# Section 2
# Summarized history of air heating and sheathed heating elements

# Summarized history of air heating and sheathed heating elements

The invention of sheathed heating elements comprising a metal tube swaged around a coiled heating wire, and which is insulated by compressed magnesia, was an essential step of the electrothermics development. Thanks to their mechanical strength, impermeability and resistance to corrosion, these are the most professional heating technical solutions. The appearance of these heating elements, now universally used, was the result of a combination of different advanced techniques of the early 20th Century.

Over the last two decades of the 19th Century, the emergence of electric heating had revealed the need to find reliable solutions for converting electricity into heat. The first electrical heaters were platinum wires (inherited laboratory equipment), nickel silver or even iron. Research carried on resistive elements with greater resistivity and good temperature resistance.

On October 12, 1878, St. George Lane Fox-Pitt filed patent in England 4043, in which he developed the use of electricity for lighting and heating. This patent, based on the use of platinum filaments, was not followed for heating but it was the basis for the development of electric bulbs.


"LE FERRO-NICKEL"

SOCIÉTÉ ANONYME — CAPITAL 2,500,000 FRANCS. — SIÈGE SOCIAL A PARIS, 10, RUE DE LOUVOIS

DÉPOT & AGENCE COMMERCIALE A PARIS, 17, RUE DU PONT-AUX-CHOUX, 17

FONDERIES, LAMINOIRS & TRÉFILERIES DE LIZY-SUR-OURCQ (S.-ET-MARNE)

ANCIENS ÉTABLISSEMENTS GOTTIAU FILS — FUSIONNÉS EN 1884

AVEC LA SOCIÉTÉ DITE : " FONDERIE DE NICKEL ET MÉTAUX BLANCS "

FABRIQUE DE MAILLECHORT

1895 Ferronickel (Ultimheat Museum document)

In 1884, French Henri Marbeau, a pioneer in the manufacture of Nickel in New Caledonia and France, founded the company "Le Ferro-Nickel'' in Lizy sur Ourcq. He became the first to obtain sufficiently pure alloys of iron and nickel, which nickel content was mastered, to be used as heating wires. These alloys (patented in 1884 and 1888) with different proportions of nickel were set forth at the Paris Exhibition of 1889. Their temperature resistance and resistivity were incommensurate with wires used previously.

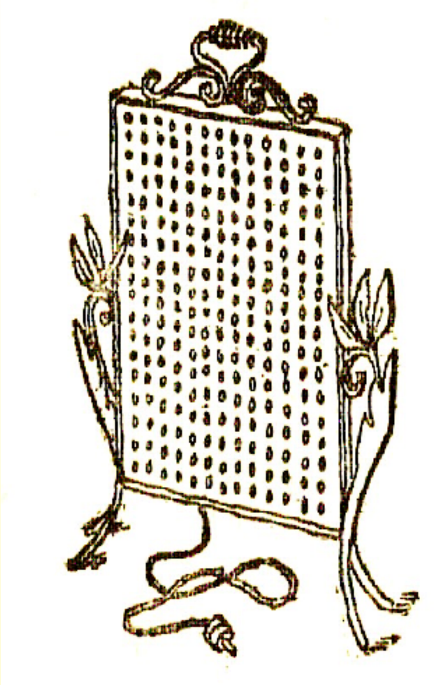
Between 1888 and 1890, the exponential growth of incandescent lamps, which carbon filament supports are made of platinum causes the tripling of the price of this material in 2 years, from 900 to 2,750 francs per kg, which made it too expensive for heating applications.

Ironically, carbon, rapidly dropped for incandescent lamps, now returns in the form of braided fibers in the quartz tube heating elements radiating in the shortwave infrared.

From 1890, heating wires embedded in an asbestos board were used for irons (Carpenter, USA).

The electric furnace set forth in 1891 by the Austrian Friedrich Wilhelm Jenny Schindler still uses platinum heating wires embedded in an insulating enamel. It will be presented at the Chicago World's Fair in 1893.

In 1891, the English manufacturer R.E.B. Crompton presents at the London Exhibition at the Crystal Palace, a frying pan and other electrical heating devices (which will be shown in a catalog in 1894 «Domestic Electric Machinery, Electrical Heating and Cooking Electrical Apparatus») in which the heating element is a copper zigzag wire embedded in the enamel forming the bottom of the pan. It quickly turned out that the heating wires broke quickly because the expansion coefficient of the enamel was lower than that of the metal plate it was layed on. In the same year, a similar solution used by the Carpenter Electric Company (St. Paul, Minesotta) on electric kettles experienced the same troubles.



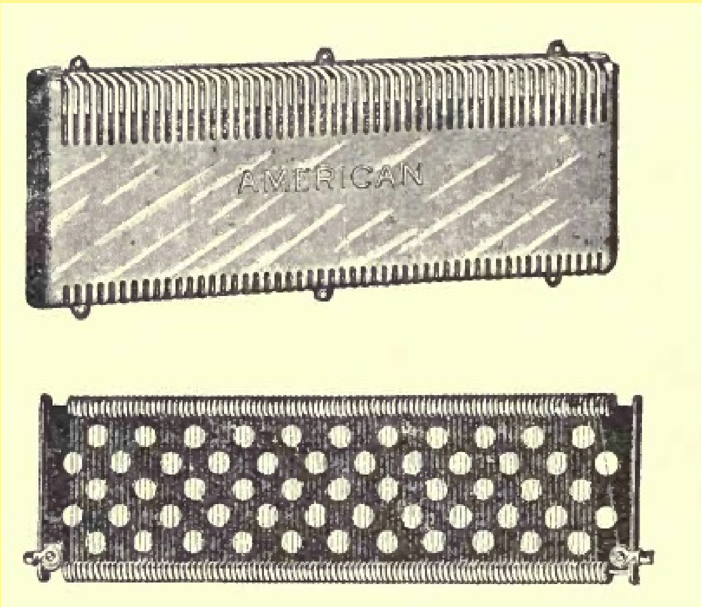
Crompton electric heater
(ca1895, Ultimheat Museum document)

1898 electric cooker by Grimm, Schindler-Jenny patent (Ultimheat Museum document)

At the same time in Switzerland, the company Grimm & Co. develops a similar range of products under license from the Austrian Schindler-Jenny and Stuz, which will be presented at the Chicago Exposition in 1893. The maximum temperature reached is 250°C then, because it is limited by the performance of insulating enamels.

In 1893, the Scottish Alan MacMasters in Edinburgh, proposed to perform the first Crompton toaster using bare heating wires made of iron. This device, called ''Eclipse'' and produced around 1894 was a commercial failure, because the heating wires used to melt.

