# Motion and occupancy detection in buildings

## 1 Motivation

The detection of motion and occupancy builds the foundation of a demand-based room air conditioning. For the detection, different measurement methods are used in practice.

wall mounted motion sensor

ceiling mounted motion sensor

## 2 Physical measurement methods

Different physical measurement methods are suitable to detect motion:

- High frequency (radar)

- Ultrasound

- Infrared

- Optical

Hereinafter just the passive infrared method (PIR) for motion detection will be considered and described. The following descriptions are based on products by Thermokon Sensortechnik GmbH. However, all movement sensors based on the PIR method work identically. Even those from other manufacturers. They just differ in thermal and optical resolution.

## 3 Motion vs. occupancy

From a building automation's viewpoint, the terms motion and occupancy stand for the same purpose. Both terms want to indicate, whether a person is within the detection range or not.

| Physical view | Technical view | Building automation view |
|---|---|---|
| Detection of *Infrared sources* | Detection of *motion* within the detection range | Detection of *occupancy* |

Therefore, the different product names *motion sensor* and *occupancy detector* show different perspectives on the same product. Both names are used synonymously and can't be distinguished from each other in terms of their meaning. Solely the technical characteristics of the product are responsible for the quality of motion or occupancy detection.

PIR motion sensors need a minimum of movement for a reliable function. If there is absolutely no movement, the sensor can't detect motion even if the name "occupancy detector" allows this fallacy.

## 4 Infrared radiation

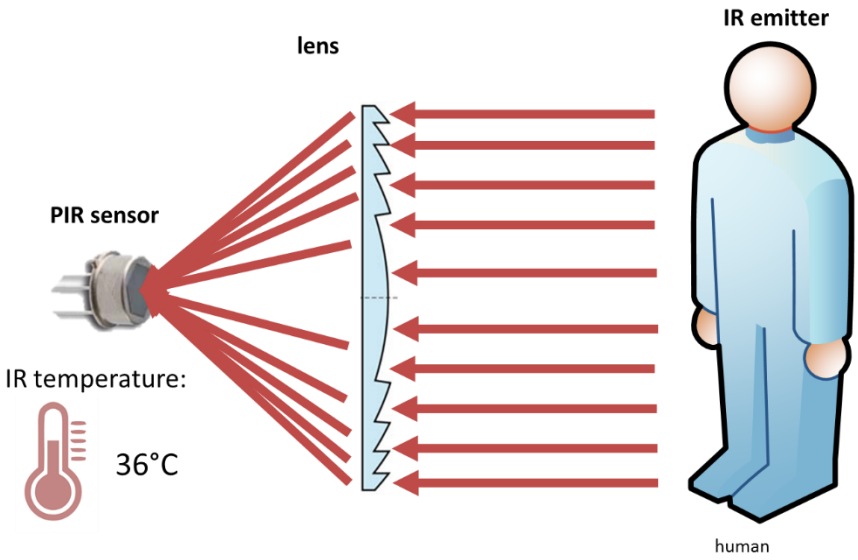
PIR motion sensors detect infrared (IR) radiation or thermal radiation. Infrared radiation is energy, that is emitted by every physical mass whose temperature is above absolute zero of 0°K (-273°C).
Furthermore, PIR motion sensors work in a passive way. Specifically, they don't emit infrared radiation but detect occurring ones. By doing so, IR radiation can be set equal with the surface temperature of an object. An object with a surface temperature of 25°C emits an equivalent IR radiation.


Due to the relatively high body temperature of humans, PIR motion sensors work well for detection of human motion. Usually the surface temperature of humans is significantly higher than the ambient temperature.

