Cooling Technology, KTH 1979
[14] Duffie, J, Beckman, W: Solar Engineering of Thermal Processes: Wiley & Sons 1980
[15] McIntyre, D.A.: The Thermal Radiation Field: Building Science Vol 9, 1974
[16] McIntyre, D.A., Griffiths I.D.: The effect of uniform and asymmetric thermal radiation on comfort: Proc. of the 6th international congress of climatistics "clima 2000", Milan, March 1975
[17] Chrenko, F.A.: Heated ceilings and comfort, Journal of the Inst. of Heating and Ventilation Engineers, Januari 1953
[18] Olesen B.W. et al.: Thermal comfort in a room heated by different methods: ASHRAE transactions, vol 86 part one, 1980
[19] Fransson, J et al: Utvärdering av Bo-klimat och fuktstyrning I Falun: Swedish Committee for Building Research, SPAR 1993:67
[20] Tillman A-M. et al.: Packaging and the environment- Life-cycle analyses of selected packaging materials – Quantification of environmental loadings: Chalmers Industrial Technology, Göteborg 1992
[21] Fanger P.O.: Thermal Comfort, Analysis and Applications in Environmental Engineering: Danish Technical Press, Copenhagen 1970.

Dimensioning key



Placing the panels

You should attempt to follow these rules of thumb to obtain as equal distribution of heat radiation as possible.

Against the outer wall without windows: the panel closest to the wall should be positioned as shown in figure 1.

Against the outer wall with windows: if the outer wall has normal or large glassed areas the panel can be placed closer to the wall. A concentration of the heating effect should be made to reduce the risk of any draughts and to obtain the requisite operative temperature value. With smaller windows a concentration is rarely necessary. Rules of the thumb are hard to give in these cases as variations in the size of windows and shapes of buildings are immense.

Spacing between panels/strips: is evident from figure 2. The recommended spacing between panels/strips is presented in the diagram as a function of the installation height. Using the recommended spacing heat radiation will be equal in size between the heaters as well as directly under them.

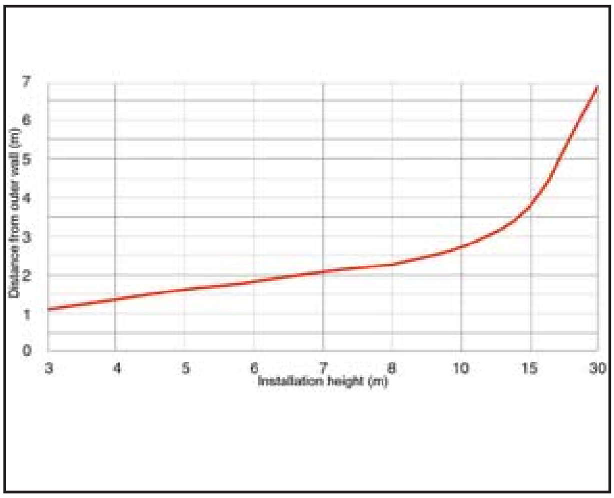


Figure 1. Recommended spacings between the ceiling heater closest to the outer wall (without window).

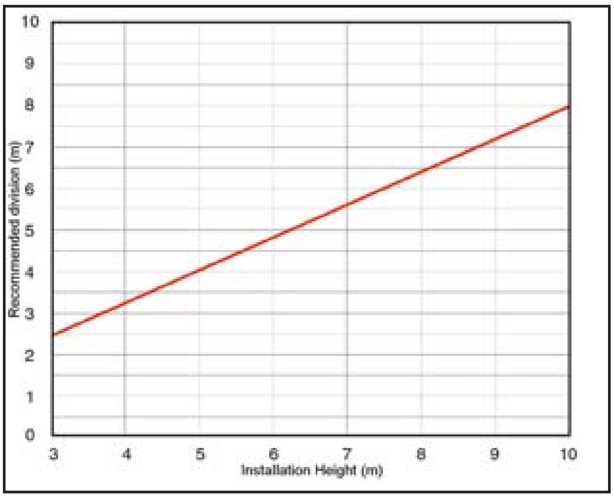


Figure 2. Recommended spacings between panels with ceiling heating.

