CAPTEC SCIENTIFIC CATALOGUE

Custom-Made Heat and Radiant Flux sensors

Highly sensitive and easily miniaturizable with very low inertia, this new sensor line includes conductive flux and radiant flux sensors , heating elements and surface thermocouples.
Custom made and ranging from a fraction of square inch to more than ten square feet, these are used for specific measurements in a wide range of industries. Inexpensive and simple to use CAPTEC heat flux sensors take the form of thin metallic plates which measure the energy crossing their surface without temperature dependence. They are used in a variety of applications, including insulation and air conditioning control processes, chemical reactions, phase changes, wear measurement, bearing or brake heating measurements, frost detection and concrete setting. The radiant flux sensors unlike the heat flux sensors, are sensitive to only energy transfer by radiation. These are used in air conditioning systems to anticipate heat input from sunlight, for emissivity measurements, fire or intrusion detection systems, hot spot control and remote temperature measurements. The company's line of heating elements and surface thermocouples are extremely thin measuring less than 200µm, with their resistance independent of temperature.
(French Technology Press Office Publication)

This bulletin is *CAPTEC' s primary catalogue* of heat flux sensing elements and assemblies. We have tried throughout the bulletin to give you - the designer and specifier – scientific information and technical data to help you understand the capabilities and limitations of CAPTEC thermal sensors. Please do not regard any of existing sensors as final. We have a wide array of alternate materials and techniques to propel sensor performance beyond published specifications.

Memo *Heat flux measurement*

In the literature and commercial documentation, different types of sensors are used for the same denomination '*heat flux /heat flow sensors*. In the main field of application ,viz., the measurement of heat transmission through walls, the purpose is to measure the '*density of an energy current' with the dimension of W/m^2* . We call the sensor used for this purpose a heat flux sensor.

The field of thermal analysis represents a different application of the heat flux sensor. Here the purpose is to measure all types of caloric effects, such as specific heat, heat of melting, heat of solidification, heat of hydration, mainly on small quantity of sample materials. The aim is to determine *the amount of heat exchanged in Watt* by the sample during exposure to a certain temperature program. Another useful application is the *measurement of the energy level of laser beams* . Here also the purpose is to measure heat in Watt. For a sensor used to measure heat in Watt, the term heat flow sensor is more appropriate.
In fact, there is no basic difference between the heat flux sensors intended for the above purposes when using heat flux sensors with copper foils since the highly conducting coating acts to make thermal uniformity over both sides, for example when sensing the non uniform heating on a surface absorbing a laser beam or when testing thermal conductivity of non homogeneous insulating materials.

Heat flux sensors found applications in industrial processes such as boilers or piping that have large but steady differences in temperature across insulation. Other applications concern building enclosures- walls roofs and floors - that are subject to smaller but varying differences in temperature across them. The U.S. standard practices agree substantially about the following definition of a heat flux sensor i.e. '*a rigid or flexible device in a durable housing composed of a thermopile (or equivalent) for sensing the temperature difference across a thin thermal resistive layer which gives a voltage output proportional to the heat flux through the sensor'* The building practice adds '*the manufacturer normally provides a calibration relating output voltage to heat flux at a rated temperature, according to a calibration procedure of the manufacturer choosing, that is unlikely to pertain to the measurement at hand'*. In CAPTEC heat flux sensors, balanced thermoelectric panels are housed between copper foils; since the devices are calibrated with a steady heat flux through the sensor; any deviation from the steady heat flux through the sensor will result into erroneous measurements

Radiant flux measurement

The need for quantitatively analyzing the radiant environment of an object or a location or exchangd thermal radiation beween two objects is encountered in such diverse technological areas as physics, climatology, medicine architectural, human and agriculture engineering. In the latter field for example, the problem may involve ascertaining the total amount of the thermal radiation incident upon a portion of the terrain during a given time interval or under various weather conditions. In architectural engineering, measurements of the 2π radiation exchanged between the walls, windows and ceilings of a structure provide valuable design information. Radiometers can also be employed in medical research to investigate the net radiation absorbed by a human body or an animal in their environment or to measure from a remote position the radiated heat loss from the average surface temperature of a heat producing means such as radioactive material or a chemical reaction

Conventional thermal radiometers are devices comprising a receiving surface acting to absorb thermal radiation. The incorporated thermocouple system with one junction exposed to the radiation and the other kept at constant temperature by means of contact with a polished reflecting heat sink. A steady state calorimetric technique is involved in their operation since the net absorbed radiation on the absorbing surface is converted into temperature increase**..** When exposed to a source of thermal radiation, such radiometers absorb energy at the same rate per unit area as would other surface having the same location orientation as the exposed surface and absorbed radiation is obtained from the reading when the calibration is known.