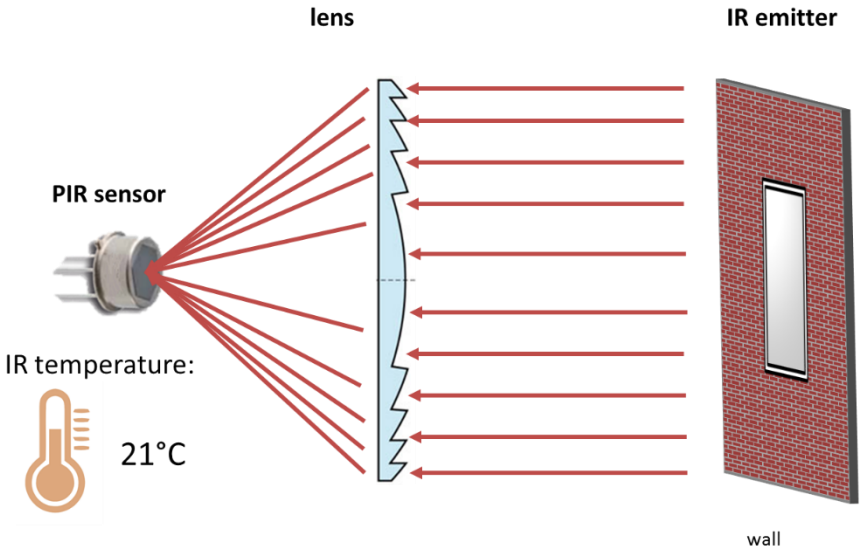
## 5 Measuring method

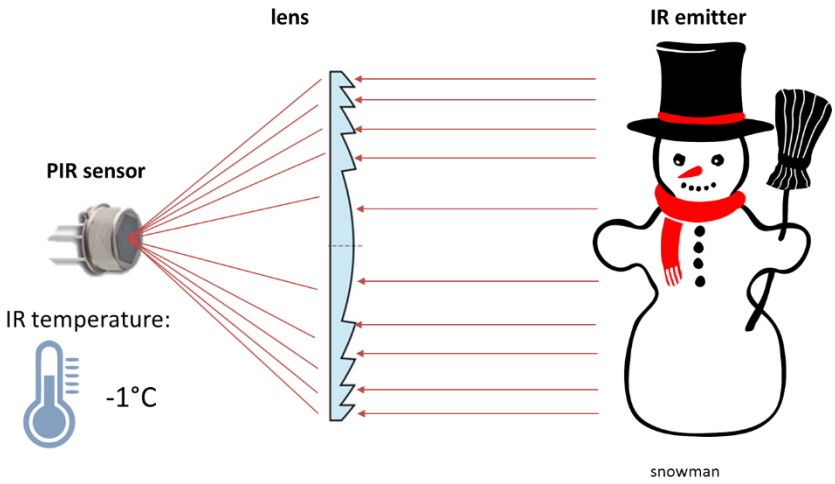
The emitted IR radiation of an object is collected from the PIR sensor element through a lens. The amount or intensity of the IR radiation is converted into a voltage signal. Therefore, the voltage signal varies with the change of the IR radiation. This voltage change is interpreted by the electronics and is subsequently converted into a switch signal, indicating motion.

The emitted IR radiation of a human is equivalent to its surface temperature of about 36°C.



A wall with a surface temperature of 21°C emits less IR radiation than a human body.