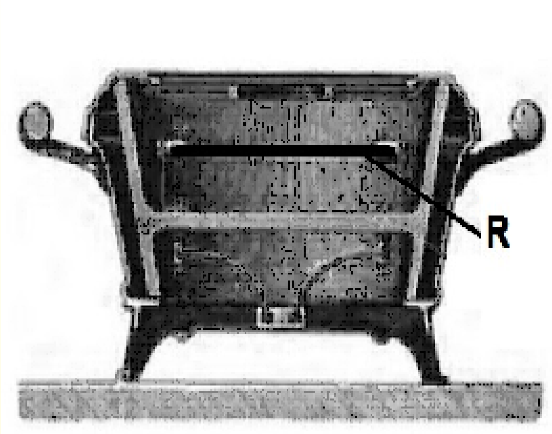
By 1894, the Vaudeville Theatre, London, was the first public place to be heated with electric heaters. But at this time, electric heaters were already commonly used to heat the trams because electricity was already available. Heating wires used to be made of galvanized steel or nickel silver also called «German silver».



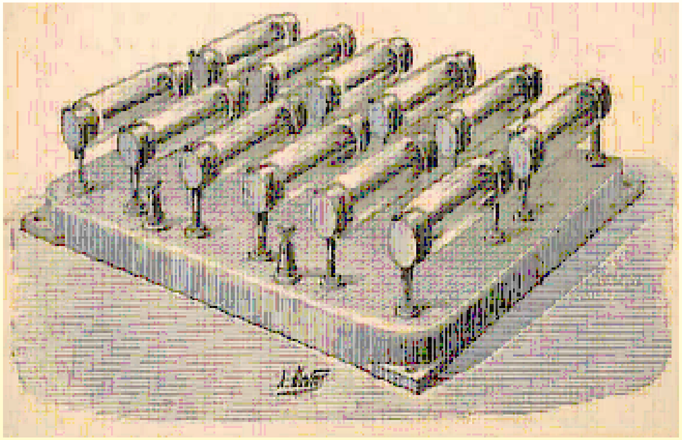

1895 Tramway heater, made of nickel silver wires stretched between porcelain insulating parts (extract from ''Electric heating'', by Edwin J. Houston and A. E. Kennelly, 1895)


Extract from the electrical devices in the Guise Familistère range in 1897 (Ultimheat Museum document)

The technique of enameled heating wire is applied in France for the first electrical appliances of the Familistère de Guise (Dequenne), presented in their 1897 catalog, under Crompton license, at the Universal Exhibition of 1900, which uses nickel silver wires and then ferronickel wires. The enamel technology has evolved and breakages are less common.



1899 Parvillée's metal ceramic heating element
(Ultimheat Museum document)



1898 Le Roy's electric hot logs
(Ultimheat Museum document)

From 1899, the French company ''Parvillée Frères et Cie'' patented and manufactured high-power heating elements made of metal ceramic sintered (nickel, quartz and kaolin base), running red outdoors, paving the way for the first electric heating and cooking professional devices, shown in operation in the La Feria restaurant at the Universal Exhibition of Paris in 1900.

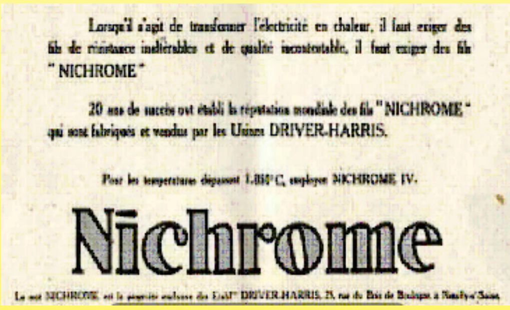
These elements may be considered as the ancestors of the heating elements made of silicon carbide, currently used in industrial furnaces.

In 1898, the French Le Roy used a 100 × 10 × 3 mm « graphitoïde silicon « bar surrounded by a glass envelope in which there is vacuum, as a heating element, in order to produce 80 watts hot logs.

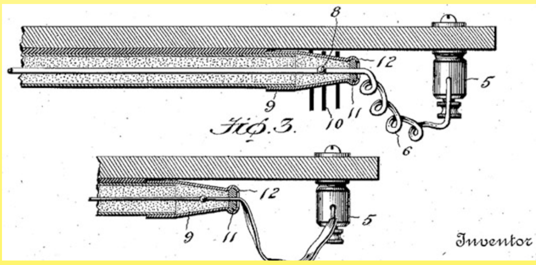
This element resistivity is 230,000 times greater than the nickel silver wire, and withstands 800 ° C. These hot logs will be used for twenty years.

Around 1902-1903, the ferronickel heating wire gradually replaces the nickel silver wire in applications requiring high operating temperatures. The ferronickel heating wires are wound on a ceramic, asbestos or mica core, or sandwiched between two enamel layers.

The quick development of domestic appliances (irons, water heaters, room heaters), and the demand for heating wires and better systems tickled manufacturers research, particularly in the USA, which was at the forefront of household electrification.




1923 Ad for Nichrome wire
(Ultimheat Museum document)



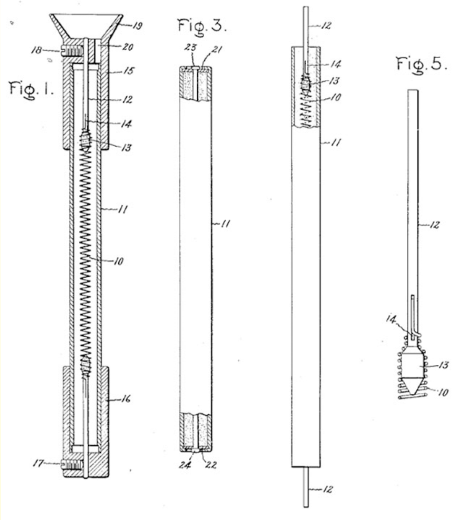

1914 Wiegand patent, straight heating element insulated with magnesia in a tube

In March 1905, the American engineer Albert Leroy Marsh at Hoskins Manufacturing Co. in Detroit made an important discovery for the heating elements: a 80% nickel and 20% chromium alloy, which is later named Nichrome, which resistivity, corrosion resistance and temperature resistance allow the making of reliable and durable heaters. (U.S. Patent No. 811,859, February 1906). This alloy Nichrome 80/20, withstanding continuous 900-1000°C temperatures, essential to radiate in the infrared, allowed to make heating elements incandescent in the air. At this time, no material but platinum which was too expensive, would allow to meet this need.

