Wireless Occupancy Sensors for Lighting Controls

Lighting use constitutes between 10 and 20% of the total energy consumption in commercial buildings.[1] Adding lighting controls is a simple retrofit option that can save on energy costs while helping meet agency and federal energy savings mandates (see Table 1). Some energy codes and federal standards require the use of lighting controls.

Room Type	Occupancy Sensor Lighting Energy Savings [2]
Classroom	10%–75%
Conference Room	20%–65%
Office, Private	13%–70%
Office, Open	5%–35%
Restroom	30%–90%
Storage Area	45%–80%
Warehouse	50%–90%

Table 1. How much can you expect to save when you install occupancy sensor lighting controls in these rooms?

Occupancy sensors increase lighting energy savings by turning off or turning down the lights when rooms are unoccupied. Lighting energy savings of 10% to 90% are possible depending on room usage.

Photo courtesy of Pacific Northwest National Laboratory.

Lighting controls that reduce or turn off the lighting when a space is not in use can save a significant amount of energy. Studies have shown that adding lighting controls can reduce lighting energy use by 10% to 90% or more depending on the use of the space in which the sensors are installed. One study conducted on a university campus found that installing wired occupancy sensors to control lighting in more than 200 rooms in 10 buildings provided an annual cost savings of about $11,900 with a simple payback of 4.2 years.[3]

Although many of the sensors installed in facilities are hard wired, wireless sensors that use radio frequency to communicate with lighting fixtures are a viable option (see Figure 1). These lightweight, battery or photovoltaic (PV) powered sensors can be attached to the wall anywhere with Velcro, magnets, or screws

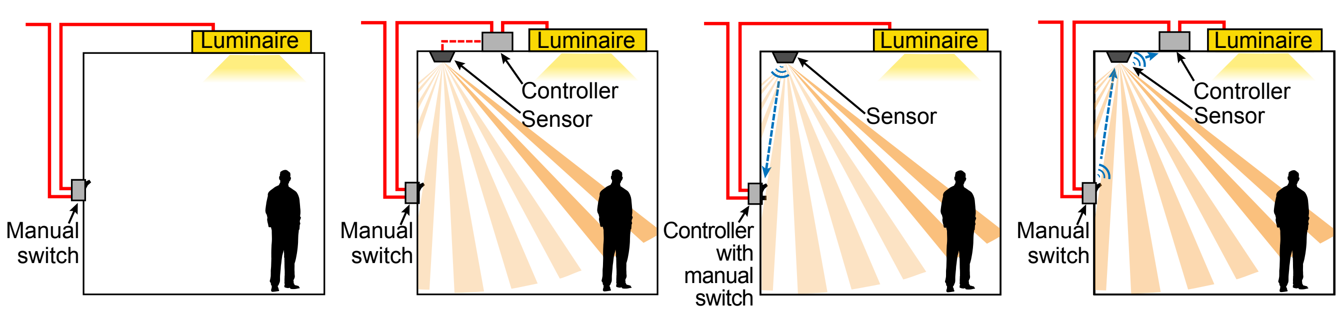

Figure 1. Sensors installed in a room to control lighting can be wired or wireless.

because no electric wiring is necessary. This means they can be installed where wiring would be impractical or impossible to install. It also means a significant reduction in labor installation cost. Another benefit is future flexibility—it is easy to move them if the room usage or configuration changes.

Where Should I Use Sensors?

Occupancy-driven lighting controls, whether wired or wireless, are cost-effective in locations that are used intermittently, like stairwells, breakrooms, conference rooms, and restrooms. Offices, which are becoming more intermittently occupied with the rise of working remotely, can be a good candidate for occupancy sensors. Other good locations are classrooms, laboratories, warehouses, parking garages, and parking lots. However, these controls are less likely to be cost-effective in open office areas or busy lobby areas that have occupant traffic throughout the day. Spaces that have steady occupancy during the day and are unoccupied at night on a predictable schedule may be better served by timer-based lighting controls. See Figure 2 to help determine which technology is best for your space.

