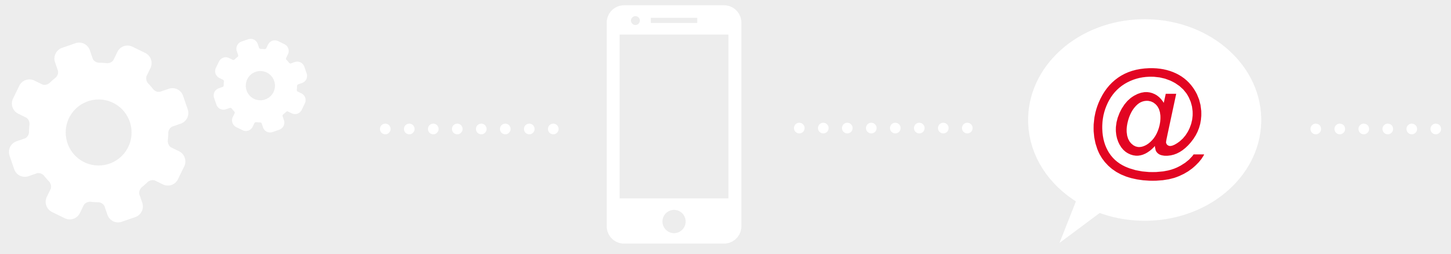
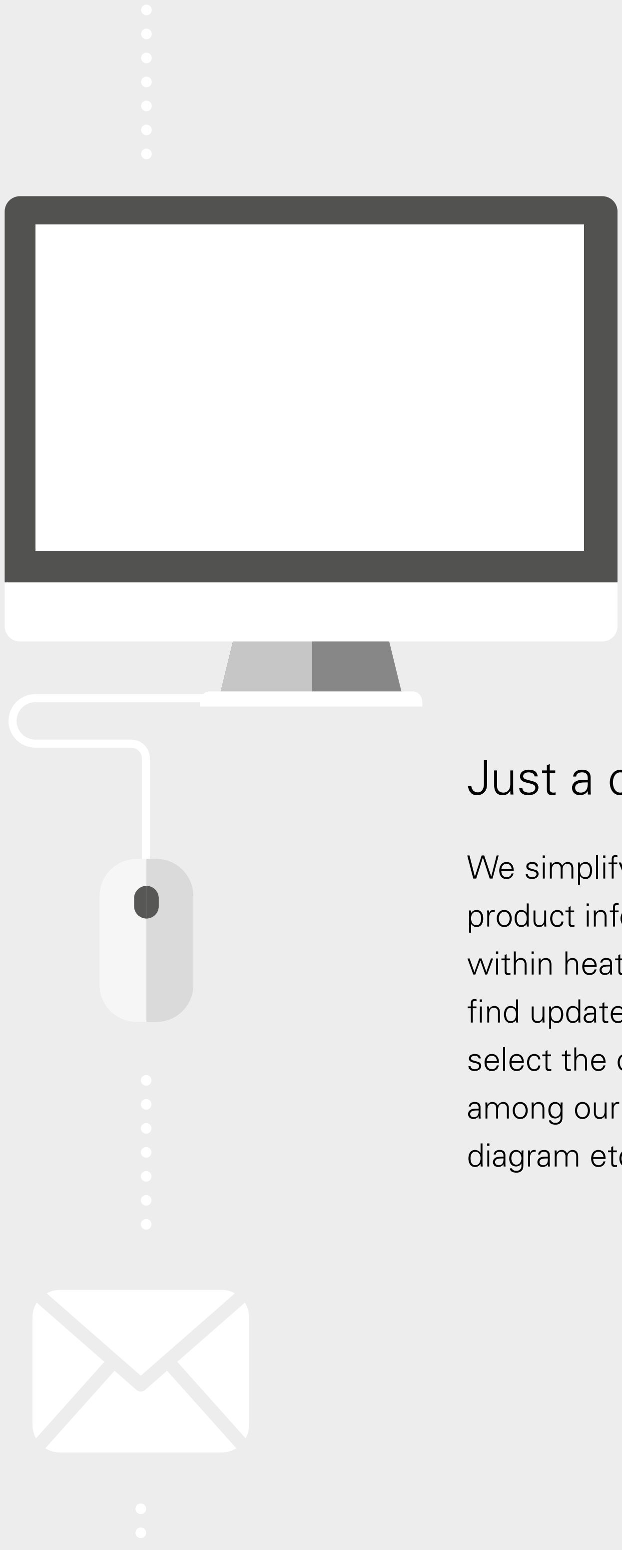
TECHNICAL HANDBOOK
RADIANT HEATERS





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We simplify everyday life by giving you relevant product information together with our knowledge within heating. At www.frico.net you will always find updated information, you can receive help to select the correct product and get inspiration from among our references, see our news, manuals, wiring diagram etc.

Technical handbook Radiant heaters

Heating - Energy

The need to heat a building depends on the temperature difference between the room air and outdoor air.

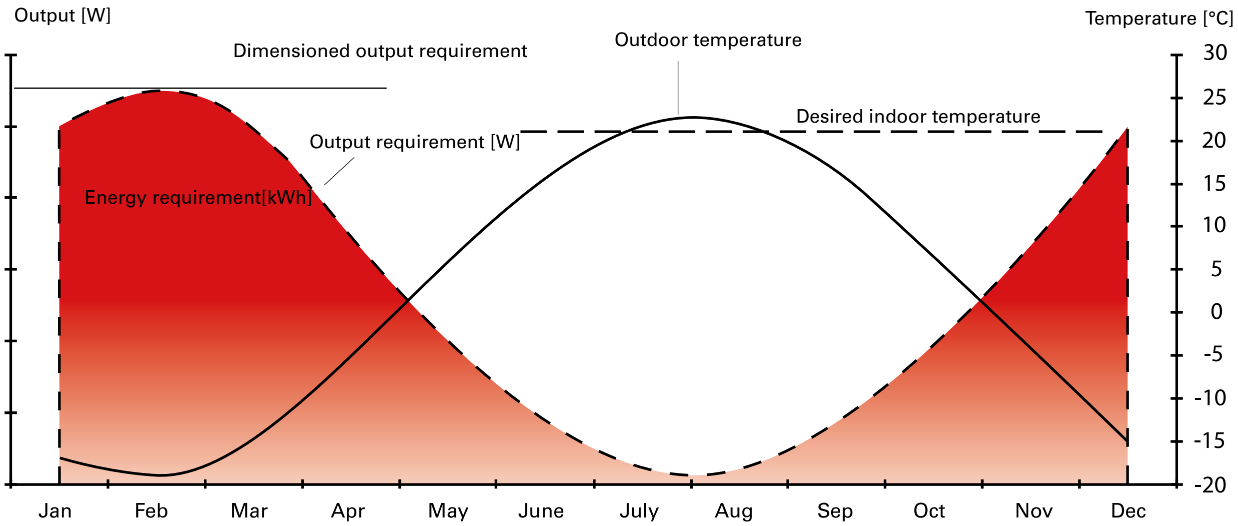
Energy losses in a building can be divided into two parts:

- Transmission losses: losses via building structures (roof, walls, etc.).
- Ventilation losses: losses through ventilation, leakage and openings.

The temperature of the outdoor air varies with the seasons and location, while the temperature of the rooms air should be maintained at a balanced and comfortable level.

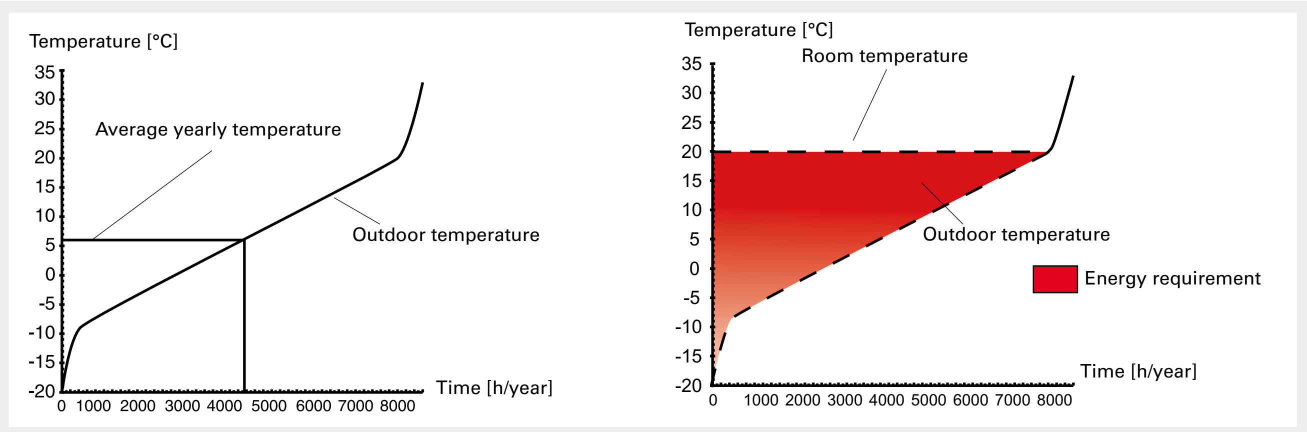
The energy requirement for a building is the energy consumed during a year, i.e. the coloured area in the diagram below.