- **The CAPTEC radiant flux sensors**

The new line of CAPTEC radiant flux sensors is designed to measure the net absorbed thermal radiation on one black body sensing area whose temperature is measured at the same time; double sided radiant flux sensors are designed to sensed the difference in absorbed thermal radiation on two sensing area pointing in opposite directions The temperature changes produced by absorbed thermal radiation are not used to determine the rate of absorbed thermal radiation. Since radiant flux φ_0 incident on the sensing area is determined independently from the sensor temperature, its expression in Watt/m^2 from the Stefan Boltzman relationship is used for the sensor immediate calibration when $T_{surroundings}$ and T_{sensor} are known,.. A shutter is placed between the radiation source and the radiant flux sensor to measure the response speed lower than 0,1sec

Mounting the radiant flux sensor

Since absorbed thermal radiation is directly measured independently of the sensor temperature, there is no need to mounted the sensor in good thermal contact on a surface to obtain good results. The presence of air bubbles, dirt, water trapped between the back sensor side and the support may change the sensor temperature ; since the sensor temperature is measured at every time, there is no measurement error in absorbed thermal radiation. When the sensor is suspended in the air, the sensor temperature is determined by heat transfer through in the air

2π irradiance, 2π irradiance asymmetry, 4π irradiance

The plane radiant temperature T_{pr} in Kelvin, ($T_{pr} = t_{pr} + 273$ °C) is a parameter used to describe incident radiation in one direction within an enclosure, It is the 2π irradiance σT^4_{pr} (in Watt/m^2) on one side of a small plane element. Its the uniform temperature of an enclosure giving the same irradiance on a small plane element as the actual environment. According to the Stefan Boltzman law, the net absorbed thermal radiation on the small plane element from its surroundings only depends on the difference between the fourth power of the absolute plane radiant temperature and that T_{pe} of the small plane element:

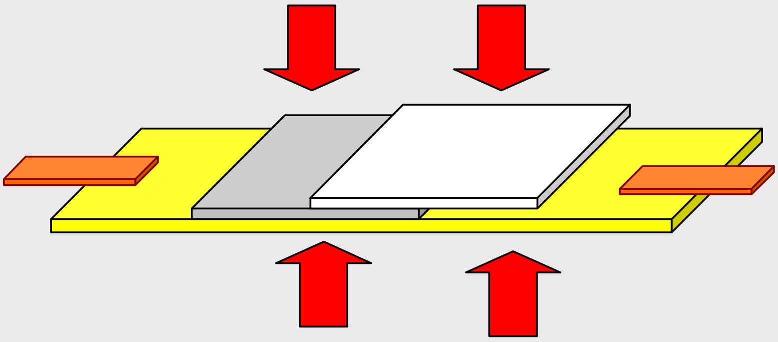
$$\varphi_{radiant} = \sigma (T^4_{pr} - T^4_{pe}) \quad \text{in Watt/m}^2 \quad (1) \quad \sigma = 5{,}68\ 10^{-8}\ W/m^2\ K^4$$

The 2π irradiance asymmetry is defined as the difference in 2π irradiance on the two opposite sides of a small plane element.The 4π irradiance is defined as the sum of the 2π irradiance on the two opposite sides of the small plane element.

Plane radiant temperature, radiant temperature asymmetry are parameters defined in relation to a small plane element and introduced in ISO 7746 `Thermal environments- Instruments and methods for measuring physical quantities'

The heat flux sensitive element

It has been recognized for a long time that when a first continuous material is coated with a highly conducting deposit of different thermoelectric power on one portion located in a temperature gradient between a heat source and a heat sink region, thermocouple junctions operating at the coated ends should be interconnected in series.