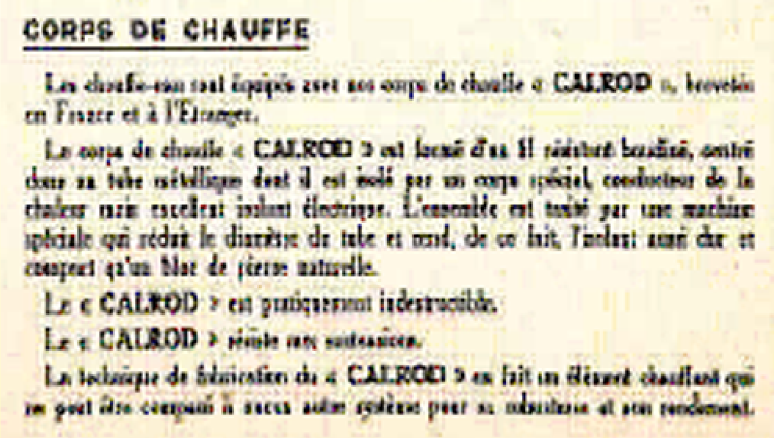
It allowed to make the first electric toaster with bare resistances or in quartz tubes in 1908 (Radiant heaters in quartz tube, patented January 12, 1908 by William S Andrews). These heating elements under radiant quartz tube will be the ancestors of the quartz tubes used in infrared heating and in radiant cooking stoves.

In January 1914, Edwin L.Wiegand young American engineer filed several patents related to mass production of iron heating elements. for the soles of irons, he invented heating wires positioned in a «cement or pressed powder» heat conductor. This was the origin of the company Chromalox in Pittsburgh, which then began mass production of these heating elements for irons.

On January 3, 1914, he filed, among other things, a patent for a tubular element comprising a straight heating wire, insulated with magnesia (patent US1127374).




1918 Charles Abbott's patent



CORPS DE CHAUFFE

Les chauffe-eau sont équipés avec nos corps de chauffe « CALROD », brevetés en France et à l'Étranger.

Le corps de chauffe « CALROD » est formé d'un fil résistant boudiné, centré dans un tube métallique dont il est isolé par un corps spécial, conducteur de la chaleur mais excellent isolant électrique. L'ensemble est traité par une machine spéciale qui réduit le diamètre du tube et rend, de ce fait, l'isolant aussi dur et compact qu'un bloc de pierre naturelle.

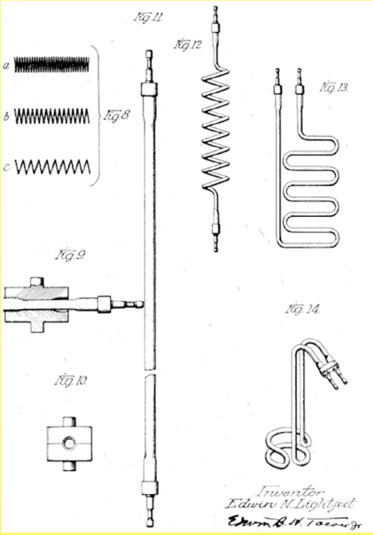
Le « CALROD » est pratiquement indestructible.

Le « CALROD » résiste aux surtensions.

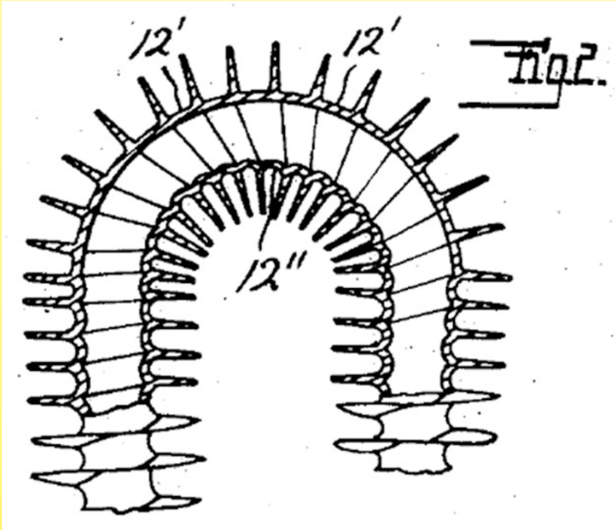
La technique de fabrication du « CALROD » en fait un élément chauffant qui ne peut être comparé à aucun autre système pour sa robustesse et son rendement.

1932 Calrod product description in the Als-Thom catalogue (Ultimheat Museum document)

On November 15, 1918, Charles Abbott, Pittsfield, Massachusetts, Engineer for General Electric USA, filed the 1.367341 Patent, where wire wound heating elements surrounded by magnesia are compressed by necking of the tube. These heating elements will be known under the brand name «Calrod», also called in France «shielded heating elements» and marketed by Thomson (Als-Thom) around 1930.



1920 Edwin Lightfoot's patent




1930 Charles Paugh's patent

On June 22, 1920, Edwin N. Lightfoot, of company Cutler Hammer, filed the US1359400 patent, which describes the contemporary shielded elements, their forming possibilities, the rolling methods, and an automatic filling machine which principle is still used nowadays.

On December 16, 1921, the Norwegian Christian Bergh Backer invented a system for producing magnesia by oxidation of magnesium metal by steam under pressure. In this method, as the later Backer called «Conversion Process», it is no longer the compression of the metal tube which compresses magnesia, but magnesia is produced directly in the tube. This oxidation produces magnesium hydroxide which volume is twice the original metal volume. The hydroxide is then converted by heating into magnesium oxide, which is both an electrical insulator and a thermal conductor (Norwegian Patent 37862, U.S. Patent 1,451,755 granted on 17/04/1923, last update 16340). Despite the loss of electrical insulation due to the conversion of hydroxide into oxide in this system (which were offset by subsequent modifications of the method in 1936), these two production systems, Calrod and Backer will compete for decades. But only the Calrod process has survived, thanks to its simplicity of manufacture as a self evidence.

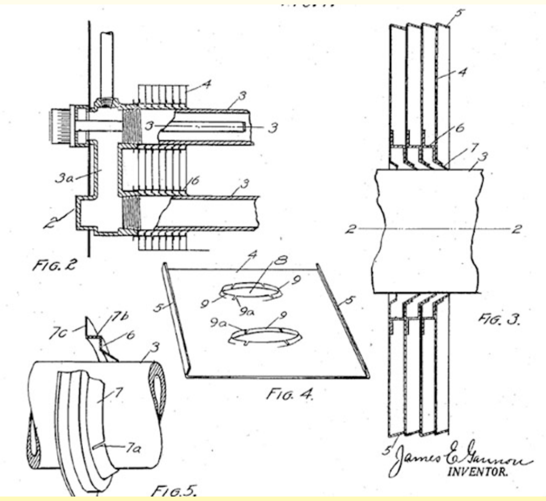
These two systems will allow the production of shielded heating elements with high power densities, which will be limited only by the maximum possible temperature of the internal heating wire and by the tube capacity to exchange its own heat with the external environment.