The design output requirement for a building is the output required to maintain the required room temperature when it is cold outside.



Duration diagram

A common method of illustrating the energy requirement for heating is to use a Duration diagram. The Duration diagram has two axes. The X axis shows the number of hours in one year, the Y axis the outdoor temperature in °C. One can draw a curve to describe the duration of the outdoor temperature in each place. If the average temperature for the year, is +8 °C, then it is colder than +8 °C for six months or 4380 hours.
If a line for desired indoor air temperature is inserted into the diagram, e.g. 20 °C, this line will intersect with the duration diagram to show the number of degree hours that are needed for heating to 20 °C. The number of degree hours is a measurement that is proportional to the energy requirement for heating. For any particular place, one can either calculate based on such a diagram or consult climate tables, later on in the chapter.



Heating systems

The heating system must cover all energy losses, both from transmission and ventilation.
Three main types of heating systems are:

- Radiant heating
- Air heating
- Convective heating, i.e. radiators and convectors

Radiant heating

Radiant heating transfers heat to surfaces and objects without warming the air on the way. Surfaces are heated and then in turn heat the air within the room. People experience the direct contribution of radiant heat as warmth. The room feels comfortably heated even if the air temperature is relatively low. Radiant heating also prevents overheated air gathering under the ceiling. The equalized distribution of temperature vertically as well as the somewhat lower air temperature contributes to large energy savings.

Radiant heat effectively counteracts cold radiation and cold draughts from large windows, for example.

Air heating

Heating with warm air covers transmission and ventilation losses by supplying heated air to the building. The warm air cools along the outer walls, due to transmission losses. Therefore, the supply air temperature must be higher than the desired room temperature.

Because the heated air is lighter and rises in the room, large temperature differences between the ceiling and the floor can occur. At times, it may be necessary to equalize the differences with e.g. ceiling fans.

Convective heating

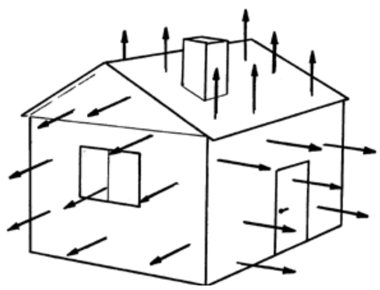
Convective heating transfers heat to the room by warming the air as it passes hot surfaces, radiators, or convectors. The air flow past the radiator or convector is maintained by thermal currents. The warmed air rises and is replaced by colder air. Rotation, or convection, of the air occurs.

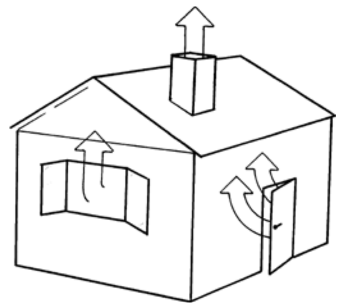
Cold draughts from e.g. windows are effectively counteracted by the rising stream of warm air if the heat source is placed under the window.

Technical handbook

Energy savings

Heat losses





Transmission losses

The size of transmission losses varies according to the areas of the building parts and insulation. The losses are proportional to the temperature differences between indoor air and outdoor air.

Ventilation losses

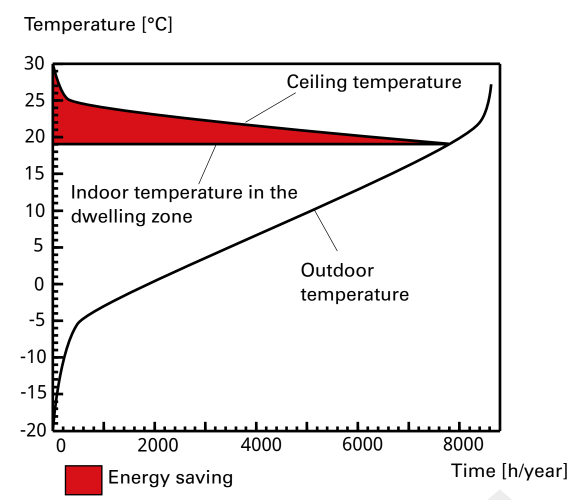
The ventilation in a building is either mechanical or of the natural type. Mechanical ventilation most often consists of a supply and exhaust air unit that makes heat reclamation possible. Natural and involuntary ventilation consists of thermal currents causing warm air to rise and leak through openings and unsealed areas.

Methods to reduce heat losses and heat costs

Improved insulation of a building naturally reduces heat losses and increases energy savings, but there are other methods of reducing heating costs as well.

Equalizing temperature differences

Warm air is lighter than cold air and is gathered in the highest spot inside a building. Vertical temperature differences between floor and ceiling occur. The temperature gradient (°C/m) is a standard of the temperature rise per metre of height and varies depending on the heating system and the season. In rooms with high ceilings, the temperature difference between the dwelling zone and the ceiling is often very big, between 10-15 °C. Equalizing the temperature differences can reduce heat losses by as much as 30 % while making optimal use of the heat.



Radiant Heaters

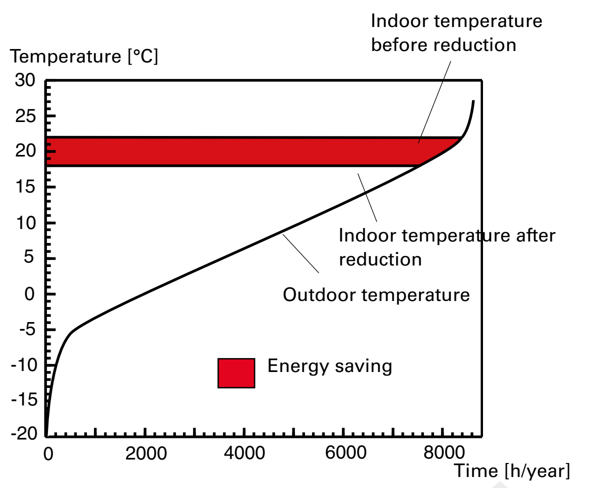
Heating with a ceiling mounted radiant heater is indirect. The heat develops when heat rays meet surfaces such as floors, walls, machines, etc. The surfaces then heat the air in the dwelling zone. The temperature difference between ceiling and floor thus becomes very small.

Ceiling Fans

Heating with e.g. fan heaters or radiators gives relatively high temperature gradients. The installation of ceiling fans is a very simple and inexpensive way to equalize the temperature difference. The heated air is pushed down from the ceiling to the dwelling zone.

Lower indoor temperature

Another method of saving energy is to lower the indoor temperature. However, this must be done without sacrificing the comfort.



• Lower air temperatures

Using radiant heaters, the air temperature in a room can be lowered by a few degrees while still maintaining an experienced high temperature, the so-called operative temperature. A reduction of the temperature by 1 °C results in energy savings of around 5 %. Operative temperatures are those temperatures which human beings feel. They are the sum of the air temperature and radiation temperatures. All objects provide radiant temperature changes. Cold surfaces cause a subtraction and warm surfaces an addition. Operative temperatures can be described thus:

$$t_{op} = \frac{t_{air} + t_{rad.}}{2} = \frac{t_{air} + (t_{air} + \Delta t_{rad.})}{2} = t_{air} + \frac{\Delta t_{rad.}}{2}$$

where t_{air} = air temperature
$t_{rad.}$ = radiant temperature (incl. air temperature)
$\Delta t_{rad.}$ = radiant temperture change (excl. air temperature)

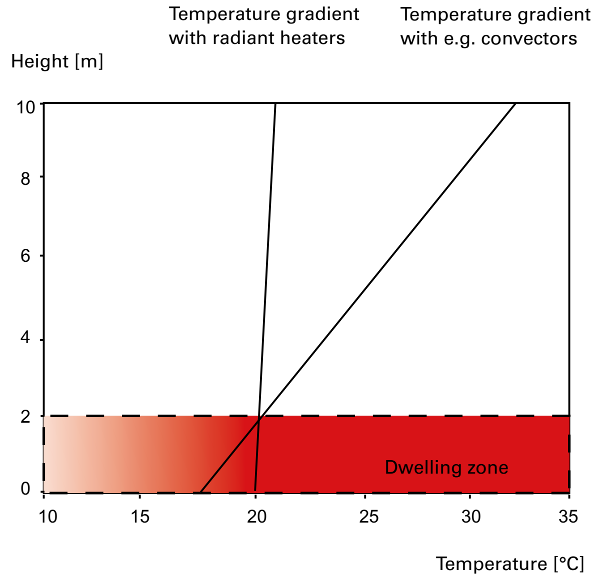
• Zone and spot heating

With radiant heaters, different zones of a building may have varying temperatures. The entire building does not have to have the same high temperature if for example work stations are far apart. Even the comfort aspect means that different work situations require different temperatures. Spot heating can be regarded in the same way as spotlighting. When someone is there, the heating or lighting is increased.