It is recognized now that the coated junction is a planar sensitive element responsive to the heat flux difference incident on the junction ends. A simple way to sense heat flux is then to protect one of the junction ends with a thermal insulating layer and to read the output voltage. The zero reading indicates zero heat flux across the coated junction.

Figure1 The zero reading indicates balanced incident heat flux on the coated ends

These sensitive elements are now incorporated in numerous devices generating most thermal functions; they represent a dramatic breakthrough in thermal sensing technology. This scientific catalogue summarizes some of the applications of the CAPTEC technology for thermal measurements:

Thin foil coated thermocouple

The same technology has been used to achieve plated thermocouple which consists of :

- a thin foil in a first material coated at one end with another material
- joined together at its coated end with a single wire in the material used to make the coating

when having the open end soldered junctions at the same temperature, the open end emf is observed to be proportional to the coated end temperature T

Figure 2 Coated thermocouple meander

The balanced self generating panel

Balanced self generating panels or planar thermopiles with numerous plated junctions connected in series covering uniformly a thin insulating plastic layer. The terminal ends have soldered lead wires for electrical connection.

Each junction ends is covered by a thermal insulating layer acts in order to produce unbalanced heat flux incident on the coated ends directly proportional to incident heat flux . Unbalanced heat flux on the junction ends results into gradients of electric potential, collected along the meander to finally build a millivolt output voltage. All the gradients of electric voltage are reversed when heat is extracted from the thermoelectric panel. Since polarity of the output voltage is positive when heat enters the top side and negative in the other case; such a device requires no special wiring nor special signal conditioning. The size of the thermopile panel is adjusted to cover exactly the area on which heat flux is to be sensed and computer aided design produces uniform or profiled heat flux sensing elements to meet your precise needs. Such devices are directly responsive to heat flux; they can be directly installed on conventional controllers and other readout devices.

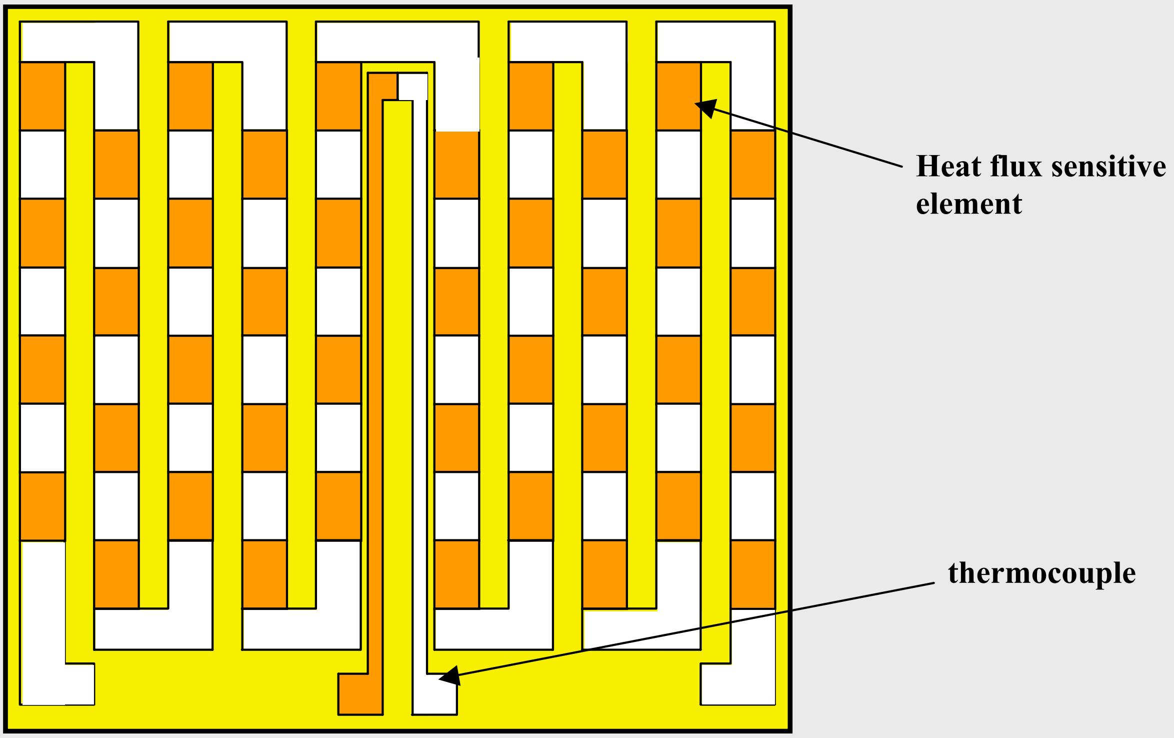
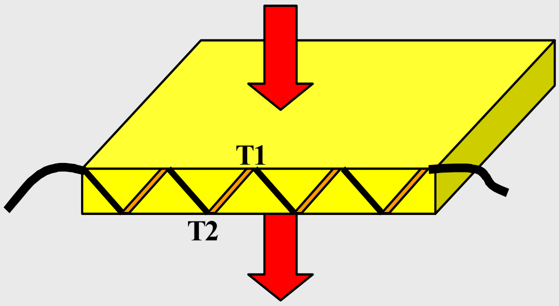