In the case of heating a liquid, the liquid itself will limit its thermal conductivity and its flow speed, corresponding to its thermal capacity. In the case of air, it quickly became obvious that the exchange surface of the tube should be increased to take advantage of the high power densities achievable. Therefore, both ways were explored: helical fins on tubes that are then formed or fins crimped on pin shape tubes.

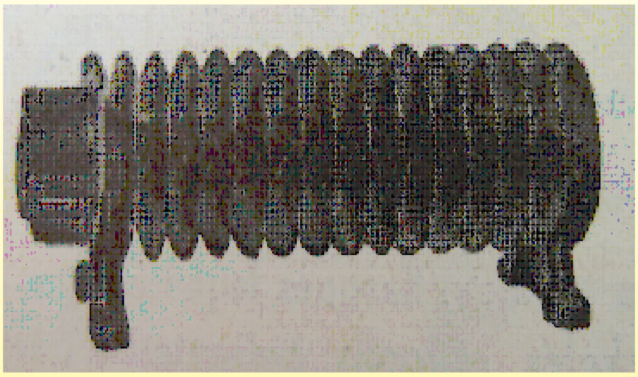
# Historical and technical introduction

On June 16, 1930, Charles Paugh of the Wolverine Tube Company, filed a patent (Patent US1909005 A) for a method of producing added fins on metal tubes, allowing subsequent tube bending.

These helical fins were quickly used for central heating radiators, and the manufacturing technique was easily transposed to shielded heating elements.



1927 James Gannon's patent


1932 Radiator using Als-Thom's spiral coil fin heaters (Ultimheat Museum document)

On December 8, 1927 James E. Gannon, American Electric Heating Company, introduced the first electric heater using rectangular fins crimped onto a shielded hairpin heater element (Patent US1788516 A).

Technical developments since the 1930s have mainly focused on improving the quality of magnesia powders, of resistive wires, and in the appearance of metal tubes with high heat and corrosion resistances (among other materials: 304, 321, 316 stainless steel and Incolloy 800, 840, 825).

The arrival of Iron Chrome Aluminum alloys in 1931, invented by Hans Von Kantsow in Sweden (who founded the company Kanthal, acronym of his name and Aluminum), allowed the making of heating wires with an even higher temperature resistance than Nickel Chromium and resistant to corrosion. These wires have now become a standard of high temperature resistance.


NOUVEAUTÉS DU SALON MÉNAGER 1939

APPAREILS ÉLECTRO-DOMESTIQUES THOMSON

BOUILLOIRES AU CALROD

Les bouilloires THOMSON sont composées d'une cuve, en métal chromé ou en porcelaine, dans laquelle plonge un élément CALROD inoxydable, aisément détachable.
Cette nouvelle formule de construction comporte de nombreux avantages :
— Rapidité de chauffe DOUBLÉE.
— Nettoyage à grande eau possible.
— Robustesse et sécurité : le CALROD est indestructible, même fonctionnant sans eau.
— Hygiène et propreté de la cuve PORCELAINE.
— Possibilité d'employer les deux cuves (métal et porcelaine) avec un seul élément : DEUX BOUILLOIRES presque au prix d'une.
— GRANDE CAPACITÉ : 1 litre 3/4 (1,750 l.), mais faculté de chauffer les plus petites quantités de liquide.

Bouilloire 950 W cuve chromée . . . . . . . . . . 220. »
Bouilloire 950 W cuve porcelaine . . . . . . . . . 165. »
(Autres modèles 550 W : voir catalogue.)

1939 Calrod heating elements made of Stainless Steel (Ultimheat Museum document)

After a period of prohibition to use electricity for heating, imposed in 1941, several manufacturers of shielded elements such as Métanic, Rubanox, Spirox, were born in France from 1945.

Technology and research then carried on sealing the ends of the tubes, because the hydrophilic properties of magnesia make it slowly lose its insulating properties. The development of silicone resins (1945-1950) and epoxy resins (1955-1957) greatly improved this critical point.

Since that time, there was little change in the concept of manufacturing shielded heating elements and improvements appeared mainly in the quality of raw material, and of new refractory and stainless alloys used for metal tubes and heating wires.

The evolution and democratization of devices for making sintered silicon carbide elements, as well as quartz tubes and bars helped make infrared radiant elements with a very high yield.

# Useful technical tables for air heating

# Useful technical tables for air heating

## Figures provided in this section are results of tests made in our laboratory. Charts were smoothened by computer, and are given for specified power and for information only.

## Type 3AY

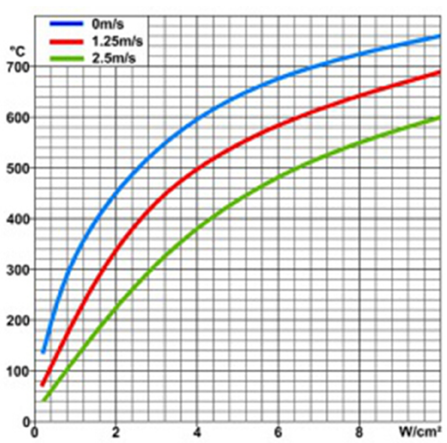
| Estimated life expectancies for magnesium oxide insulated heater types made in stainless steel or refractory alloys. | | | | | | | |
|---|---|---|---|---|---|---|---|
| Surface temperature | | Time (years) | Time (hours) | Surface temperature | | Time (years) | Time (hours) |
| °C | °F | | | °C | °F | | |
| 700 | 1300 | 23 | 200.000 | 980 | 1800 | 0.15 | 1200 |
| 760 | 1400 | 9 | 80.000 | 1040 | 1900 | 0.01 | 360 |
| 815 | 1500 | 3.5 | 30.000 | 1095 | 2000 | - | 180 |
| 870 | 1600 | 1 | 8700 | 1150 | 2100 | - | 48 |
| 925 | 1700 | 0.3 | 3000 | | | | |

For a standard sheathed element, the surface temperature of 870°C (1600°F) is the maximum temperature to insure expected heater life greater than one year. These values are for information only, and data are provided for heating elements using Nickel Chrome alloy wires whose cross section is optimized, and which are insulated with good quality pure magnesia, not contaminated. This deterioration of heating wires at temperatures well below their melting point is due to chemical reactions that occur at high temperature between the iron oxide (which is a contaminant of magnesia), and the wire itself.
Note: When the sheathed elements are used in medium infrared radiant heating, this temperature of 870°C (1600°F) is generally exceeded if the surface load is equal to or greater than 10W/cm² (60W/in²). This is the main reason of the short life expectancy of these heaters in this application.

### Average surface temperature and average air temperature of air heaters described in this catalogue
### Temperature cycles of some tables are due to built-in temperature controls.