Sensors Can Be Used For Two Types of Lighting Control Strategies

- Occupancy Sensors (auto on/auto off). With this strategy, the sensor automatically turns on the lights when someone enters the space and turns off the lights after a user-designated time period if no movement is detected.

- Vacancy Sensors (manual on/auto off). With this strategy, the person entering the room manually switches on the lights. If they are left on when the person leaves the room, after a certain amount of time with no movement, the sensor will turn off the lights.

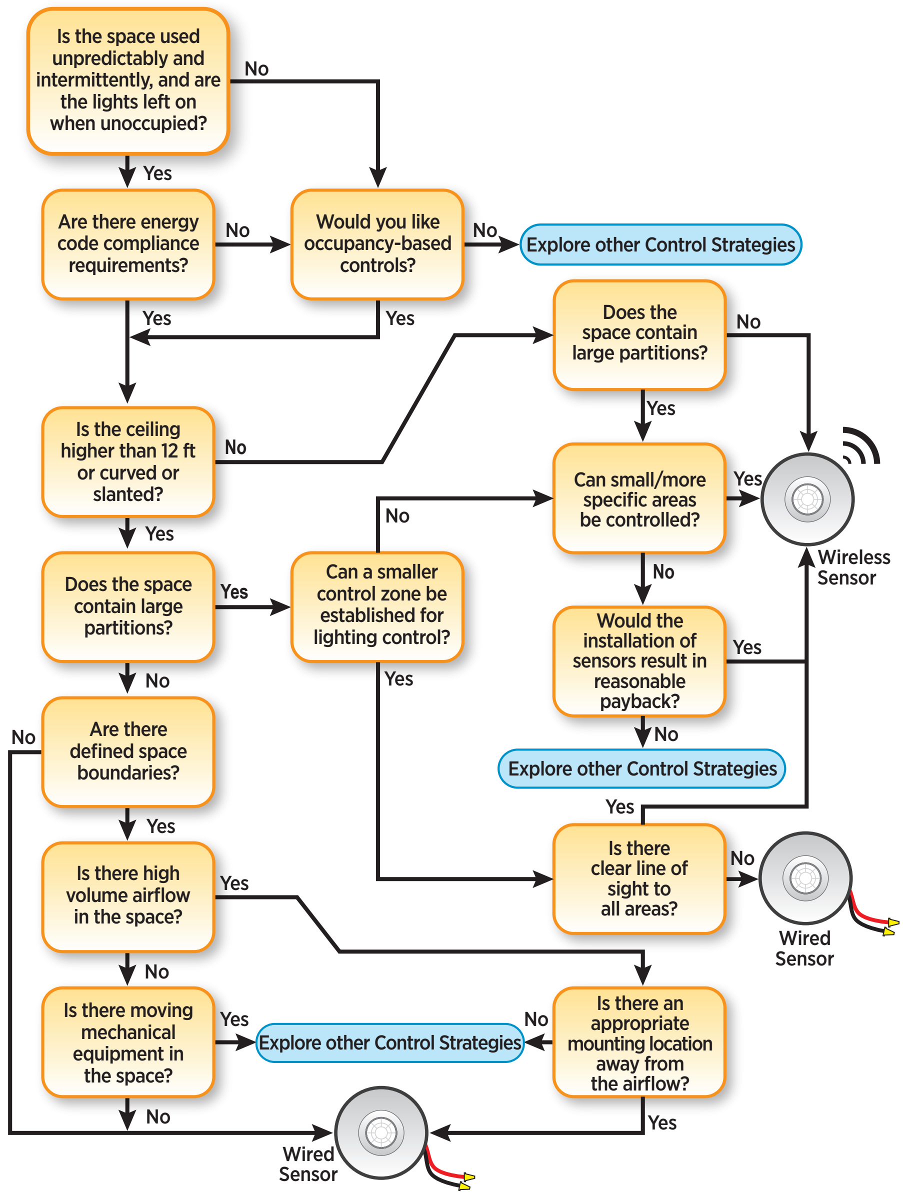

Figure 2. Which Technology is Best for Your Space? Use this decision tree to determine which lighting control technology is better for a given room—wireless sensors or wired sensors.