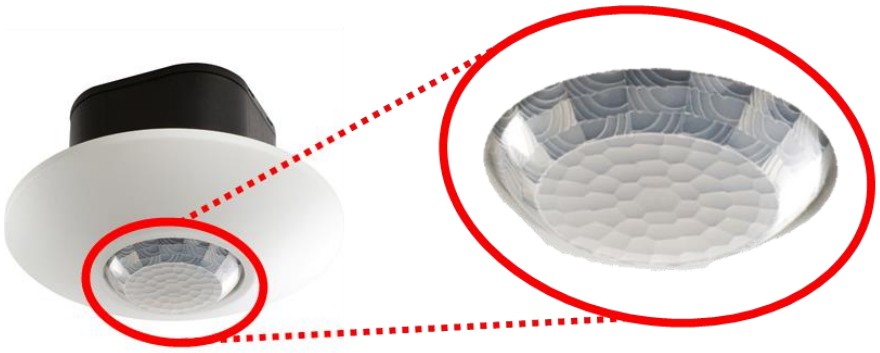


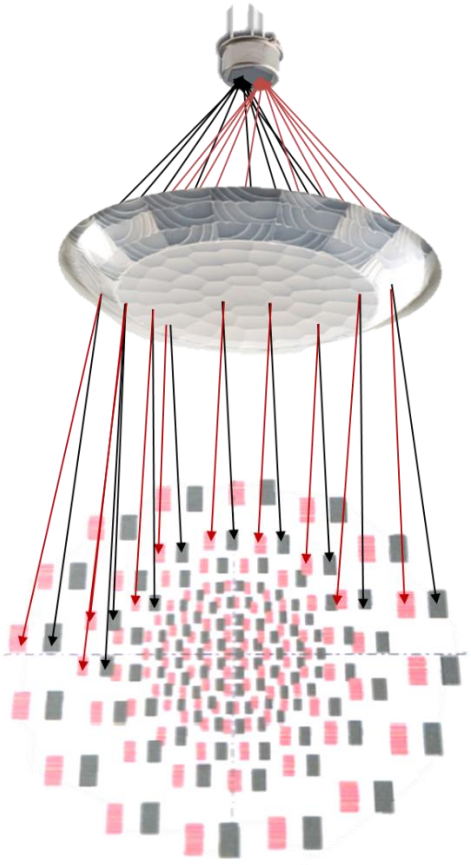

Even snow (surface temperature -1°C) emits IR radiation. Up to the absolute zero temperature of -273°C (0°K), every object emits IR radiation.

## 6 Detection zone

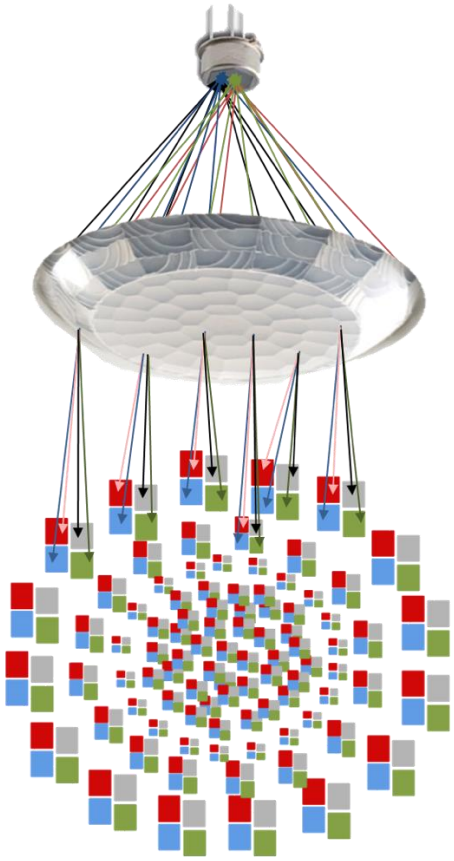
Usually single, twofold or fourfold PIR sensor elements are used for motion detection. As shown in chapter 5, the PIR sensor element is placed behind the lens. The lens itself consists of many individual lens segments.



Every single lens segment collects the IR radiation of a certain area on the PIR sensor element. Combined with the lens geometry, different detection sections are scattered within the detection range.