• Low temperature gradient

Heating with radiant heaters provides a highly equalized vertical temperature distribution. The heat develops when the rays meet surfaces such as floors, walls, machines, etc. The surfaces in turn heat the air in the dwelling zone. The temperature differences between the ceiling and the floor become very small and ”overheating” minimal. Especially in buildings with high ceilings, great energy savings are obtained compared to conventional heating systems.

The temperature gradient [°C/m], the temperature rise per metre of height, is very low for radiant heaters, approx. 0.3 °C/m. Warm air heating or heating with conventional radiators causes significantly greater temperature differences per metre of height with temperature gradients of 2.5 and 1.7 °C/m respectively, at full output.



• Time control

When there is no-one in the building, e.g. at night and on holidays, the temperature can be lowered.

Reduce leakage

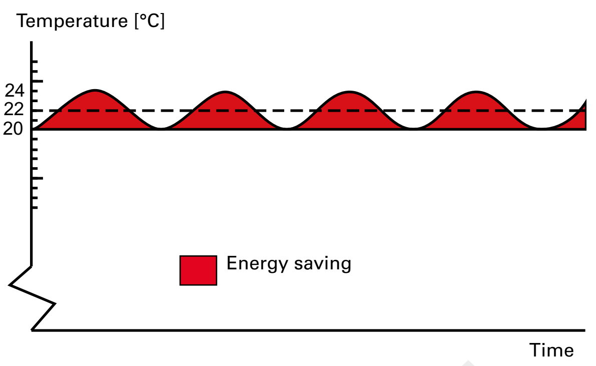
Tremendous energy losses often occur through openings such as doors and gates. Expensive heated or cooled (air-conditioned) air disappears through the opening. This can be prevented by the installation of air curtains. Air curtains create a separation between different temperature zones. Balanced ventilation and shorter opening times also contribute to the reduction of energy leakage. Read more about Frico air curtains on our website.

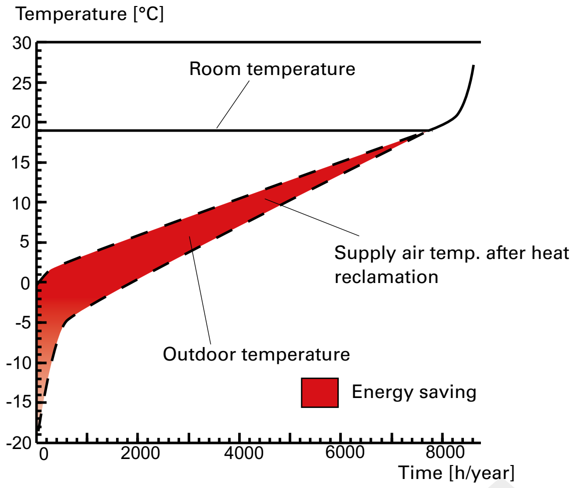
Greater equalization of temperatures

A standard on/off thermostat can be used to vary the temperature around a set value. If the desired temperature should never be lower than 20 °C, the average temperature is approximately 22 °C. With a triac-controlled output regulator, the room temperature can be set to 20 °C and the temperature won't deviate from the setting. Lowering the temperature by 1 °C gives energy savings of 5 %.

Heat reclamation

To reduce ventilation losses when ventilation is mechanical, a portion of the energy content of the exhausted air can be reclaimed. One simple method is to immediately recycle portions of the warm exhaust air to the supply air unit, so-called return air. Another way is to use a heat exchanger that takes in and returns portions of the heating energy to the building.

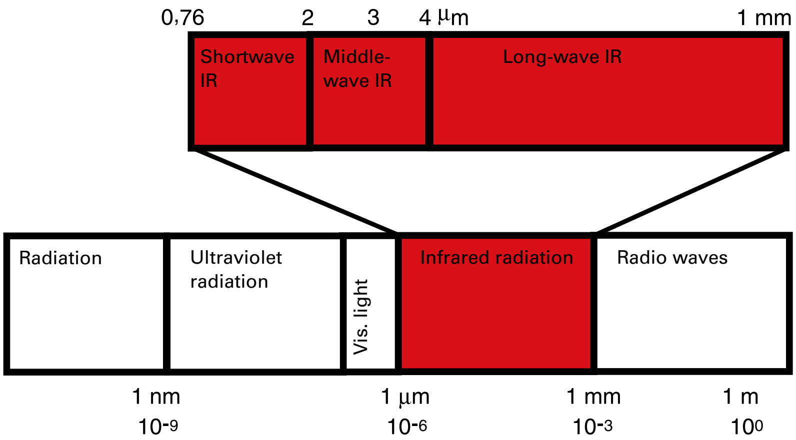




What is radiant heating?

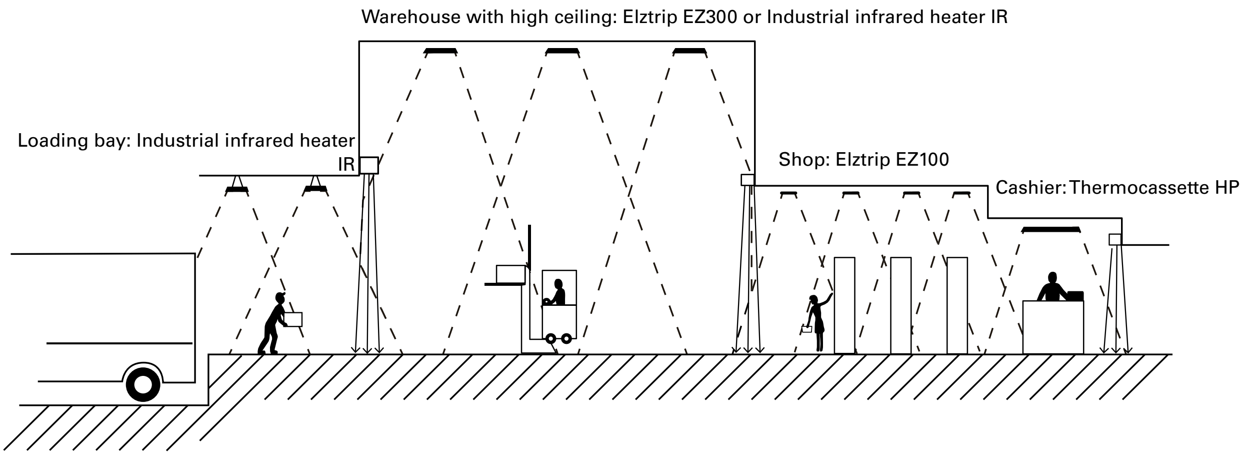
Temperature radiation arises because all bodies emit energy in the form of electromagnetic radiation. Because the radiation comes from a warm body, it is called heat radiation. The figure below shows where temperature radiation is found in the electromagnetic spectrum. Wavelength and radiation intensity from radiant heaters are temperature dependent. The higher the element temperature of the radiant heater, the shorter the wavelength and the higher the radiation intensity.

Two bodies only exchange radiation if there is a temperature difference between them. Human beings constantly exchange heat with their environment. When you loose a lot of heat you are cold. It is necessary to reach a thermal point where there is balance, this point corresponds with the so called comfort temperature. The comfort temperature is defined by the air temperature, wall temperature, air speed and atmospheric humidity. Heating with radiant heating is perfect to maintain a good comfort.