Vacancy sensors could potentially yield greater energy savings than occupancy sensors because they give the occupant a choice of whether or not to turn on the lights. If there is enough ambient light, for example from daylight entering through windows, the occupant may choose not to turn on the lights at all, whereas with the occupancy sensor, the lights will come on automatically regardless of how much daylight is in the room.

Vacancy sensors work well in most types of rooms with daylighting, including offices and conference rooms. They can work well in other rooms with light switches near each entry. Vacancy sensors are not recommended for areas where there are many entries that do not have light switches, such as stairwells, corridors, or warehouses. In addition, they do not work well for areas where some level of lighting is needed immediately, like stairwells and mechanical rooms, unless the controls are set to dim but not turn off the lights during hours of expected use.

Vacancy sensors may not be appropriate in spaces where there is a code requirement for a minimum level of light at all times. Occupancy sensors work well with all room types, but savings will be greatest with rooms that do not have windows or other sources of ambient light, like break rooms and restrooms.

How Do They Work?

An occupancy sensor detects the presence of movement within its given range. The sensor detects motion and transmits the signal to the control unit. If no movement is detected after a period of time set by the user, the controller determines that the space is unoccupied and switches off the light. The control unit processes signals from the sensor to increase or decrease power to the light fixture. In a wireless occupancy sensor, the sensor sends a wireless signal to the controller, and the controller increases or decreases the power to the luminaire. Signal repeaters can be installed if the signal has to be relayed more than 50 feet from the sensor to the controller. Controllers need to be connected at the junction box (except for controllers that are part of a wall switch).

The two most common types of occupancy sensors are passive infrared and ultrasonic sensors (see Figure 3), but other types are also used.

Passive Infrared (PIR) (wired or wireless)

PIR sensors are typically used in small, enclosed spaces to detect major motions such as occupants moving in and out of a room. They are less adept at picking up small movements like typing on a keyboard. They have a nominal limit of about 15 feet (but lower mounting heights might be more practical), and the sensor must have direct line of sight with the moving object to detect movement. They should not be mounted close to heating, ventilation, and air conditioning (HVAC) supply registers, which can disrupt their detection. PIR sensors have a thin film sensing material that generates electricity when exposed to heat. When an object passes in front of a background like a wall or the ground, the sensor detects the change in signal and converts that change into a pulse that sends a signal to a controller for a light. PIR sensors are passive; they don't actively send out signals. Because PIR sensors are passive, they require very little power, which makes them an ideal sensor technology for wireless sensors. PIR wireless occupancy sensors are powered by batteries or PV cells.

Ultrasonic (wired)

Ultrasonic sensors detect occupancy by constantly emitting high-frequency sound energy signals that can move throughout a room and around objects in a room. The sensing ability of ultrasonic sensors is based on the Doppler shift principle, where the sensor records a

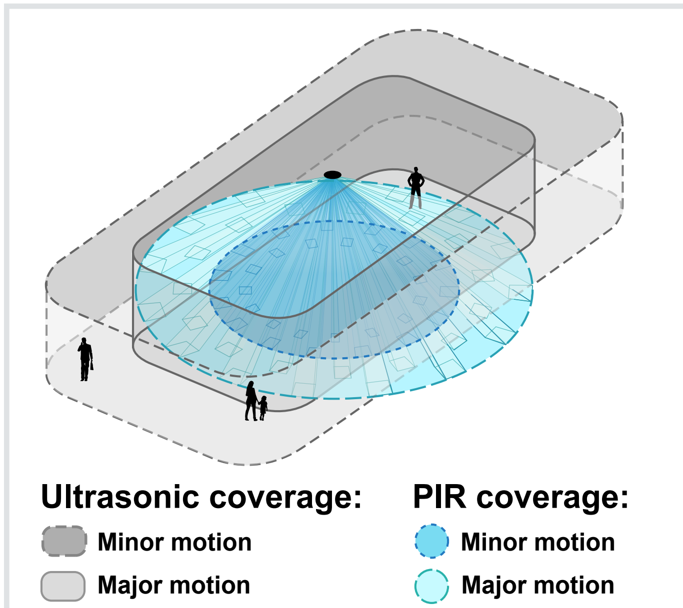

Figure 3. Comparison of Ultrasonic and PIR Ceiling-Mounted Occupancy Sensors

The PIR sensor, which could be wired or wireless, has a smaller coverage pattern (depicted by the light blue and darker blue cones), while the ultrasonic sensor, which is only available as a hard-wired system, has a larger coverage area (depicted by the gray rectangles).