Multiple lens with twofold PIR sensor element

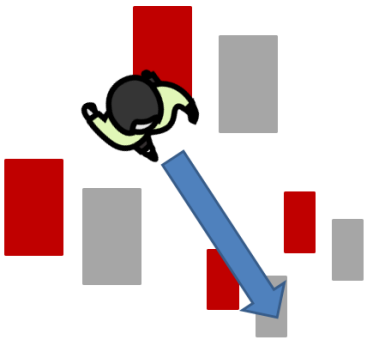


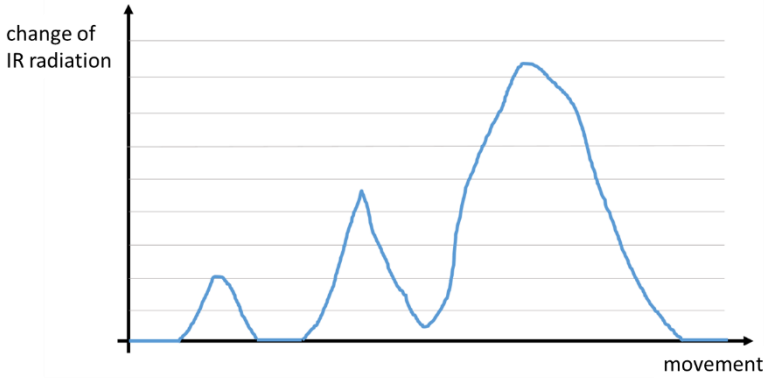
Multiple lens with fourfold PIR sensor element

| Amount of lens segments | PIR sensor | Amount of detection zones |
|---|---|---|
| 55 | twofold | 110 |
| 111 | fourfold | 444 |

A motion sensor with a fourfold PIR sensor has twice as much detection zones compared to a twofold PIR sensor if the same lens is used. Though the spatial extension of the detection range depends on the lens and not on the sensor element. If a fourfold PIR sensor element is used, the detection range is covered by a higher amount of detection zones. The more detection zones are scattered across the detection range, the better small movements can be detected.

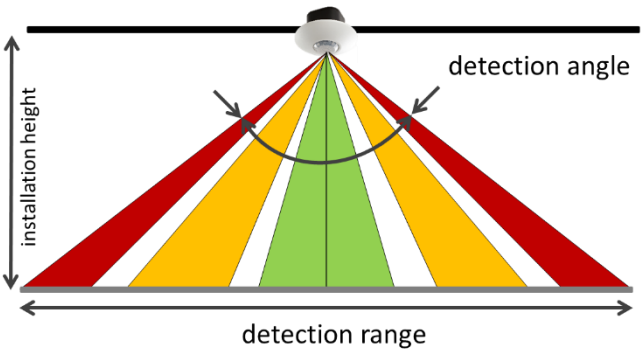
If an IR emitter (e.g. human) crosses a detection zone, the IR radiation within this zone changes. If the zone is just touched, the change is quite small. Though when the zone is crossed completely, this change is significantly higher as shown in below illustration.

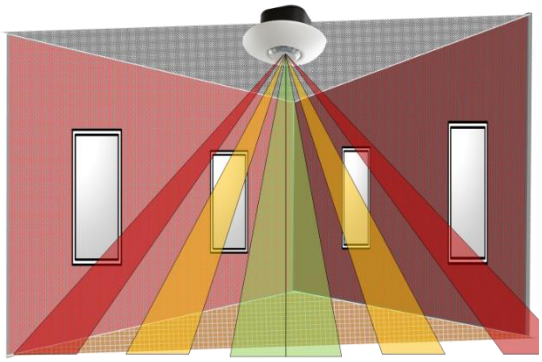





The PIR sensor element then creates an analogue voltage signal, which is equivalent to the radiation change within the detection zone. This analogue voltage signal is evaluated and processed in order to trigger a switch signal, that can be used by the downstream control unit.

The spatial extension of the detection range depends on the lens coverage angle, the motion sensor type and the installation height. These data are specified in the technical documentation of the respective devices.



Due to the lens geometry of a ceiling mounted motion sensor, the amount of detection zones at the center is much higher than in the outer circle.