Electromagnetic spectrum

Examples of usage of various radiant heaters



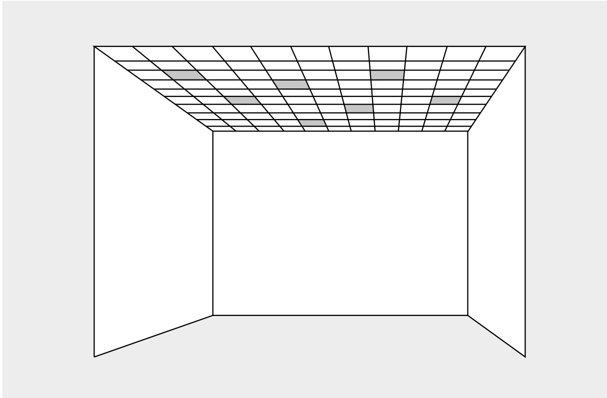
Guidance – radiant heating indoors

Total heating

The output requirements of a building must be calculated when designing a heating system. Read about Output and energy calculations on the following pages. For radiant heaters with a lower element temperature (e.g. Thermocassette HP and Elztrip) there is a rule of thumb to estimate approximately how many radiant heaters are required to heat a building:

$$\text{Min. number of heaters} = \frac{\text{Area of the premises [m}^2\text{]}}{\text{Installation heigth [m]} \times \text{Installation heigth [m]}}$$

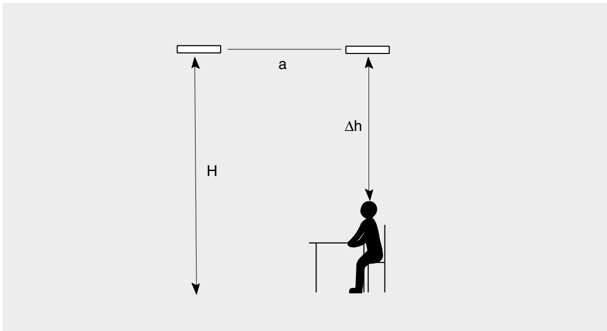
This formula is a basic estimation of the minimum number of radiant heaters needed to maintain the comfort. To calculate the right output for each heater, the total heating requirement must be calculated.



Example of the total heating with Thermocassette HP installed in a suspended ceiling.

Recommended distances for Elztrip

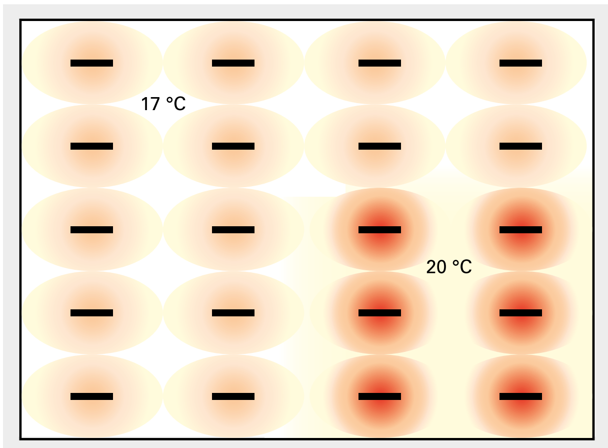
When planning an installation, the distance between the heaters should not be greater than the height between heater and floor, that means (a) should be less than (H). See pictures. In rooms not often used, the comfort demands are usually lower and the distance between the heaters can be increased. In rooms frequently used, the distance between a sedentary person and heater should be at least between 1.5 to 2 metres (Δh). When these two guide lines are followed, the difference in operative temperature will not exceed the comfort level Δtop= 5 °C. This means that the difference between the real temperature and the temperature that we sense, will not be more than 5 °C.



Recommended distances for Elztrip

Zone heating

Different work situations require different temperatures. With radiant heaters such as Elztrip, it is simple to divide the building into temperature zones or to spot heat individual work stations. This results in lower heating costs and better heating comfort.



Plan sketch: Temperature zones with radiant heaters.

Suitable radiant heaters for zone heating are Thermocassette HP, Elztrip, IR and Aquaztrip, depending on the installation height and the condition of the building.

Complementary heating

As addition to other heating systems and when expanding an existing system, radiant heaters are often a simple, inexpensive solution. For a water heated building, putting up a single or a few electrical heaters is often a smoother and more flexible solution than extending the water pipe system.

Further enhances energy efficiency

Heating with radiant heaters is very energy efficient, however there are even greater possibilities for energy savings while maintaining comfort. Improved results can be achieved by supplementing with a black bulb sensor (which measures the operative temperature) or presence detector (which ensures that the heater is only used when necessary).

Black bulb sensor

The addition of radiant heating's direct heat means that the air temperature in the building can be slightly lowered by a few degrees without affecting the level of comfort. Read about perceived, operative temperature on the previous pages.

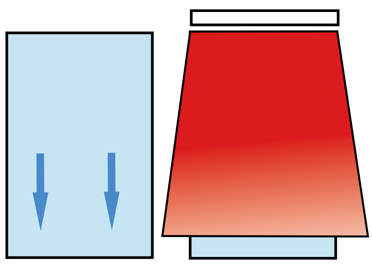
A black bulb sensor which measures the perceived combination of air and radiant temperature is connected to the thermostat in order to fully utilise this output. When it is at its coldest, the radiant addition will be at its greatest resulting in the largest saving thanks to the black bulb sensor. Lowering of the air temperature by 1 °C gives an energy saving of approx. 5 %.

Presence detector

A radiant heater starts to heat immediately once it is switched on, which is ideal when used in combination with a presence detector. Thus, the radiant heater is only used when necessary, which ensures energy saving.

Cold draught protection

A cool surface such as a window has a chilling effect on the neighbouring air. Radiant heaters provide efficient and economical protection against cold draughts caused by windows by heating the window's surface. The colder the window, the more radiant heat it will draw. The radiated heat "automatically" migrates to where it is most needed, which facilitates the creation of a comfortable indoor climate.

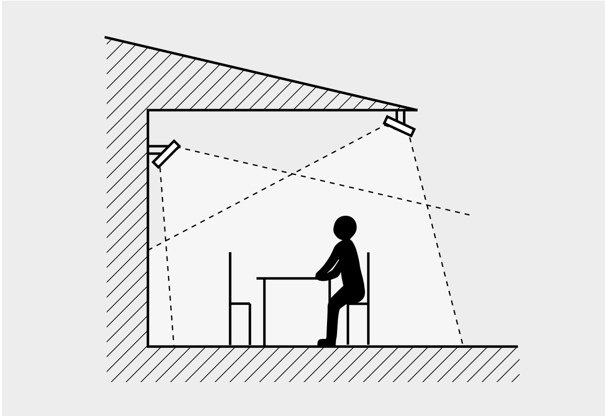


Suitable radiant heaters for draught protection are Thermoplus, Thermocassette HP, Elztrip and Industriinfra IR, depending on the installation height and window area.

Guidance – radiant heating outdoors

Positioning

The heaters must be placed so that they cover the area to be heated. Optimum comfort is achieved if the heat is distributed from at least two directions.



The heaters should heat from at least two directions for even heating.

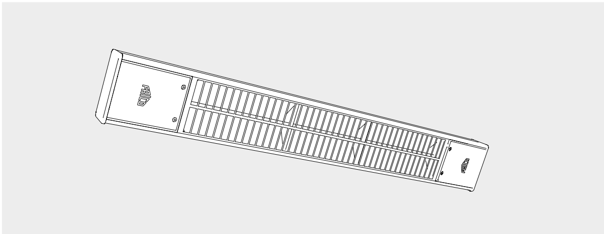
Output requirement

A rule of thumb for the output requirement can be used to estimate how many and which radiant heaters are required. The output demand can be reduced if the area to be heated is protected. For enclosed areas, the output demand must be calculated.

Should it be very windy, a higher output heater would be required to ensure adequate heating. The same applies to installation height; should the heaters be installed relatively high, a higher output would be required.

Infrared heater with tubular elements

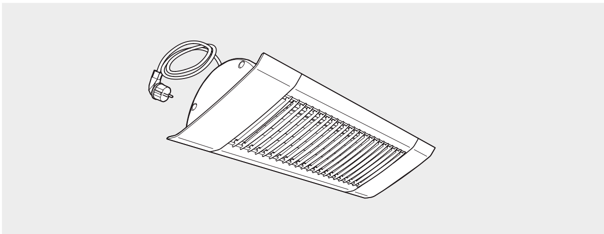
750–1000 W/m² raises the perceived temperature by approx. 10 °C.
If the area only has a roof: at least 1000 W/m².
If the area has three walls: 750 W/m².



Infracalm is an example of an infrared heater with tubular elements.

Halogen and carbon infrared heaters

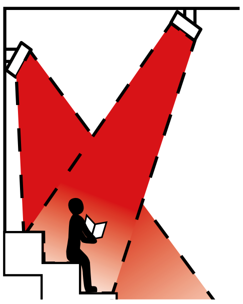
600–800 W/m² raises the perceived temperature by approx. 10 °C.
If the area only has a roof: at least 800 W/m².
If the area has three walls: 600 W/m².



Halogen infrared heater IH and Carbon infrared heater IHC have the same appearance, but with different lamps and heat distribution.

Installation height

Should the heater be mounted at a raised height, distribution should be directed in such a way that it can be felt all the way down to the seating area. However, should the heater have a low placement, directed radiant heat can be perceived as uncomfortable and a radiant heater with wide distribution would be more suitable.



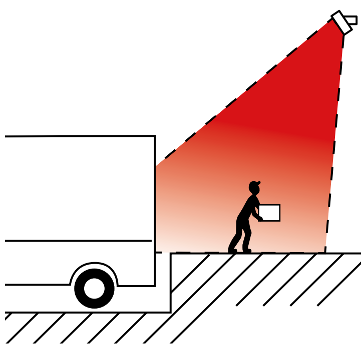
Problem solutions for outdoors

Radiant heaters are not only used for pavement cafés and terraces, they can also be used as a solution for numerous outdoor heating problems.