Figure 3 the balanced self generating panel

Recently, CAPTEC has applied a patent for thermal sensors including a balanced self generating panel with interlaced coated thermocouple and heat flux meander on the same plastic support. The thermocouple is incorporated to provide temperature measurement in the measuring section.

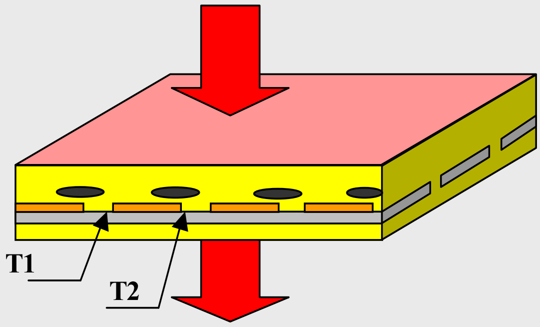
CAPTEC technology and design focus on trying to '**measure more with less'** that this to include in a same measuring section interlaced thermoelectric meanders (in the same materials and on the same polyester film) for **simultaneously measuring heat flux and temperature in the measuring section**

• *Application for measuring heat flux*



Conventional heat flux sensors are based on measuring temperature differences. The measured temperature difference produced by heat flux across a thermal insulating layer can be sensed by a series association thermocouples incorporated in the sensor. Historically these devices have been used as thermal insulation tester for building insulating materials

CAPTEC sensors are not based on sensing temperature differences across the sensor thickness but on sensing tangential gradients of electric potential produced by heat flux across the balanced self generating panel. Under quasi steady state condition, the readout indicates the mean heat flux across the thickness even though the whole is undergoing a slow change in temperature difference.



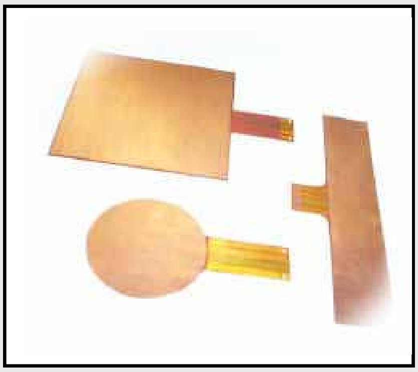
Measuring simultaneously heat flux and temperature changes

CAPTEC technology and design combines simultaneously heat flux and temperature measurements in the measuring section. These quantities are related by the thermal properties of the material in which the sensor is embedded (or by the thermal properties of the material of the surface on which the sensor is mounted)

Heat flux and temperature changes versus time may thus regarded as thermal signals which can be handled by using the well known techniques of signal analysis as well in the time domain as in the frequency domain.