change in frequency when the occupant moves relative to its position. Because ultrasonic sensors are actively sending out a signal, they require more power. For this reason, ultrasonic sensors are hard wired, not wireless. Ultrasonic sensors are well suited for spaces requiring a higher level of sensitivity and/or where a clear line of sight is not possible because of partitions, tall furniture (e.g., bookcases), odd-shaped rooms, bathroom stalls, etc. Ultrasonic sensors have a greater range than PIR sensors because ultrasonic sensors are not line-of-sight dependent; they fill the space with the signal. They are also sensitive enough to detect small movements like typing and page turning. Their accuracy is affected if they are placed in close proximity to sources of air vibration, like HVAC registers or fans.

Bluetooth (wired or wireless)

Bluetooth sensors detect the presence of people or objects by transmitting a signal between a transmitter and a receiver. In exterior applications such as parking garages, when a large object (e.g., a car) blocks the signal flow, the sensor determines that the space is occupied. These can be used with wireless occupancy sensors. However, they detect the presence of a vehicle, not people. True energy savings in parking applications stem from the detection of people, not vehicles.

Microphonic (wired)

Microphonic sensors detect presence by constantly monitoring for sound. When sounds are detected, the sensors determine that the space is occupied. This is a passive sensor technology. There are a few wireless occupancy sensor models that use microphonic sensors.

Video Image (wired)

Video images sensors use a camera and video analytics to determine whether or not a space is occupied. This is an active technology in that the sensor is always working. However, this sensor technology requires more power, so it can only be used with wired sensors. Video and microphonic-based occupancy sensors are making inroads, but are very application-specific.

Dual Technology (wired)

Dual-technology sensors use PIR sensors together with another sensor technology, either ultrasonic (active) or microphonic (passive). Dual-technology sensors activate lights only when both technologies detect the presence of occupants. They can give a higher likelihood of "false off" conditions.

Although one ultrasonic sensor can detect movement across large spaces, around partitions, or throughout odd-shaped rooms, a single PIR sensor cannot. However, several wireless PIR sensors strategically located throughout the room might achieve comparable coverage.

How are Wireless Sensors Powered?

If the room has a manual switch set up for wireless transmission, the wireless sensors need an independent power source that interprets the sensor pulses. This source will power the circuit board, the wireless signal transmission from the sensor to the controller, and the signal reception from the manual switch to the sensor.

Battery-powered PIR sensors typically run on standard 3-volt CR123A lithium batteries, which have a typical life of 11 years to 12 years,[4] although factors such as operating schedule, time-out settings, and room temperature have a significant effect on the frequency of battery replacement.

Some manufacturers offer wireless occupancy sensors that are powered by PV cells. These can be an excellent solution for sensors placed in locations that are difficult to access for battery replacement, such as industrial settings. However, they must be located in places where there is enough ambient light, either from daylight or from lights operating in the room, to produce power to operate the sensor.

For wireless sensors powered by PV cells, a charging time is typically provided indicating how many hours are required to reach full charge based on the amount of light reaching the PV cell, measured in footcandles. Higher light levels may require less time, and lower light levels may require more time. To quickly convert from lux to footcandles, divide the lux value by 10.

When considering installing PV-powered wireless sensors, note that they are typically larger than battery-powered wireless sensors and, of course, they have to be positioned so that the PV cells will be exposed to ambient light.