Heating sedentary spectators in a sports stand is something that radiant heaters can do well.

Problems with ice formation on e.g. loading bays can be easily solved with an infrared heater for outdoor use which is mounted on an outer wall.

Temporary heating is often required for outdoor customer events. A radiant heater on a portable stand which can be moved around as required is a practical solution.

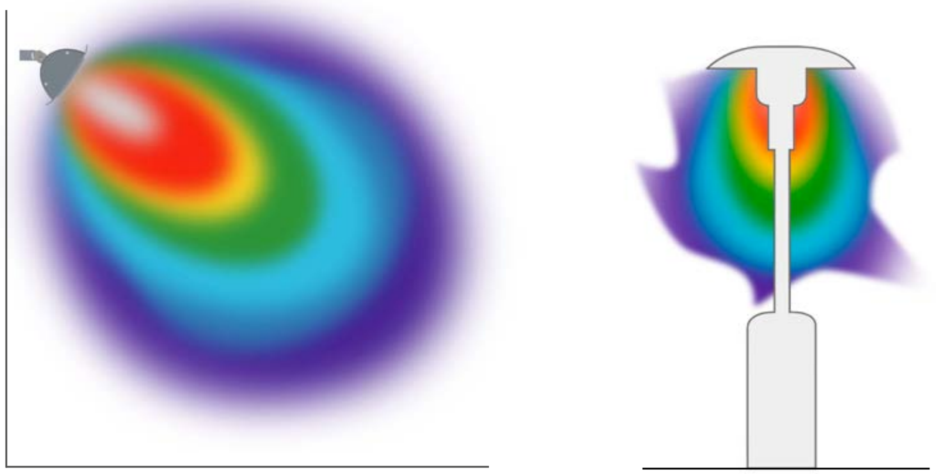


Comparison between electric infrared heaters and gas heaters (LPG)

An alternative to an electric infrared heater is a terrace heater using LP gas. A gas heater requires no electrical connection, which at times can be practical, yet there are more advantages of electric infrared heaters.

Advantages of an electric infrared heater:

- Energy efficient - nearly all additional energy is converted to heating
- Safe to use
- Copes better with weather and wind
- Requires a minimum of maintenance
- Heats immediately as soon as you press the on button
- Can also be used in smaller areas where oxygen supply is limited
- Better for the environment
- Space effective
- Low operating costs



The comparison between Frico's infrared heater IHW and a gas heater (LPG) indicates that the gas heater does not last as long and delivers a variable result.

Calculation example - operating costs

Area: 15 m²
Used 8 hours/day
Used 100 days/year

Infrared heater IHW10 (2 pcs)		Gas heater (LPG)	
		Gas cylinder 11 kg	20€
Electricity rate (European average)	0,2€/kWh	Gas consumption	1 kg/h
Operating cost per hour	0,4 €	Operating cost per hour	1,8 €
Operating cost per day	3,2 €	Operating cost per day	14,4 €
Operating cost per year	320 €	Operating cost per year	1440 €

Output and energy calculation

Output requirements

Heat losses from a building consist of two parts. Transmission losses through walls, floors, windows, doors and the roof, and ventilation losses.

Transmission losses:
$P_T = A \times U \times (t_{room} - DUT)$

Ventilation losses:
$P_v = q \times c \times \rho \times (t_{room} - DUT)$
or
$P_v = Q \times (1- \alpha) \times (t_{room} - DUT) \times 0.33$

where
U = thermal transmittance value [W/m² °C] (=K-value)
A = area of enclosed surfaces [m²]
t_{room} = room temperature [°C]
DUT = lowest dimensioned outdoor temperature of the district [°C]
q = calculated outdoor air flow [m³/s]; forced air flow need not be regarded
c = specific heating capacity [J/kg°C]
ρ = density [kg/m³]
Q = air flow [m³/s]
α = efficiency of heat reclamation, 0 - 1

The thermal transmittance values, U-values, can be read in tables and diagrams or be calculated if the constituent materials are known.

Energy requirement

The energy requirement for heating is determined by the output requirement and the number of degree hours required for heating to the desired temperature. The theoretical energy requirement goes down due to internal heating energy E_1.

Actual energy requirement

$$E = \frac{Pt}{t_{room} - DOT} \times °Ch + \frac{Pv}{t_{room} - DOT} \times °Ch - E_1$$

Internal heat energy
$E_1 = P_i \times A_{floor} \times \text{Operation} \times 8760$

°Ch = number of degree hours for heating
E_1 = internal heat energy [Wh/year] (depending on room activities, is read off in tables and diagrams)
P_i = internal heat output [W/m²]
Operation = operation time factor for internal heat output

Operation time factor is calculated from the operation time for the activity and is:
Operation = (hours/24) × (days/7)
hours = number of hours per day in operation
days = number of days per week in operation

Ventilation systems can also have operation time factors if they are run at half speed or stopped during the night.

Technical support

Frico Technical support offered free of charge :

- Output and energy calculations
- Solutions to heating problems and energy saving advice
- Dimensioning and positioning
- Solutions for heating and comfort

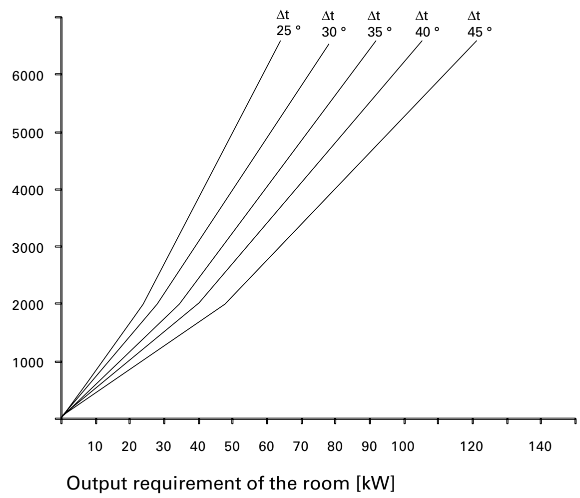
Contact us to discuss heating and energy savings.

On our website www.frico.net you can easily make an output calculation by filling in data about the building and and temperatures. The more precise your information is, the more certain will the results of the calculation be.

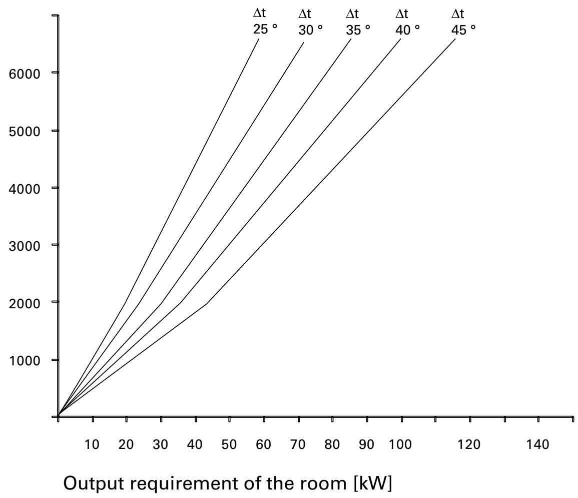
Ready reckoner, output requirement

For those who do not know all the facts about the premises an estimation of the output requirement can still be made. If you know the room volume and the desired room temperature you can read off the output requirement in the diagram below. The basis for the diagram is output requirement calculations made according to accepted methods. In the calculations, the air flow is set to one air change in the room or building per hour. It is provided that the four walls are outer walls and the roof above the ceiling is outdoors. In the output requirement diagram A and B, the average U-value is set at 0,25 and 0,4, which is equivalent to a well insulated building. In diagram C the average U-value is set at 1.0, indicating that the building is less well insulated. The curves Δt in the diagram show the difference between room temperature and the lowest outdoor temperature.