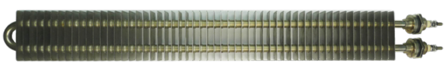
Figures provided in this section are results of tests made in our laboratory. Charts were smoothened by computer, and are given for specified power and for information only.

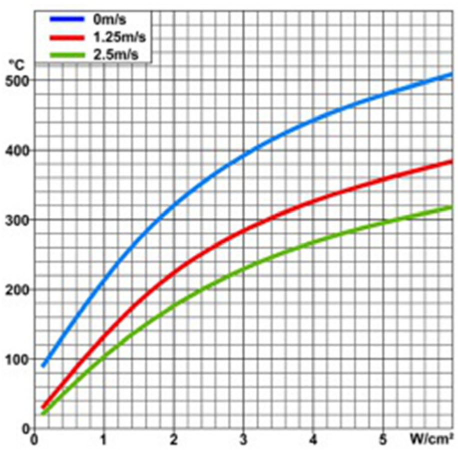
**9SR, P3 of section 4**




Surface temperature of a dia. 10 mm stainless steel sheathed tubular heating element, VS surface load, in still air, and in ventilated air. (RT=20°C)

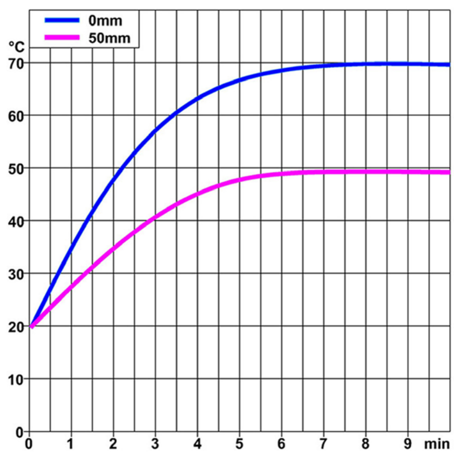
**9SX, P4 of section 4**






Surface temperature of a stainless steel finned heater, 25 x 50 mm fins, VS surface load, in still air, and in ventilated air.(RT=20°C)

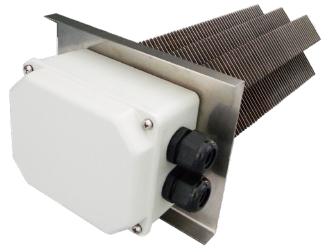
**9NN, P7 of section 4, 400W**

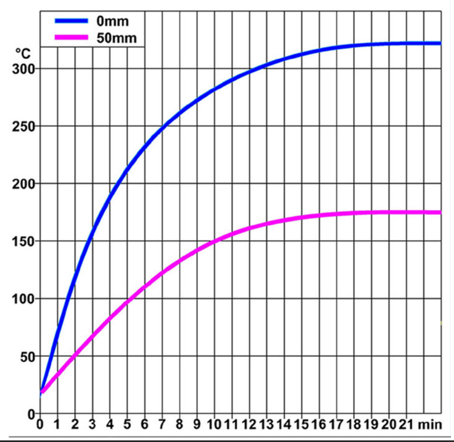



Surface temperature of a compact duct heater, and temperature measured at 50mm from the air outlet grid, air speed 2m/s.

# Useful technical tables for air heating

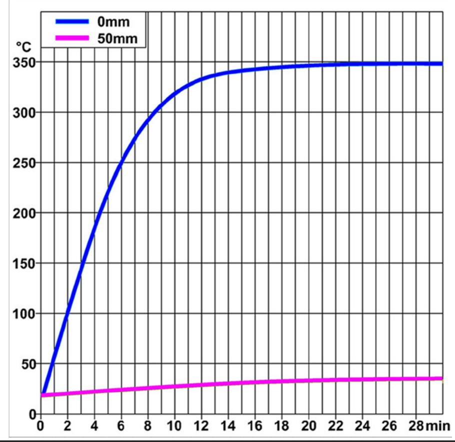
## 9NF, P8 of section 4, 4000W





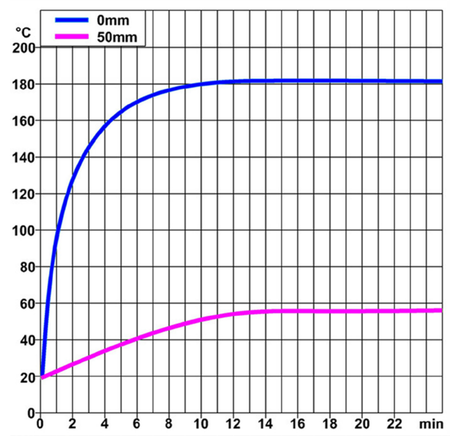

Fins surface temperature of a medium power duct heater, and temperature measured at 50mm from the fins, air speed 2m/s.

## 9SQ, P9 of section 4, 500W



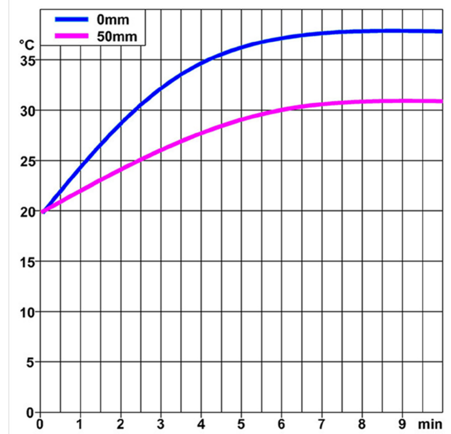

Surface temperature of remodeling sheathed heater, and temperature measured at 50mm from the sheathed element, natural convection.

## 9SY, P10 of section 4, 1050W



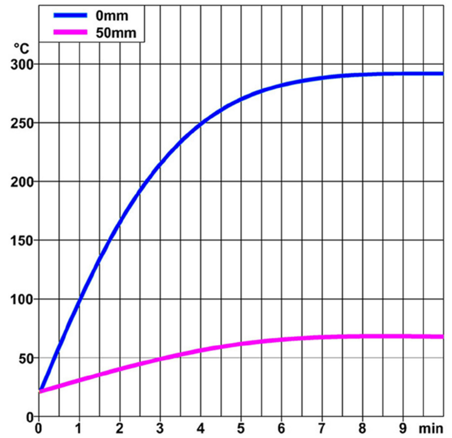

Surface temperature of remodeling finned sheathed heater, and temperature measured at 50mm from the fins, natural convection.