A third power option has recently come to market for wireless sensors. This technology utilizes kinetic energy—the physical action of manually pushing a button or flipping the light switch. This kinetic energy generates just enough power to transmit a signal from the switch to the controller; it would be used for powering the switch, not the sensor. A kinetic power source could be paired with a PV cell, which would charge the sensor.

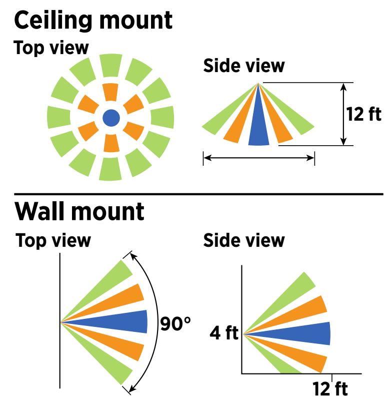

Figure 4. Fresnel lenses molded into the faceted cover of the sensor broaden the sensing area, both horizontally and vertically.

What Time Delay Setting Should I Use?

How long should the light stay on once no motion is detected? The less time it stays on, the higher the savings will be. One study of motion-sensor-controlled lighting installed at office workstations showed savings of 22% with a 30-minute delay; 32% with a 10-minute delay; and 46% with a 1-minute delay.[5] However, very short time-out periods are often correlated with occupant dissatisfaction. Time delays of 10 to 30 minutes are common.

National Electrical Manufacturers Association (NEMA) guidelines recommend a 15-minute time delay. However, you may want to start with a 10-minute delay for greater energy savings and adjust to a longer time delay if occupants request it.

What Type of Light Source Should I Use?

Some light sources work better with certain types of controls than others (see Table 2). Occupancy sensors require light sources that are quick starting with a short restrike time (the time it takes the light to go to full output after being in a low or off state).

Occupancy sensors work well with quick-starting sources such as light-emitting diode (LED), fluorescent, and incandescent. They do not work well with metal halide and other high-intensity discharge lamps because of their long restrike times (1 to 15 minutes).

One concern with the use of occupancy sensors is whether more frequent switching (turning the lamp on and off) will reduce the life of the lamp.This is not an issue for LED and incandescent sources but it can be an issue for fluorescent lamps.

Where Do Wireless Occupancy Sensors Work Best?

Sensors can be mounted on the ceiling or on the wall of the space to be monitored (see Figure 4). Wireless sensors can be mounted in places where no electric wiring exists or where wiring would be difficult to install. Because wireless occupancy sensors are lightweight, they can be attached to the wall or ceiling with Velcro or magnetic tape as well as screws. Because no wiring has to be run, it is easy to adjust their location if needed, which makes them an excellent option in areas that will be frequently reconfigured.

Wireless sensors work best in smaller, enclosed spaces where the mounting height of the sensor will be less

Considerations	Incandescent	Linear Fluorescent	High Intensity Discharge	LED
Lighting equipment used in commercial buildings by bulb type, 2018 [1]	19%	68%	4%	44%
Does switching affect lamp life?	No	Yes – mitigated with ballast selection	Yes	No
Restrike time	Instant	Quick	Long	Instant
Absolute lighting energy savings	High	Moderate	High	Moderate
Potential issues	None	Dimming or bi-level ballasts can cost twice as much as standard on/off ballasts.	Long warm-up and restrike times.	May require a bi-level driver.

Table 2. Which light sources work best with lighting controls?