Standard heat flux sensors

Standard heat flux sensors are coppered foil devices having a well defined sensitivity not influenced by the thermal properties of the material in which they are embedded. They are rigid or flexible and their main characteristics are:



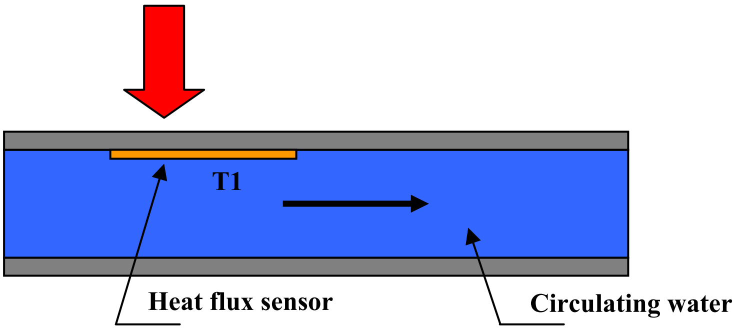
- A reduced thickness as low as 0,4mm; sizes of the sensing area ranging from 5x5mm to 300x300mm
- A reduced thermal resistance of the order of 0,00015°C/W/m^2
- A standard minimum sensitivity equal 0,35 µV/W/m^2 for each cm^2 of sensing area (sensitivity of a sensor is equal to the product of 0,35 by the sensing area in cm^2)
- Temperature range – 200°C - +200°C
- Response time lower than 0,5 second
-

Since the main operational error encountered when measuring steady heat flux as well as transient heat flux arises from the disturbance of the thermal pattern by the sensor used to measure it, the thinner is the sensor the better are the measurements since:

- The temperature drop across the sensor is extremely reduced; in fact, this temperature drop occurs within the contact thermal resistance between the back sensor sides and the surrounding materials (typically about 0,0015°C/W/m^2)
- The period of time required to reach steady heat flux inside the sensor is reduced

Special heat flux sensors are devices of:

- increased sensitivity: 0,7 µV/W/m² for each cm² of sensing area
- with a guard for thermal conductivity measurements ; available sizes(30x30xmm guard 50x50mm) (150x150mm guard 300x300mm) (300x300mm guard 600x600mm)
- waterproofed to be immersed in various liquids
- devices designed for measurement in soil
- optimized to be used up to 250°C under steady conditions (rigid or flexible)
- optimized to be used up to 380°C under steady conditions
- with etched holes in their sensing area (to pass a liquid flow for example)



Custom heat flow device cooled by circulating water

• *Application for measuring absorbed (or emitted) thermal radiation*

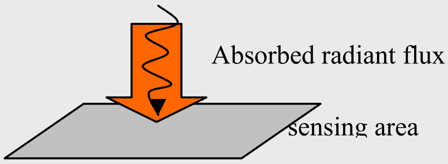
Radiation is a process by which heat flows from one body at higher temperature to a body at lower temperature. Radiant flux sensor are designed to sense the net thermal radiation absorbed by their sensing area from the radiant environment at higher temperature or the net thermal radiation emitted by their sensing area in their environment at lower temperature.

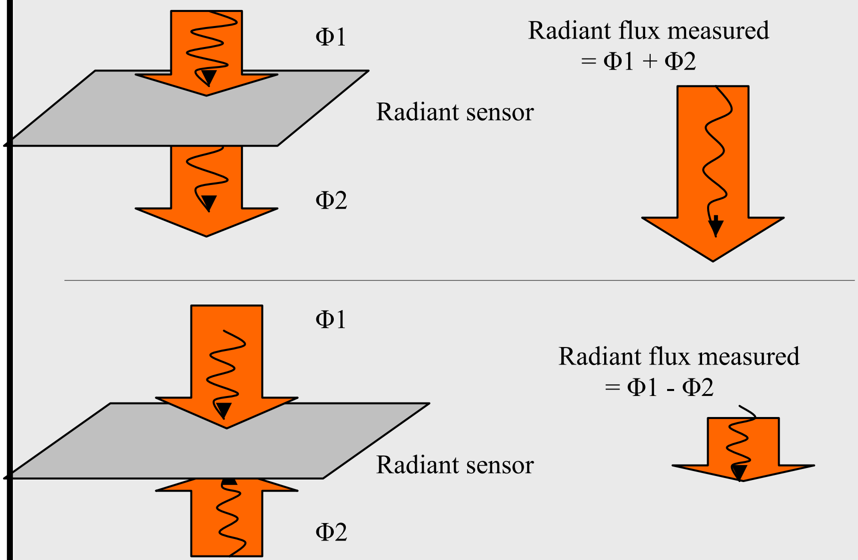
Conventional thermal radiometers are based on sensing the temperature increase produced by the net absorbed thermal radiation on their sensitive surface of known emissivity. Their operation exploits a steady state calorimetric technique giving the net absorbed radiation on the absorbing surface which is emissivity dependent is determined by the Stefan Boltzman relationship $\varphi_{radiant} = \varepsilon\,\sigma\,(T^4_{surroundings} - T^4_{sensor})$ with $\sigma = 5{,}68\ 10^{-8}\ W/m^2\ K^4$ and ε emissivity.