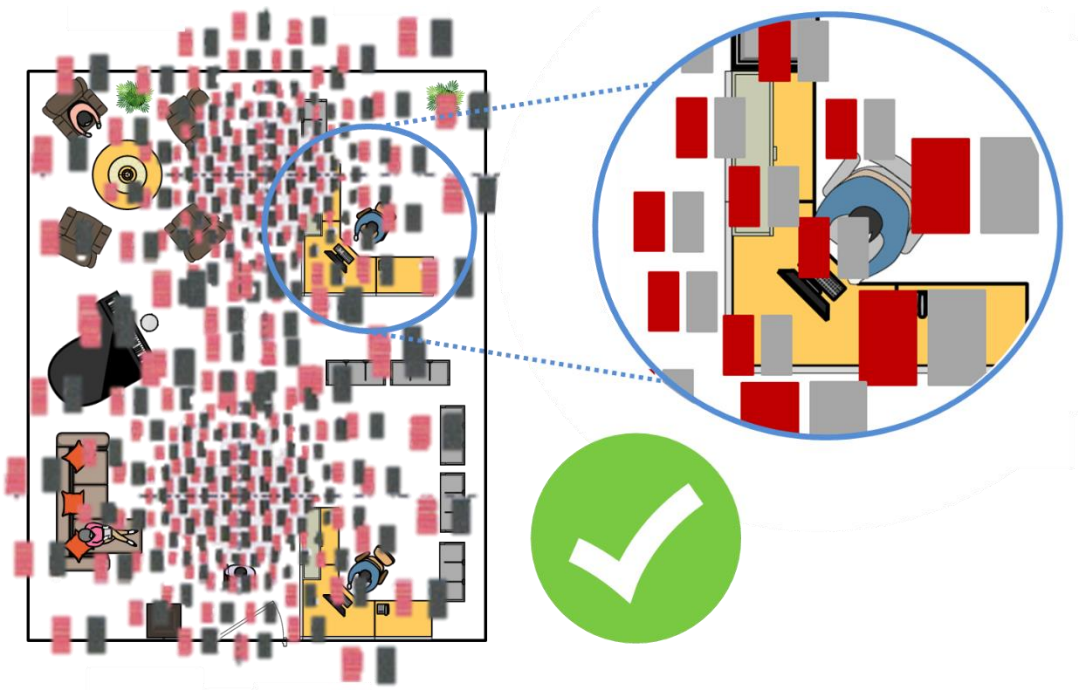
| Green (center) | Yellow (peripheral areas) | Red (outer circle) |
|---|---|---|
| High density; numerous detection zones | Middle density; many detection zones | Low density; few detection zones |

## 7 Placement

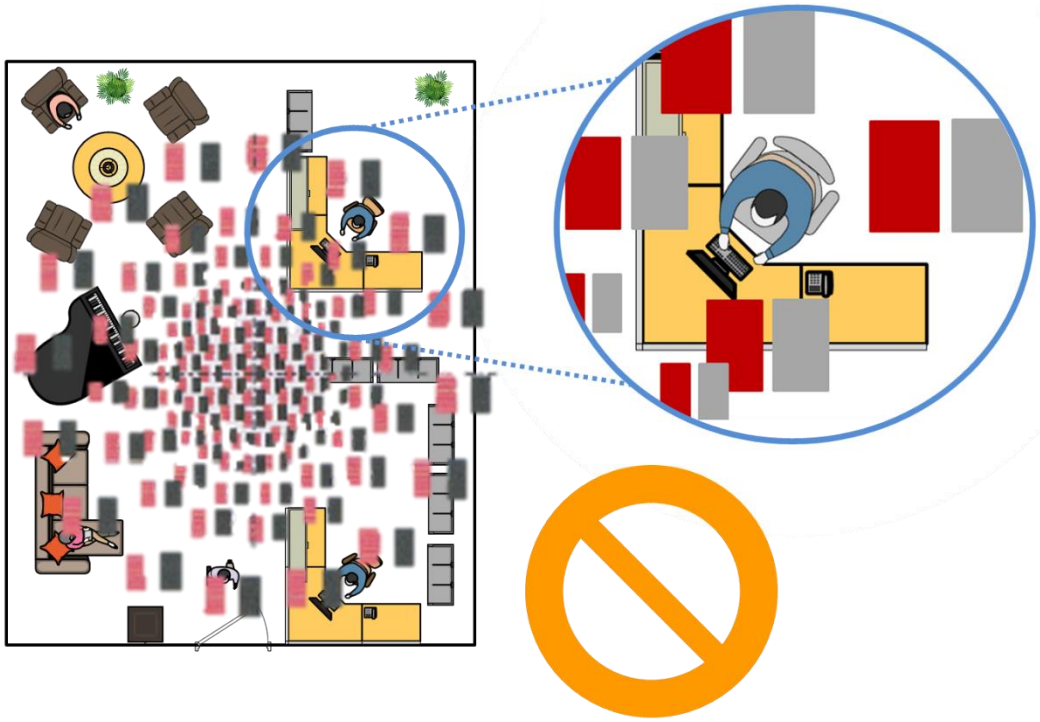
The right placement of a motion sensor is required for a reliable motion detection. Furthermore, it is necessary to use the right type of motion sensor.