Room Type	Recommendations	Caution
Breakroom	• For large breakrooms, ceiling-mounted sensors are highly recommended.	• Sensors placed in small breakroom areas or rooms without doors must be carefully positioned to avoid picking up movement from adjacent areas. Smaller spaces may be better served by wall-mounted rather than ceiling-mounted occupancy sensors; however, they should be positioned so that they are not blocked by open doors from entry ways, refrigerators, or cabinets.
Classroom	• The sensor should cover the instructor's desk, the room entrance, and other areas where people might sit for long periods of time. • Mount the sensor on the wall with the door to avoid false positives.	• Avoid ceiling-mounted sensors that could be obstructed by things that are hung from the ceiling. • Make sure that the sensor is not blocked when the door is left open.
Conference Room	• Larger conference rooms may need multiple sensors for complete coverage. • Rooms with manual-on switches can use a ceiling-mounted sensor over the table and presentation area.	• Position the sensor so it is directed away from doors and windows.
Corridor	• Make sure all access points into the corridor are covered by the sensors. A longer time-out is recommended to avoid distractions for occupants in the rooms lining the corridor. • For long-range sensors, the corridor width has an effect on detection length. • Use signal repeaters in long corridors to assure that there are no signal drops.	• Occupancy sensors are preferable to vacancy sensors for corridors because vacancy sensors would require numerous switches by doorways.
Office, Private	• The office desk must be within the minor motion coverage area of the sensor to be affected by actions such as typing on a keyboard and page turns. • Consider placing the sensor above the door to detect the door opening and closing.	• Private offices tend to have limited space. Designers must avoid placing sensors within 4 feet of air vents. • Sensors should not be blocked when the door is left open.
Office, Open	• Complete coverage must be provided in the walkways with overlapping coverage to avoid blind spots. • If cubicle walls are tall, individual wall-mounted sensors may be needed.	• Do not use short time outs for open offices because constant switching can be a nuisance for neighboring cubicles.
Restroom	• In-wall sensors can work well for individual restrooms. • Ceiling-mounted sensors should be used over the stalls; if not, longer time delays are recommended. • Multiple sensors are recommended for odd-shaped restrooms.	• Traditionally, wired ultrasonic sensors were used in restrooms. If using wireless passive infrared sensors, more than one sensor will be needed if there are partitions in the room.
Warehouse	• In some situations, horizontal mounting of hallway and corner sensors helps better adjust the field of view of these sensors. • Find sensor models specifically designed for high-bay locations when mounting sensors in warehouse ceilings.	• Standard ceiling-mounted sensors don't work well because of the typically high ceiling heights. • The sensors must be placed carefully to protect them from being accidentally knocked off by forklifts and other equipment.

Table 3. Best Practices When Using Wireless Sensors.

than 15 feet from the door or floor area to be monitored. Multiple sensors can be installed in spaces with visual obstructions like partitions or large equipment.

In areas where some level of light is needed at all times, wireless sensors can be used with bi-level switching, which reduces the lights' output level to 50% (or some other percentage of full output) but doesn't turn them off completely when the space is not in use. To add this bi-level capability, most fluorescent and LED lamps will require replacement of the existing ballasts or drivers with multi-level ballasts or drivers.

In buildings and sites with high security needs, security concerns associated with installing wireless network points must be considered. Care must also be taken to assure the sensors are using a radio frequency band that has not already been taken by the building's wireless internet, cell phone signal, cordless phones, radios, etc. See Table 3 for best practices when using wireless sensors.

Wireless Sensor Placement Guidance

- Do keep in mind the sensor's range limit. The range of the sensor should reach the floor of the area to be monitored and cover the zone of interest (see Figures 5 and 6).
- Do position the sensor to trigger the lights as soon as a person enters the space.
- Do assure that the sensor will maintain an unobstructed line of sight to task areas at all times, i.e., that equipment won't be periodically positioned in the room in a way that blocks the sensor.
- Do consider locating the sensors where they can't be tampered with.
- Don't mount wireless sensors in warehouses or other places with ceilings higher than 15 feet unless you can find a way to bring the sensor closer to the floor, for example by mounting it on a lighting fixture.
- Don't install sensors within 4 feet of an HVAC supply register or fan.
- Don't locate a wall-mounted sensor where it will be blocked when the door is open.
- Don't install sensors to point into hallways or other spaces that may trigger a false presence of occupancy.
- Don't install sensors on an inclined ceiling; they do not perform well when positioned at an angle.