CAPTEC radiant flux sensors are directly responsive to the net thermal radiation $\varphi_{radiant} = \sigma(T^4_{surroundings} - T^4_{sensor})$ incident on their exposed sides acting as black body receiver. Even though the two plastic film comprise reflecting metallic strips on their external sides, the sensor behaves like a black body thermal receiver.

CAPTEC radiant flux sensors are IR flat plate radiometers responsive to the net thermal radiation emitted or absorbed by their sensing area even in the case where radiation is combined with heat transfer though convection conduction and radiation. They can be used without I.R. window as components, to be surface mounted or suspended in the air.

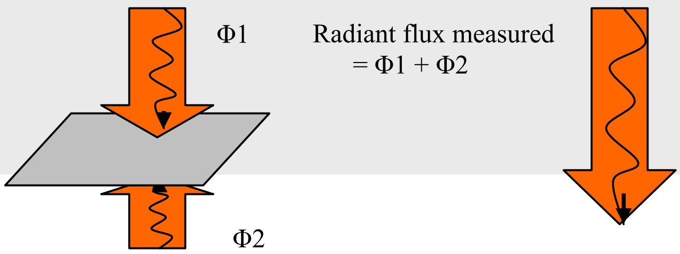
- **Single sided standard radiant flux sensors** are 'black 'body' plane 2π radiometers of the type that measure the net thermal radiation incident on their sensing area whose temperature is measured at every time They can be pasted on surfaces or suspended in the air.

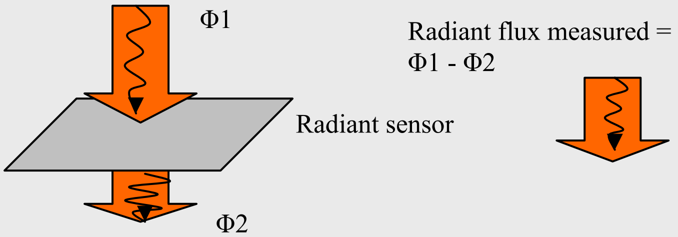




- **Double sided radiant flux (A-B) sensors, are differential radiometers of the type that compares net thermal radiation absorbed on their both sides,** independently of their own temperature.
- They can also used to sense the net radiant flux across their double sided sensing area. They are designed to be suspended in the air to compare their radiant environments. They can be custom shaped and sized in a great variety of forms (plates or cylinders ....)

- **Double sided 4π radiant flux (A+B) sensors are** 4π **hemispheric radiometers** of the type that detect net absorbed thermal radiation incident from all directions of the space



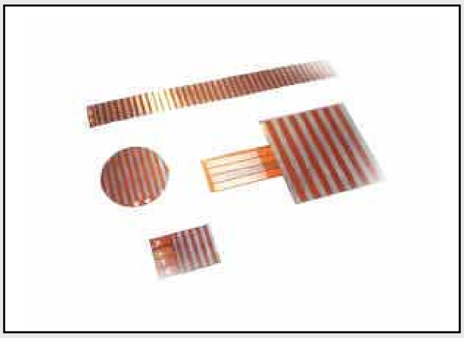


The readout only depends on the absorbed or emitted thermal radiation density on the sensor sides and is not influenced by the mean emissivity. The sensor temperature can be measured and is influenced by the combined effects between radiation absorption and heat transfer through conduction, convection and is emissivity dependent.