## 9PF, P3 of section 5, 100W



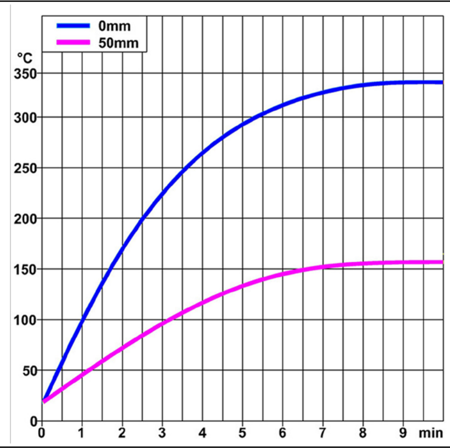

Surface temperature of cabinet heater, and temperature measured at 50mm from the air outlet grid, air speed 2m/s

## 9CG1, P5 of section 5, 3000W



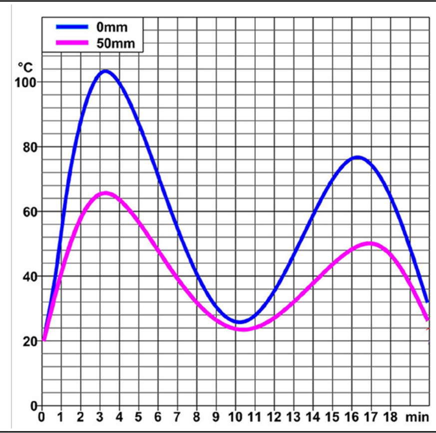
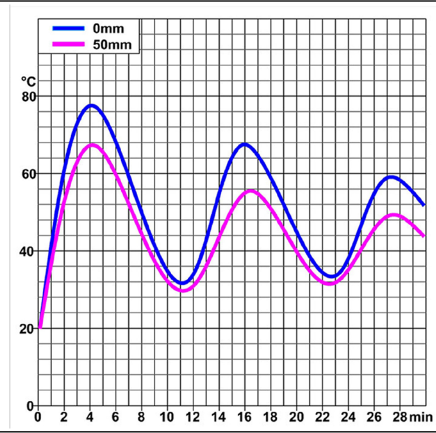
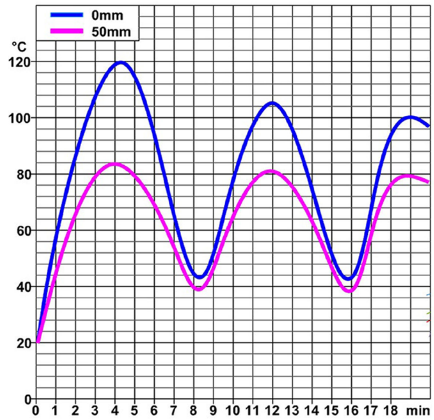
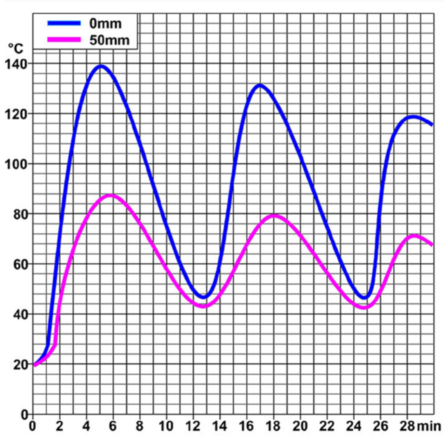
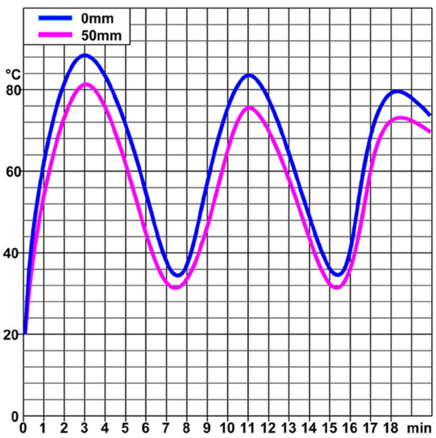
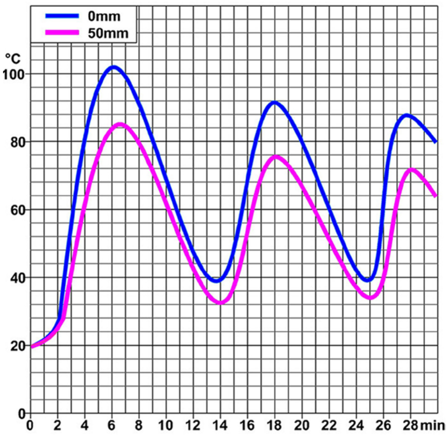

Outlet grid surface temperature of enclosed finned heater, heater, and temperature measured at 50mm from the air outlet grid, natural convection

## 9CG3, P6 of section 5, 4000W



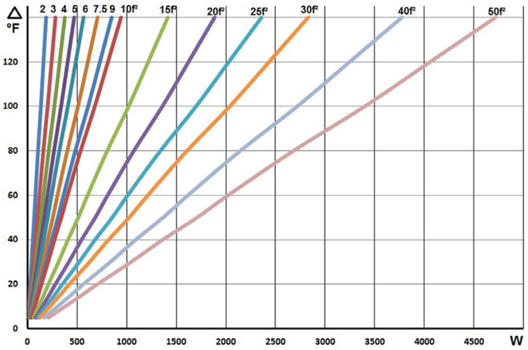
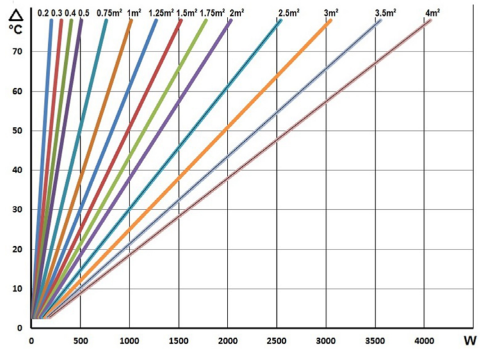

Outlet grid surface temperature of an enclosed finned heater, and temperature measured at 50mm from the air outlet grid, natural convection.