Installation heights and temperature

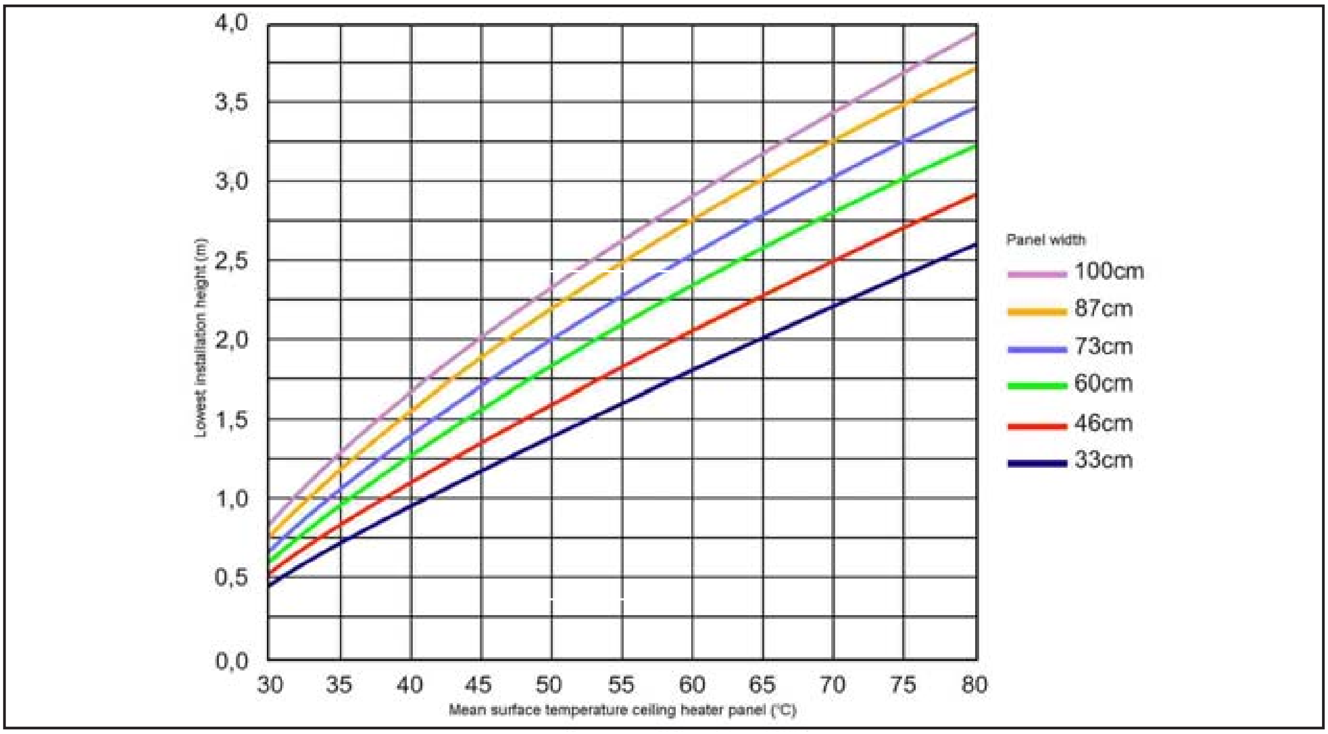


Figure 3. Lowest installation height for the ceiling heater with radiant temperature asymmetry of 5ºC. Ceiling heater length 3.6m.

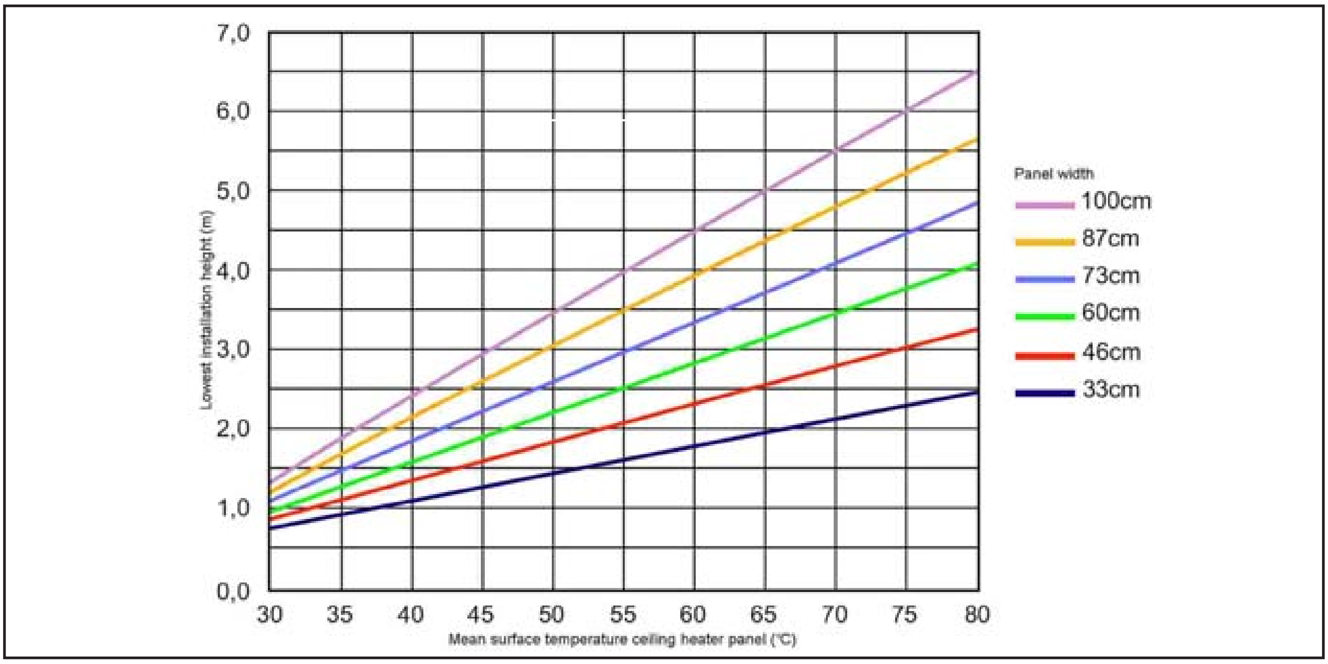
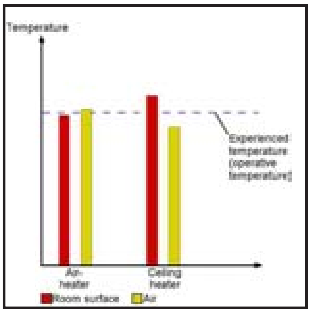
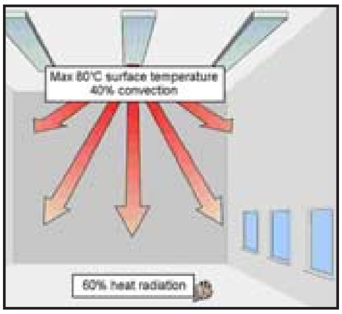