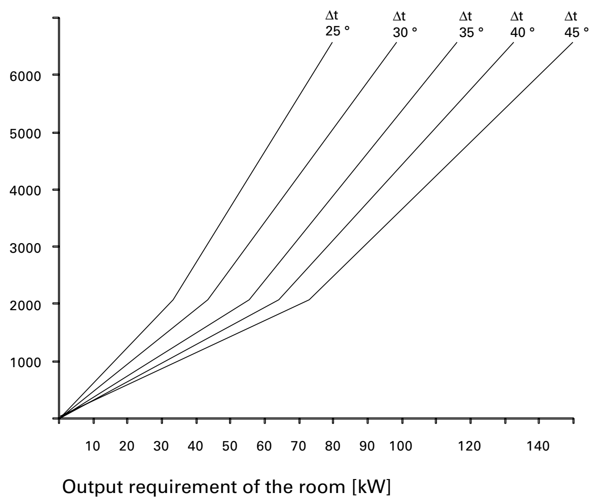
Output requirement diagram A
Average U-value 0.25



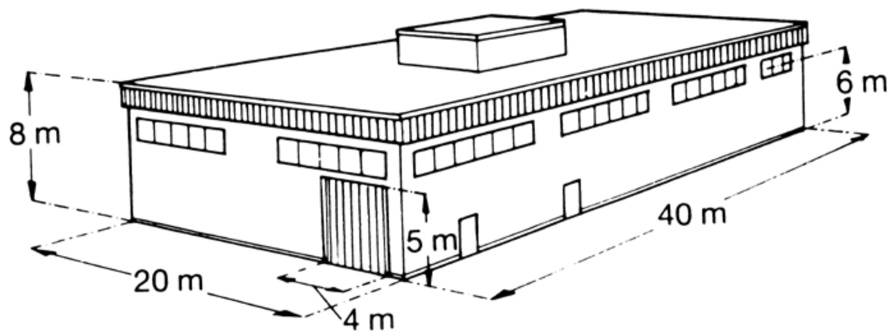
Output requirement diagram B
Average U-value 0.4



Output requirement diagram C
Average U-value 1,0



Calculation example



Input

Object: Industrial building

Building dimensions
Length: 40 m
Width: 20 m
Height: 8 m
Window area: 130 m²
Doors: 25 m²

Construction materials

Walls:	Light concrete block 30 cm	U = 0.6
Roof:	Light concrete block 30 cm	U = 0.6
Windows:	2-pane, 6 m above floor	U = 3.0
Doors:	Ins. sheet metal, folding door	U = 1.0

Time in operation: 12 hrs/day, 5 days a week

Ventilation
Natural ventilation, day: 0.4 ch./h
Natural ventilation, night: 0.3 ch./h
Internal heat output: 5 W/m²

Indoor temperature
Desired day temperature: +18 °C
Desired night temperature: +15 °C

District data
Dimensioned outdoor temperature DOT: -18 °C
Annual average temperature: 5 °C
Average wind velocity: 4,0 m/s

Estimation

Output requirement

Transmission losses: $P_T = A \times U \times \Delta t$

	Area [m²]	U-value	Δt [°C]	Output [W]
Outer wall	805	0.6	36	17388
Roof	800	0.6	36	17280
Floor	800	0.3	36/2	4320
Window	130	3.0	36	14040
Doors	25	1.0	36	900

Total transmission losses: 53 928 W

Ventilation losses: $P_V = V_{building} \times n \times \Delta t \times 0{,}33$

	Bldg. air volume [m³]	Air changes [ch./h]	Δt [°C]	Output [W]
Day	6400	0.4	36	30413
Night	6400	0.3	33	20909

The maximum ventilation losses are during the day.

Dimensioned output requirement:
53 928 + 30 413 = 85 kW

Energy requirement

Transmission energy: $E_T = P_T/\Delta t \times$ °Ch
E_T = 53 928/36 × 97 330 = 146 MWh/yr

Ventilation energy: $E_V = P_V/\Delta t \times$ °Ch
Day: 30413/36 × 97330 × 12/24 × 5/7 = 29 MWh/yr
Night: 20909/33 × 97330 × (1 - 12/24 × 5/7)= 40 MWh/yr

Internal heat: $E_I = P_I \times A_{floor} \times 8760$
E_I = 5 × 800 × 8760 × 12/24 = 12,5 MWh/yr

Total energy requirement: $E_T + E_V - E_I$ = 202,5 MWh/yr

Calculation example

Assume that the industrial building in the example is to be heated either with radiant heaters, e.g. industrial infrared heater IR or fan heaters. Based on that, we make a computer calculation of output and energy requirements especially for these heating methods.

The calculation program also takes the temperature gradient °C/m (temperature rise per metre of height) into consideration which is of great importance with reference to the height of the building and the method of heating.

Area and height	
Bldg. ground area	800 m²
Roof area	800 m²
Building height	8 m
Window area	130 m²
Mounting height, window	6 m
Door area	25 m²
Outer walls area	805 m²
Infiltration	
Air changes, day	0.4 ch./h
Air changes, night	0.3 ch./h

U-value	
Window U-value	3.0 W/m² °C
Door U-value	1.0 W/m² °C
Outer wall U-value	0.6 W/m² °C
Roof U-value	0.6 W/m² °C
Floor U-value	0.3 W/m² °C
Extra heat sources	
Internal heat	5 W/m²
Energy price	
Electricity rate (European average)	0,2 €/kWh

	Radiant heaters	Fan heaters	Fan heaters with ceiling fans	
Temperature				
Dim. indoor temperature	17	18	18	°C
Dim. outdoor temperature	-18	-18	-18	°C
Annual average temp.	5	5	5	°C
Temperature gradient	0,3	2,5	0,3	°C/m
Night temperature	14	15	15	°C
Time in operation				
TIO day temperature	11	12	12	h/day
TIO night temperature	13	12	12	h/day
Days/week in operation	5	5	5	days
RESULTS				
Output				
Transmission losses	54 201	68 684	55 699	W
Ventilation losses	+ 30 202	+ 35 693	+ 31 046	W
Total losses	84 402	104 377	86 745	W
Internal heat	- 4 000	- 4 000	- 4 000	W
Total net output req.	80 402	100 377	82 745	W
Output req./m²	101	125	103	W/m²
Output req./m³	13	16	13	W/m³
Energy kWh/yr				
Energy req. daytime	88 075	130 340	103 787	kWh/yr
Energy req. nighttime	+ 70 252	+ 88 309	+ 71 975	kWh/yr
Total gross energy req.	158 327	218 649	175 761	kWh/yr
Internal heat	- 12 514	- 12 514	- 12 514	kWh/yr
Total net energy req.	145 813	206 135	163 247	kWh/yr
Annual operation cost	29 163	41 227	32 649	€/yr

Energy saving

A comparison of the energy requirement results from the calculations:
Industrial infrared heater IR: 146 MWh/yr
Fan heaters: 206 MWh/yr
Fan heaters and ceiling fans ICF: 163 MW/yr
Energy savings with radiant heaters: 60 MWh/yr

Radiant heater IR result in approx. 30 % lower energy consumption when compared to fan heaters. If ceiling fans are used with the fan heaters, the difference is 20 %.

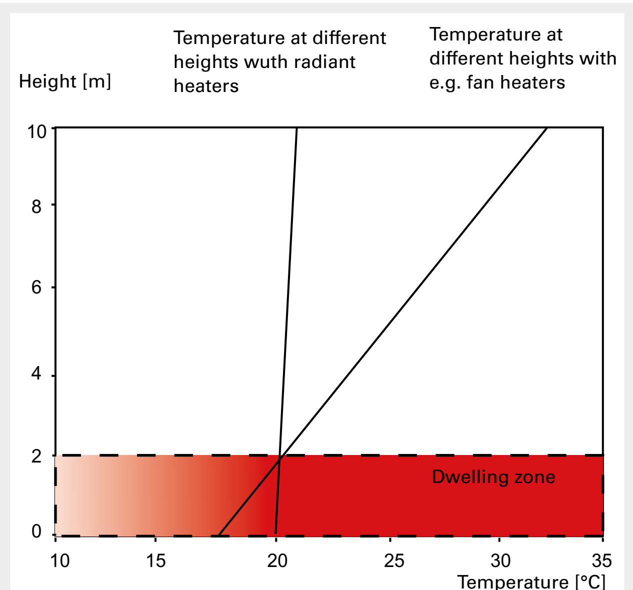
Savings factors

- **Low Temperature Gradient**

Radiant heaters have a relatively low temperature gradient (approx. 0.3 °C/m) compared to fan heaters (approx. 2.5 °C/m). Vertical temperature is better equalized, which means lower heat losses and better use of supplied heating output in the dwelling zone.

- **Radiant temperature contribution**

Industrial infrared heaters also supply a radiant temperature contribution ”free of charge”. The air temperature in the room can be lowered somewhat with a maintained operative (experienced) temperature. The diagram below shows how large the radiant temperature contribution is with the IR 4500. The heaters are ceiling mounted at a height of 8 metres above the floor. Measurement is done 1.5 metres above the floor. (Height above point of measure = 6.5 m.)