# Useful technical tables for air heating

| 9CH,P7 of section 5, 3000W | 9CL, P8 of section 5, 1500W | 9CJ, P9 of section 5 |
|---|---|---|
|  |  |  |
|  |  |  |
| Outlet grid surface temperature of an enclosed finned fan heater, with thermostat control, and temperature measured at 50mm from the air outlet grid, air speed 1m/s. | Outlet grid surface temperature of an enclosed finned fan heater, downward blowing, with thermostat control, and temperature measured at 50mm downside the air outlet grid, air speed 1m/s. | Outlet grid surface temperature of an enclosed finned fan heater, with thermostat control, and temperature measured at 50mm from the air outlet grid, air speed 2m/s. |
| 9CK, P11 of section 5, 4000W | 9CR, P13 of section 5 | 9CS, P14 of section 5, 4000W |
|  |  |  |
|  |  |  |
| Outlet grid surface temperature of an enclosed finned fan heater, with electronic control, and temperature measured at 50mm from the air outlet grid, air speed 2m/s. | Outlet grid surface temperature of an enclosed finned fan heater, downward blowing, with thermostat control, and temperature measured at 50mm downside the air outlet grid, air speed 2m/s. | Outlet grid surface temperature of an enclosed finned fan heater, downward blowing, with electronic control, and temperature measured at 50mm downside the air outlet grid, air speed 2m/s. |

# Useful technical tables for air heating

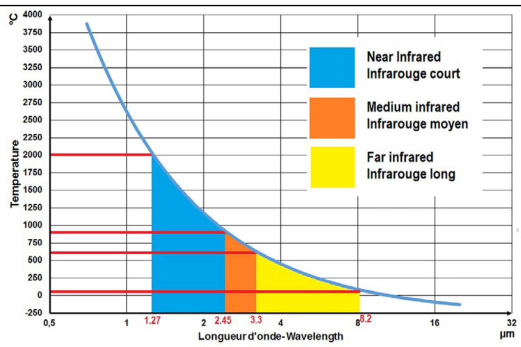
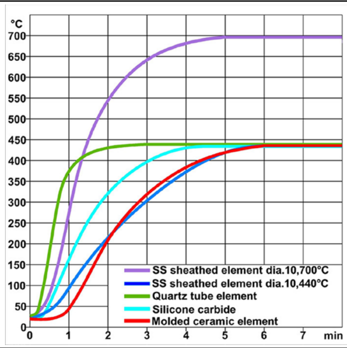
## Indicative power selection chart of cabinet heaters (Non insulated metal cabinets)

| Power upon cabinet outside surface (ft²) and requested delta of temperature between inside and outside. Plastic cabinets: divide by 2. Outdoor vented area: add 50% | Power upon cabinet outside surface (m²) and requested delta of temperature between inside and outside. Plastic cabinets: divide by 2. Outdoor vented area: add 50% |
| --- | --- |
|  |  |





## Infrared wavelengths

| Infrared heater surface temperature VS wavelength | Response time of different far infrared heaters (temperature stabilized at 440°C), compared to response time of a medium infrared heater (temperature stabilized at 700°C). |
| --- | --- |
|  |  |





There are many definitions of infrared and its division into far (long), medium and near (short), and often confusion is made between these different definitions.
- The first is that of astronomy, according to ISO 20473 which defines the infrared radiation from the red edge of the visible spectrum at 0.780 micrometers (microns) up to 1000 microns.
- The second is that of the CIE recommends that in the field of photobiology and photochemistry, cutting the infrared range into three zones: IR-A: 0.7 microns to 1.4 microns; IR-B: of 1,4 microns to 3 microns; IR-C: 3 microns to 1000 microns.
- The third, used in the field of infrared heating, defined wavelengths as follows (see table below):
**- Far infrared,** from 370 to 600°C, corresponding to a wavelength of 4.5 to 3.30µm.
However, there are infrared emitters called «low temperature infrared» for space heating (heating ceilings, wall heating for saunas, convectors called «radiant» heaters), which operate at lower surface temperatures of about 70 to 80°C corresponding to wave lengths from 8.2 to 7.8 microns.
**- Medium Infrared,** 600 to 900°C corresponding to a wavelength of 3.3 to 2.45µm
**- Near Infrared,** 900 to 2,000°C, corresponding to a wavelength of 2.45 to 1.27µm.

**Far Infrared Emitters.**
- Infrared ceramic heater made of a ceramic encapsulated wire. The surface temperature of the ceramic may range from 350°C to 650°C. Because of their design and the low thermal conductivity of the ceramic used, differences in temperature up to 200°C on the emissive surface between bumps and groves, center and edges are possible. The resulting infrared radiation is distributed over a large wavelength range. In addition, a large percentage of the radiation emitted on the rear face of such elements, only serves to heat their support.
The ceramics used to make these elements have a low emissivity in the far infrared, so, an additional percentage of the energy is dissipated in the different wavelengths. To overcome it, some of them are now covered with a black glaze. The time to reach 90% of their operating temperature, starting from 25°C is approximately 5 minutes 40s.)
- Sintered silicon carbide tube emitters: they reach an emissivity close to 100% in the 3 to 4 microns wavelength, corresponding to 450 - 690°C (840-1280°F) surface temperature. The time to reach 90% of their operating temperature, starting from 25°C is about 3 minutes 30 seconds.
- Sheathed tubular elements: usually consisting of a tube made of Inconel, specially oxidized to give it a better infrared emissivity. The tube surface gives a dark red visible radiation. Their surface temperature range from 450 to 600°C. The time to reach 90% of their operating temperature, starting from 25°C is about 5 minutes 30 seconds for a 10mm dia. tub. (About the same time than a ceramic radiant heater)

# Useful technical tables for air heating

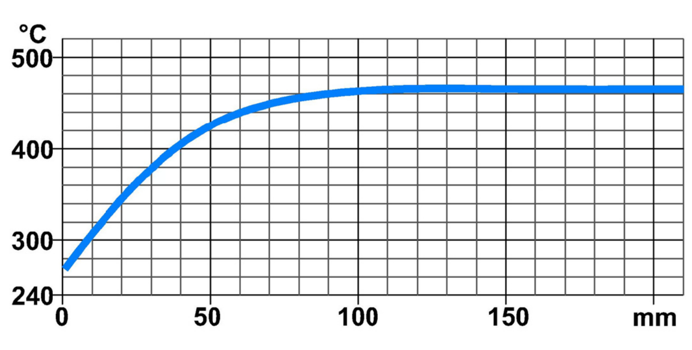
**Medium infrared emitters**
They come in two main forms:
<u>- Quartz tube elements,</u> in which a wire coil, made of chromium nickel, carbon, iron-nickel-chromium or tungsten, is placed in a milky surface quartz tube. These tubes are open at both ends, and in contact with atmospheric air. They have a surface temperature of 700°C to 1000°C; Particularly economical, but fragile, with a limited life of about 5000 hours for the heating wire reaching high temperatures in air where they are quickly oxidized.
The time to reach 90% of the operating temperature, measured from 25°C is approximately 1minute 20s
<u>- Tubular sheathed elements,</u> similar to those used in the far infrared. The high surface load gives a visible red light. The surface temperature of these components is in the range of 700°C to 800°C.
The time to reach 90% of the operating temperature, measured from 25°C is approximately 2 minutes 40s

**Near (Short) Infrared emitter**
This radiation source is constituted by an incandescent tungsten or Iron-Chromium-Aluminum filament in a quartz tube filled with nitrogen or argon and, optionally, depending on the model, a small percentage of halogen gas. The filament is heated to an average temperature of 1800°C. (Some up to 2500°C). Originally developed for applications in lighting, they emit a portion of their radiation in the far infrared, as a part of the emitted wavelengths in the visible spectrum and in the near infrared is absorbed by the quartz and converted in far infrared by the silica-oxygen chemical bond.
Their inertia is very low (a few seconds). These tubes must be cooled.