The following example of a ceiling mounted motion sensor shows how to choose the right place for the device according to its technical features. That principle can be used for all kinds of PIR motion sensors.

| Kind of movement | Necessary detection zones | Reason |
|---|---|---|
| Sitting (desk) | Inner Zones | Small movements can be detected by the high density of detection zones |
| Walking (corridor) | Outer zones | Large movements need less detection zones to be detected properly |



Two motion sensors cover the entire room. Thereby, the desk workplace is covered by many small detection zones. Small movements of the person (e.g. body rotation) cause a change in IR radiation in one of the detection zones and trigger a switching signal.



Now just one motion sensor covers the entire room. Therefore, the desk workplace is just covered by few larger detection zones. In case of small movements (e.g. body rotation), no detection zones are possibly crossed and thus no switching signal is triggered. In this case, only large movements (e.g. moving around) will trigger a switching signal.

To prevent that problem, it is recommended to adapt the type of motion sensor and its installation site to the kind of motion that should be detected. Perhaps it becomes necessary to install additional motion sensors to ensure a reliable motion detection. If the movement at a corridor should be detected, the few and big detection zones don't pose an issue for usual as movements in a corridor are significantly larger than at a desk workspace.

Perhaps a movement is even not detected or detected lately. That might be caused by the facts mentioned above and doesn't present a malfunction of the device necessarily.

## 8 Distinctive features

PIR motion sensors can be distinguished by following characteristics:

- kind of PIR sensor element (single, twofold,…)

- amount and geometry of lens segments

- type of application (wall, ceiling,…)

- quality of electronics

  For movement detection, PIR sensor elements detect fast changes of IR radiation solely and not the general increase (e.g. increase of room temperature).
  How big this IR radiation change has to be depends on the electronics specification.

- temperature change △T

  The temperature change △T indicates the temperature difference (in °K) between the detection object (e.g. persons) and the environment, which is necessary at least to ensure a proper motion detection. At normal room conditions, △T is usually big enough:

  $$36°C\ body\ temperature - 20°C\ room\ temperature = 16°C\ \Delta T$$

  At high ambient temperatures, (summer or warmer regions), the △T between humans and the environment is smaller:

  $$36°C\ body\ temperature - 20°C\ room\ temperature = 16°C\ \Delta T$$

  If a motion sensor requires a minimum △T of 4°C, the proper function of this motion sensor can be influenced significantly. If the temperature of the environment and the entering object are quite similar, the IR radiation within a detection zone doesn't change. In this case, the PIR sensor can't detect the change of IR radiation and no switching signal will be triggered.

- movement speed

  Steady temperature increases (equal to change of IR radiation) caused by sun or underfloor heating shouldn't be interpreted as movement and cause a switching signal. Therefore, objects must enter into the detection zone with a minimum movement speed. That movement speed varies between different PIR sensor elements. If a person moves into a detection zone very slowly, the movement might not be detected.