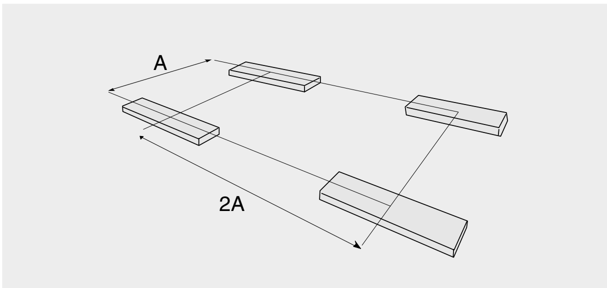


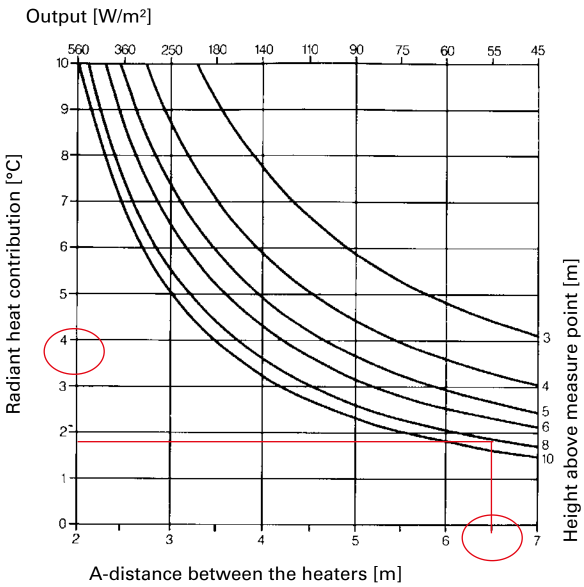
Temperature gradient at full output

The diagram for radiant temperature contribution shows:
Δt_{rad} = 2 °C, A-distance 6.5 metres between the units.

$\Delta t = t_{room} + \Delta t_{rad}/2 \Rightarrow t_{room} = t_{op} - \Delta t_{rad}/2$

In our example: $t_{room} = 18 - 2/2 = 17$ °C





Radiant heat contribution IR 4500

- **Fast heating**

Heating with radiant heaters is faster than airborne heat. If we have a lower temperature at night as in the example we can lengthen the night time temperature.

Recommendation and positioning

The output requirement for the industrial building heated with infrared heater IR is just over 80 kW. Recommendation: 18 Industrial infrared heaters IR at 4.5 kW each.

Tables for dimensioning

Basic electrical formulas

Amperage

Direct current and 1-phase alternating current at cosφ=1	3-phase alternating current Y-connection	3-phase alternating current Δ-connection
I=U/R=P/U	$I_f = I$	$I = I_f \sqrt{3}$

Voltage

Direct current and 1-phase alternating current at cosφ=1	3-phase alternating current Y-connection	3-phase alternating current Δ-connection
U=RI	$U = U_f \sqrt{3}$	$U_f = U$

Output

Direct current and 1-phase alternating current at cosφ=1	3-phase alternating current Y-connection	3-phase alternating current Δ-connection
P=UI	$P = \sqrt{3} UI \cos\varphi$	$P = \sqrt{3}\ UI \cos\varphi$

U = operating voltage in volts: with DC and singlephase AC between the two conductors, with 3-phase AC two phases (not between phase and zero).
U_f = voltage between phase and zero in a 3-phase cable.
$\sqrt{3} \cong 1.73$
I = amperage in ampere
I_f = amperage in ampere in phase wire
R = resistance in ohm
P = output in watt

Symbols for model types

= normal design (no symbol), IPX0
= drip-proof design, IPX1
= splash-proof design, IPX4
= jet-proof design, IPX5

Enclosure classes for electrical materials

IP, first figure	Protection against solid objects
0	No protection
1	Protection against solid objects ≥ 50 mm
2	Protection against solid objects ≥ 12.5 mm
3	Protection against solid objects ≥ 2.5 mm
4	Protection against solid objects ≥ 1.0 mm
5	Protection against dust
6	Dust-tight

IP, second figure	Protection against water
0	No protection
1	Protection against vertically dripping water
2	Protection against dripping water max 15°
3	Protection against sprinkled water
4	Protection against spraying with water
5	Protection against water jets
6	Protection against heavy seas
7	Protection against short immersion in water
8	Protection against the effects of long-term immersion in water

Dimensioning table for cables and wiring

Installation wires, open or in conduit		Connection wires		
Area [mm²]	Fuse [A]	Area [mm²]	Continous current [A]	Fuse [A]
1.5	10	0.75	6	10
2.5	16	1	10	10
4	20			
6	25	1.5	16	16
10	35	2.5	25	20
16	63	4	32	25
25	80	6	40	35
35	100	10	63	63
50	125			
70	160			
95	200			
120	250			
150	250			
185	315			
240	315			
300	400			
400	500			

Dimensioning table

Current load at different outputs and voltages

Output	Connection wires					
[kW]	127/1	230/1	400/1	230/3	400/3	500/3
1.0	7.85	4.34	2.50	2.51	1.46	1.16
1.1	8.65	4.78	2.75	2.76	1.59	1.27
1.2	9.45	5.22	3.00	3.02	1.73	1.39
1.3	10.2	5.65	3.25	3.27	1.88	1.50
1.4	11.0	6.09	3.50	3.52	2.02	1.62
1.5	11.8	6.52	3.75	3.77	2.17	1.73
1.6	12.6	6.96	4.00	4.02	2.31	1.85
1.7	13.4	7.39	4.25	4.27	2.46	1.96
1.7	14.2	7.83	4.50	4.52	2.60	2.08
1.9	15.0	8.26	4.75	4.78	2.75	2.20
2.0	15.8	8.70	5.00	5.03	2.89	2.31
2.2	17.3	9.67	5.50	5.53	3.18	2.54
2.3	18.1	10.0	5.75	5.78	3.32	2.66
2.4	18.9	10.4	6.00	6.03	3.47	2.77
2.6	20.5	11.3	6.50	6.53	3.76	3.01
2.8	22.0	12.2	7.00	7.03	4.05	3.24
3.0	23.6	13.0	7.50	7.54	4.34	3.47
3.2	25.2	13.9	8.00	8.04	4.62	3.70
3.4	26.8	14.8	8.50	8.54	4.91	3.93
3.6	28.4	15.7	9.00	9.05	5.20	4.15
3.8	29.9	16.5	9.50	9.55	5.49	4.39
4.0	31.15	17.4	10.0	10.05	5.78	4.62
4.5	35.4	19.6	11.25	11.31	6.50	5.20
5.0	39.4	21.7	12.50	12.57	7.23	5.78
5.5	43.3	23.9	13.75	13.82	7.95	6.36
6.0	47.3	26.1	15.0	15.1	8.67	6.94
6.5	51.2	28.3	16.25	16.3	9.39	7.51
7.0	55.0	30.4	17.50	17.6	10.1	8.09
7.5	59.0	32.6	18.75	18.8	10.8	8.67
8.0	63.0	34.8	20.0	20.1	11.6	9.25
8.5	67.0	37.0	21.25	21.4	12.3	9.83
9.0	71.0	39.1	22.5	22.6	13.0	10.4
9.5	75.0	41.3	23.75	23.9	13.7	11.0
10.0	78.5	43.5	25.0	25.1	14.5	11.6

For outputs between 0,1 and 1 kW, the amperage read is multiplied by 0.1. For outputs between 10 and 100 kW, the amperage read is multiplied by 10.

Technical handbook

Climate data

Place	Av. daily temp [°C]	Extremes in Dec. [°C]	Av. wind speed [m/s]
Scandinavia			
Tromsö	2.9	-14.9	3.0
Karesoando	-1.5	-30.2	1.5
Sodankyle	-0.4	-43.1	3.0
Trondheim	4.9	-20.2	3.2
Vaasa	3.5	-30.2	3.8
Bergen	7.8	-8.4	3.2
Oslo	5.9	-20.2	2.2
Stockholm	6.6	-16.3	3.8
Göteborg	7.6	-15.8	4.0
Copenhagen	8.5	-11.4	2.3
British isles, France, Belgium, The Netherlands, Luxemburg			
London	10.4	(-12)	-
Eelde	8.7	-14.6	5.3
De Bilt	9.3	-20.8	3.3
Ostend	9.9	-13.5	6.5
Brussels	9.9	-16.0	3.8
Lille	9.7	-14.0	4.5
Luxemburg-City	8.8	-15.2	
Le Havre	10.6	-7.8	-
Paris	10.9	-13.2	3.9
Strasbourg	9.7	-21.0	2.2
Brest	10.8	-5.0	5.0
Tours	11.2	-18.0	3.7
Nantes	11.7	-10.8	3.6
Lyon	11.4	-24.6	3.0
Bordeaux	12.3	-13.4	3.1
Tolouse	12.5	-10.5	3.6
Marseilles	14.2	-12.8	4.4
Ajaccio, Corsica	14.7	-3.6	2.6
Iberian Peninisula			
Santander	13.9	-0.2	3.6
Barcelona	16.4	-2.5	2.2
Oporto	14.4	-3.7	5.1
Madrid	13.9	-6.5	2.7
Palma de Mallorca	16.8	-1.5	2.8
Losbon	16.6	0.0	4.1
Sevilla	18.8	-2.8	1.7
Malaga	18.5	2.0	2.1
Poland, Czech Republic, Slovakia, Hungary			
Gdynia	7.9	-14.8	3.6
Warsaw	8.1	-18.9	4.1
Cracow	8.6	-17.1	2.7
Prague	7.9	-20.4	-
Ostrava	8.1	-27.9	-
Bratislava	9.6	-22.8	3.4
Budapest	11.2	-19.1	2.3
Pecs	11.5	-	3.3