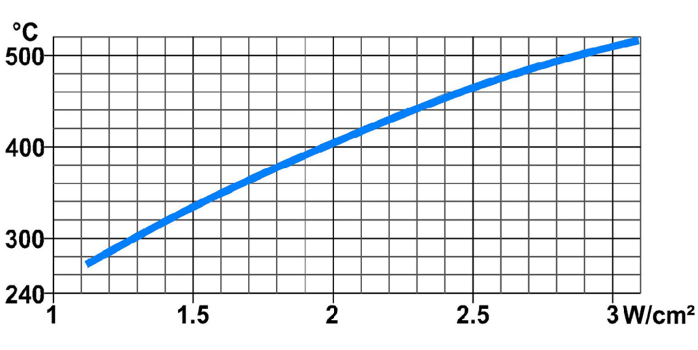
## The main types of infrared emitters

Materials are selective as to the wavelength accepted to absorb infrared energy. Most of materials show a peak of absorption between 3 and 4 microns (µm).
The wavelength produced by the heat source is dependent upon the source temperature. It is possible then to adjust the source temperature and thus the peak wavelength to match the best spectral absorption rate or wavelength. The formula providing surface temperature for a requested wavelength (µ) is:
°C=(2897/µ)-273 or °F= (5215/µ)-459
For example, if the product to heat has an absorption peak at 3.5µ, the heating element surface temperature should be: (2897/3.5)-373 = 555°C, or (5215/3.5)-459 = 1031°F.
This rule applies no matter what the construction of heat source.
Hence, filament bulb temperatures being very high, they will radiate in the near infrared, sheathed incolloy heaters with temperatures of 600 to 700°C will radiate in the mid Infrared, and ceramic heaters with 400 to 500°C surface temperature will radiate in the far infrared. What will make the difference in the final efficiency is the percentage of power supplied to the heating source that will be converted in the required wavelength.
This also means that it is possible to adjust the wavelength peak of a radiating source by controlling its surface temperature, e.g by adjusting the voltage or controlling the power, and mainly using heaters materials with the best emissivity in the requested wavelength.
Sintered silicon carbide tubes reach a radiance near 100% equivalent to a blackbody in the 3 to 4 micron zone corresponding to 450 - 690°C (840-1280°F) surface temperature.

## Thermal response of silicone carbide infrared heaters




Surface temperature of a silicon carbide infrared heater, measured at center, vs watt/cm².




Surface temperature of silicon carbide infrared heater vs ends distance. Both ends are cooler than center and radiate in a longer infrared wavelength.

## Some Material Emissivity

| Emissivity | Emissivity | | Emissivity | Emissivity | |
|---|---|---|---|---|---|
| | Polished Surface | Black Oxided | | Polished Surface | Black Oxided |
| Aluminum | 0.09 | 0.22 | Incoloy 800 | 0.20 | 0.92 |
| Brass | 0.04 | 0.60 | Inconel 600 | 0.20 | 0.92 |
| Copper | 0.04 | 0.65 | Sintered Silicone oxide, | N.A | 0.93 |
| Stainless 304,316, 321 | 0.17 | 0.85 | Blackbody | N.A | 1.00 |

# Useful technical tables for air heating

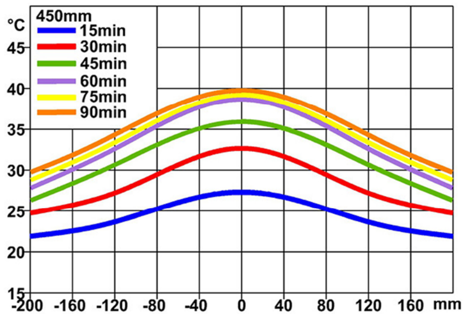
## Absorption peak of some materials (µm)

Absorption peaks are wavelengths that are the most converted in energy inside the material and will result in its heating.

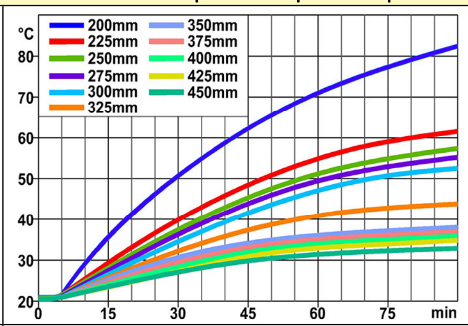
| Absorption peaks of infrared radiations | Material | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Aluminum | Linen, cotton | Concrete | Silk | Plaster | Porcelain |
| Main peak wavelength(µ) | 3 | 3 | 3 | 3 | 3 | 3 | 5 |
| Secondary peak wavelength (µ) | 6 | 8.5 | 6.5 | 6.5 | 5 | 6 | 8 |
| | **Flint, Crystal** | **Polyethylene** | **Plexiglass** | **PVC** | **Polystyrene** | **Magnesium oxide** | **Rubber** |
| Main peak wavelength(µ) | 8 | 3.5 | 6 | 3.5 | 3.5 | 3.5 | 3.5 |
| Secondary peak wavelength (µ) | N/A | 7 | 9 | 7 | 7 | 6 | 8 |

## Temperature of food products heated by infrared emitter

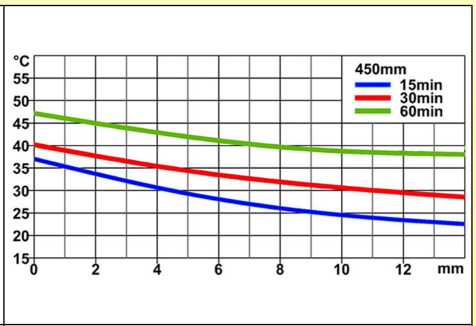
Tests carried out by subjecting a 30mm thickness sample of synthetic material (methylcellulose gel) having a UV behavior close to food. Test made from different distances, by measuring the sample temperature at 10mm deep. Tests were made with silicone carbide infrared heaters 9MH described P3 of section 7 in this catalog. The distance is measured from the edge of the reflector to the surface of the sample. Sample temperature is 20°C at the start of the test.




Temperature from center to edges, after different time, for 450mm distance between sample and heater




Average temperature at center of sample vs time, a different distances between sample and heater




Heat penetration inside sample after different heating times, 450mm distance between sample and heater