Simultaneous measurements of the net absorbed thermal radiation and of the temperature of the measuring section are combined to determine the radiant environmental temperature seen by the sensing area. Simultaneously measured changes in radiant flux and in temperature readouts versus time can thus regarded **as non correlated** thermal signals giving at every time the incident radiation from the environment seen by the sensing area

Standard radiant flux sensors

Standard radiant flux sensors are foil devices directly responsive to radiant flux (in the IR range 1-20µm) of well defined sensitivity when used in the air (or any insulating environment). They are rigid or flexible and their main characteristics are:



- A reduced thickness lower than 0,25mm and sizes ranging from 5x5mm to 50x50mm
- A mean thermal emissivity in the range 0,3 – O,7
- A standard minimum sensitivity equal 0,25 µV/W/m^2 for each cm^2 of single sided sensing area (sensitivity of a sensor is equal to the product of 0,25 by the sensing area in cm^2)
- As standard minimum sensitivity equal to 0,4 µV/W/m^2 for each cm^2 of double sided differential sensing area (sensitivity of a sensor is equal to the product of 0,4 by the sensing area in cm^2)
- Temperature range – 200°C - +250°

Special radiant flux sensors are devices of:

- increased sensitivity
- sensing the visible wavelengths
- optimized to be used up to 380°C under steady conditions
- protected with a IR transparent film on request

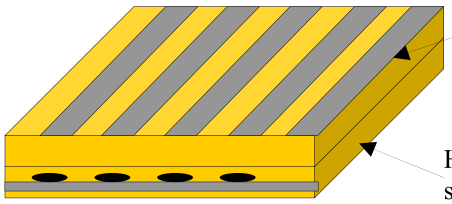
CAPTEC radiant flux sensors have been mainly used for many years in remote temperature sensors and tested in thermal equipments, that is in applications where their reliability and ability to operate in harsh environments were key factors. Now, the same quality have led to use them to measure combined heat transfer in the air. Sensors ready to be surface mounted or to be suspended in the air have been designed and are available

- ***General consideration on radiation dissociation from total heat flux***

Dissociating the absorbed thermal radiation from total heat flux could be taken by sensing the change in heat flux absorption produced by a change in emissivity of the coating covering the exposed side of a sensor having its back side is pasted on a heavy metallic plate. Such measurement are readily accomplished by matching two heat flux sensors mounted on a same surface so designed that one sensor of lower emissivity runs slightly cooler than the other of higher emissivity. The two heat flux sensors are connected in opposition to cancel the convection heat transfer from the air sample passing the sensors. In fact both thermal balances on the sensing areas are affected by the rate of heat transfer through convection and radiation measurement based on the differential measurement of thermal balances remains affected by convection

CAPTEC technology and design combines superimposed radiant flux sensor and total heat flux sensor in a **new composite device** ready to be surface mounted. The simultaneous measurement of :

- heat flux by the standard heat flux sensor whose main emissivity is that of the radiant flux sensor
- radiant flux by the radiant flux sensor acting as a black body plate thermal radiometer



thermal radiation incident on the exposed side is measured together with the rate of heat transferred through the exposed side of the heat flux sensor having a main emissivity equal to that of the radiant flux sensor. As a result, radiation absorbed by a black body receiving area, as well as total heat flux entering an exposed surface (whose emissivity is known) is determined from both measurements.

Thermal balance sensors are designed to be suspended in the air

CAPTEC thermal balance sensors incorporate the balanced self generating panel bonded on a copper foil on its back side and comprising numerous thermal paths of low thermal resistance incorporated inside the thickness of the top side plastic sheet to converted incident heat flux into numerous tangential gradients of electric voltage.

- Single sided thermal balance sensors are responsive to the total incident heat flux absorbed or emitted on their surface whose temperature is known at every time. Their coppered back side is ready to be pasted onto a surface or can be suspended in the air.
- The new line of CAPTEC sensors combines a thermal balance sensor and a radiant balance sensor mounted on the same copper foil. The two sensors are connected in opposition and having they backside to the same temperature give both radiant balance and the rate of heat transferred through convection to the sensing area

Standard catalogue heat flux and radiant flux sensors are best for small quantity needs and to prove heat flux and radiant flux measurement concepts before proceeding to custom design. Contact CAPTEC if you do not find the size and sensitivity you need. We have numerous more designs on file. Standard sensors are available to prove the interest of using these new devices, with the final objective to promote measurement of heat flux and radiant flux;