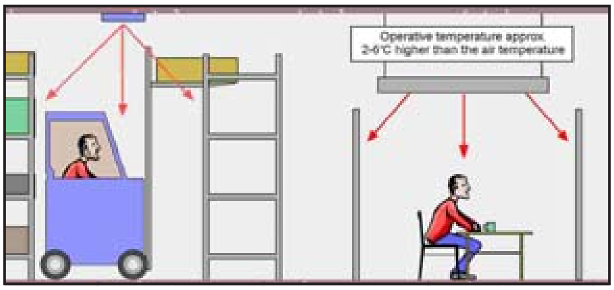
Figure 3. Lowest installation height for the ceiling heater with radiant temperature asymmetry of 5ºC. Ceiling heater length >10m.



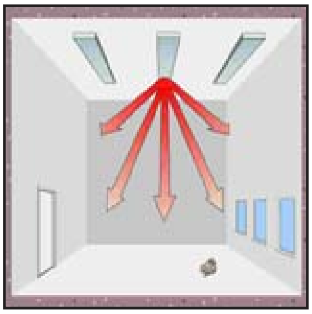
Ceiling heating heats the room surfaces via heat radiation. In tune the surfaces heat the air. This gives the prerequisites for a very good indoor climate.



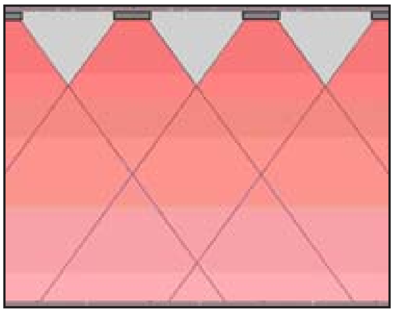
The ceiling height has no bearing on the heat reaching the entire building. Therefore the temperature does not need to be higher with higher ceiling heights.



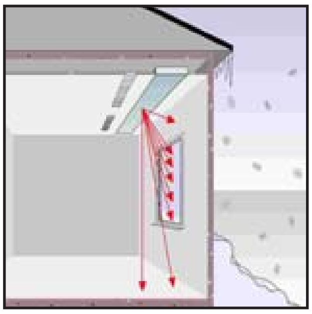
Ceiling heatings also works well for zone heating in a building. Heating of the adjacent surfaces and ceiling heating in itself means that the operative temperature can be increased by at least 2-6^{o}C above the air temperature. It will not be cold under the tables as the heat radiation indirectly reaches all parts of the room. All surfaces in the room contribute towards the heating, either through absorbing heat radiation, being heated and then radiating heat or through reflecting it. It will not be warm on your head. Frenger Systems ceiling heaters are waterborne with a standard max temperature of approx. 40-60oC, and are usually installed at an installation height of over 2.5m. This results in the heat radiation from the ceiling heaters being hardly unnoticeable.



Ceiling heating is indirectly floor heating! Radiant heat means that the floor is approx. 2-3^{o}C warmer than the air just above the floor.



Heat radiation is spread to all parts of the room that the ceiling heater can "see". Most radiation goes downwards and taking off to the sides. Heat radiation is also steered depending on the temperature if the recipient room surface.



The effect from heat radiation increases against cold surfaces. This means that the heat goes directly where it is most needed, i.e. heats the inside of a window so that the risk of cold draughts is eliminated.

Ceiling heating is among the most energy saving heating systems available. Ceiling heating allows 1-2oC lower room temperature and gives a very small temperature gradient in the building, i.e. no heat cushions by the ceiling. Ceiling heating systems can easily be changes with the enterprise. You do not need to consider the heating system when modifying the walls and floor.

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