Place	Av. daily temp [°C]	Extremes in Dec. [°C]	Av. wind speed [m/s]
Central Europe			
List auf Sylt	8.4	-8.0	6,7
Greifswald	8.3	-17.4	5,3
Hamburg	8.4	-16.4	4,2
Dresden-Wahnsdorf	8.6	-20.3	4,9
Aschen	9.7	-16.5	3,0
Karlsruhe	10.1	-21.5	2,3
Vienna	9.8	-15.3	3,0
Salzburg	8.1	-27.7	2,0
Garmisch-Partenkirchen	6.3	-22.7	1,3
Zurich	8.5	-19.3	2,8
Innsbruck	8.6	-24.8	1,3
Graz	8.3	-19.0	1,4
Geneva	10.3		-
Italy			
Milan	3.8	-7.0	-
Genoa	9.2	-2.8	-
Florence	14.4	-8.0	-
Rome	15.6	-5.0	-
Naples	16.8	-1.6	-
Mesina	17.9	-0.2	-
Southeast Europe			
Zagreb	11.6	-26.3	-
Belgrado	11.8	-19.3	-
Bucharest	11.1	-19.9	2,0
Sarajevo	9.8	-22.4	1,4
Sofia	10.4	-20.3	2,0
Skopje	12.4	-21.8	-
Tirana	16.0	-8.0	1,5
Thessalonki	16.1	-	-
Athens	17.8	-	2,0
Eastern Europe and Russia			
Murmansk region	-0.6	-	4,2
Arkhangeslk region	-1.0	-	-
Moscow	4.9	-	-
St Petersburg region	4.4	-	3,6
Baltic Countries	6.2	-	5,0
Belarussia	6.3	-	3,4
Kiev	7.6	-	-
Novosibirsk	1.0	-	-

Heat insulation, U-value

U = thermal transmittance value [W/m² °C]
U-values indicate the heat insulating capacity of a building section. The following equation can be used to calculate U-values:
$1/U = R_{si} + R + d_1/\lambda_1 + d_2/\lambda_2 + \ldots\ldots.. + d_n/\lambda_n + R_{se}$

R = heat resistance [m² °C/W]
R-values indicate the heat insulating capacity of a product or building section.
R_{si} = heat transmission resistance upon transmission from internal air to wall surface [m² °C/W].
R_{se} = heat transmission resistance upon transmission from fresh air to wall surface [m² °C/W].
$d_1, d_2, \ldots.d_n$ = thickness for respective materials [m].
$\lambda_1, \lambda_2, \ldots.\lambda_n$ = heat conductivity [W/m °C].

Material	U-value [W/m² °C]
Walls	
New building	
Wooden fascia with 15 cm insulation and plaster	0,27
Wooden fascia with 20 cm insulation and plaster	0,25
Wooden fascia with 25 cm insulation and plaster	0,22
Brick fascia with 15 cm insulation and plaster	0,27
Brick fascia with 20 cm insulation and plaster	0,24
Light concrete with 15 cm insulation	0,25
Light concrete with 20 cm insulation	0,2
Sheet metal fascia with 5 cm insulation	0,8
Sheet metal fascia with 10 cm insulation	0,4
Sheet metal fascia with 15 cm insulation	0,3
New construction for low energy house	0,18
Warehouse	0,3
One layer PVC (900 g)	5,0
Insulated hall (Thermohall)	0,6
Older building	
Single brick 12 cm	1,8
1 1/2 brick 18 cm	1,1
Light concrete block 20 cm	0,8
Light concrete block 30 cm	0,6
Concrete 15 cm	2,8
Concrete with 5 cm insulation	0,8
Concrete with 10 cm insulation	0,4
Frame wall with 5 cm insulation	0,8
Frame wall with 10 cm insulation	0,4
Frame wall with 15 cm insulation	0,3
New construction	0,3

Material	U-value [W/m² °C]
Roof	
New building	
Sheet metal pitched roof, with 20 cm insulation	0,24
Brick pitched roof, with 20 cm insulation	0,23
Older building	
Concrete beam frame 15 cm	2,8
Concrete beam frame with 5 cm insulation	0,8
Concrete beam frame with 10 cm insulation	0,4
Light concrete 20 cm	0,8
Light concrete 30 cm	0,6
Sheet metal roof, uninsulated	4,0
Sheet metal roof with 5 cm insulation	0,8
Sheet metal roof with 10 cm insulation	0,6
Sheet metal roof with 25 cm insulation	0,2

Material	U-value [W/m² °C]
Windows	
New building	
1+1 pane window (1 outer pane and 1 insulated pane)	2,5
2 pane window (2 insulated panes)	2,7
2+1 pane window (1 outer pane and 2 insulated panes)	1,0
3 pane window (3 insulated panes)	1,2
Energy class A	0,9
Energy class B	1,0
Energy class C	1,1
Energy class D	1,2
Energy class E	1,3
Energy class F	1,4
Energy class G	1,5
Older building	
1 pane window	5,0
2 pane window	3,0
3 pane window	2,0
3 pane window insulation pane	1,8

Material	U-value [W/m² °C]
Door	
Sliding entry with full panels	0,8
Sliding entry with windows and door	1,3
Folding door with windows	2,2
Folding door fully glazed	3,4
Single front door without glass	1,0
Single front door with glass	3,4
Double front door without glass	0,7
Double front door with glass	1,7

Material	U-value [W/m² °C]
Floor	
New building	
Floor with 10 cm insulation	0,2
Floor with 15 cm insulation	0,16
Floor with 20 cm insulation	0,13
Older building	
< 300 m²	0,4
> 300 m²	0,3

Temperature gradients

Convector heating	2 - 2,5 °C/m
Hot air heating - fan heaters	2 - 2,5 °C/m
Radiators and hot air heating	1,7 °C/m
Radiator heating	1,2 °C/m
Radiant heaters	0,2 - 0.4 °C/m
Floor heating	~0,1 °C/m

Values apply at full output.

Internal heat

Activities	W/m² floor area	W/employee
Shop	15	
Cafeteria	15	
Office	0-20	100
Sports centre	10	
Bakery	30	
Steel mill	50-70	
Car workshop	15	
Mechanical workshop	20	
Heavy workshop	50	
Sheet metal/welding	25	

Energy equivalents

Quantity and substance	Energy quantity [MWh]
1 m³ oil	8.000
1 Nm³ liquid propane gas	0.022
1 Nm³ natural gas	0.009
1 Nm³ town gas	0.004
1 kg liquid propane gas	0.087
1 kg natural gas	0.007
1 kg town gas	0.003

Heat conductivity

Material	λ-values [W/m°C]
Natural stone	2.4-3.6
Chalky sandstone	1.0
Concrete	1.7
Light clinker concrete	0.6
Brick and concrete hollow block	0.6
Cement mortar	1.0
Wood, particle board	0.14
Plaster board	0.22
Plywood	0.13
Fibre board	0.08
Mineral wool	0.045
Cellular plastic	0.04

Heat resistance R

Material	R heat resistance [m²°C/W]
Internal + external transmission resistance Rsi + Rse	0.17
Cellar wall, underground 1-2 metres	1.0
Below floor on ground Outer verge zone	0.7
Below floor on ground inner verge zone	2.0

Infiltration

Building	Air change/h
New building	
< 1000 m²	0,3
> 1000 m²	0,1
Older building	
< 1000 m²	0,4
> 1000 m²	0,2

Ventilation air flow

The following equation can be used for calculating the ventilation air flow:

$$Q = q \times A_{floor} \times 3.6 \quad \text{or} \quad Q = n \times V_{bldg}.$$

where q =air flow [l/sm²]
n =number of air changes per hour
A_{floor} =floor surface of the building [m²]
V_{bldg} =volume of the building [m³]

Airflows below are only recommendations.

Building	l/s m²	l/s person	Air change/h
Shop	2.1	7	4-5
Cafeteria	5	7	6.0
Public building	0.35	+7	3.0
Office	0.35	+7	1-2
School	0.35	+7	4-5
Sports centre	2.1	7	2.0
Bakery	6		6.0
Steel mill	40.0		10-15
Car workshop	30		3.0
Mechanical workshop	0.35	+7	5.0
Sheet metal/welding	5.0		5.0
Meeting-hall/smoking		20	8.0
Meeting-hall/no smoking	7	7	6.0
Minimum req.	0.35		ca 0.5