Cost Considerations – Wired vs. Wireless Sensors

Wired occupancy sensors can be expensive to install because of high labor costs and the high cost of category 5 cables, which may be required for certain spaces. Wireless occupancy sensors have lower labor costs because they are quicker to install and are usually quicker to commission. However, the lower labor costs can be offset by higher material costs because wireless sensors cost about 55% to 130% more than wired sensors (ranging in price from $170–$260 per sensor for three of the most popular wireless sensor brands versus $110–$115 for three of the most popular wired brands).[6] Moreover, the relay pack for wireless sensors also costs twice as much as wired relays and, for multi-sensor zones, the costs can increase quickly with the number of sensors.

Lighting Controls in Codes and Standards

Versions of the ASHRAE/IES Standard 90.1-2010, 2013, 2016, and 2019 Energy Standard for Buildings Except Low-Rise Residential Buildings[7] require that lights automatically turn off or reduce output in spaces like conference rooms, classrooms, breakrooms, storage rooms, private offices, etc., with a 30-minute maximum time-out setting, both for new construction and for major retrofits. Occupancy sensors are required in most codes and federal designs and help achieve this requirement.

Beyond Lighting

Wireless occupancy sensors can be used to control non-lighting loads as well. One recommendation is to use occupancy sensors with HVAC controls to setback temperature set points, turn down airflows, and trigger HVAC systems to turn on and off. Studies have shown the energy savings from these HVAC controls can be greater than the energy savings from occupancy-based lighting controls.

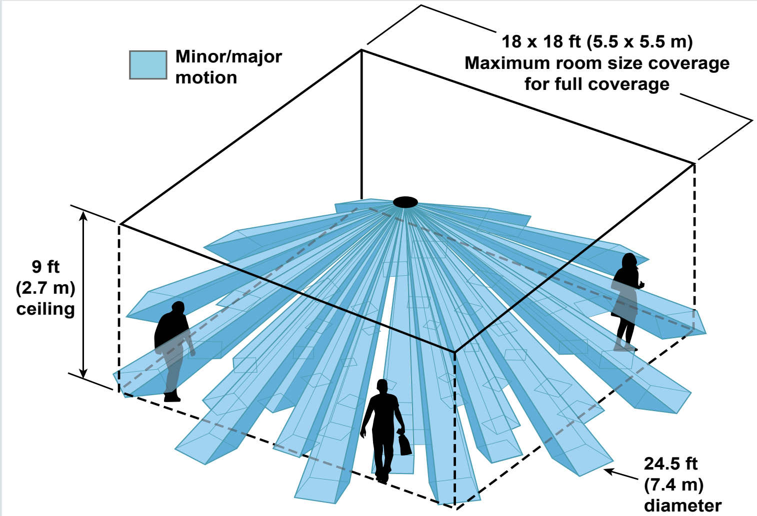

Figure 5. Detection range for one model of ceiling-mounted PIR sensors.

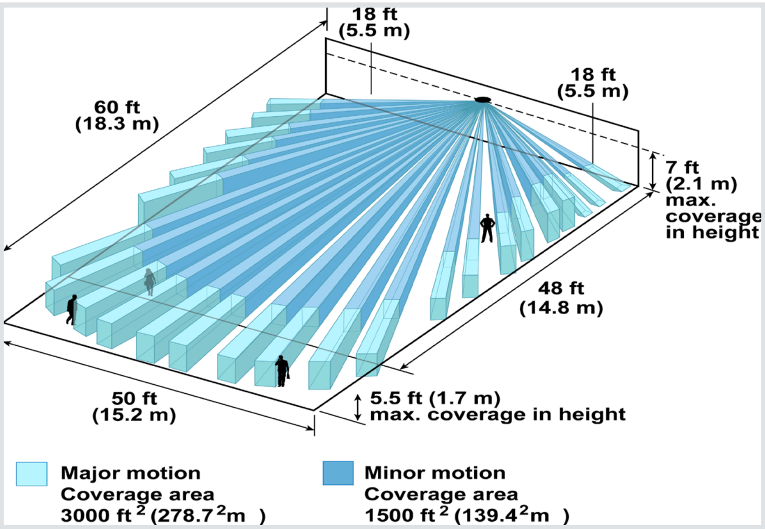

Figure 6. Detection range for one model of wall-mounted PIR sensors.

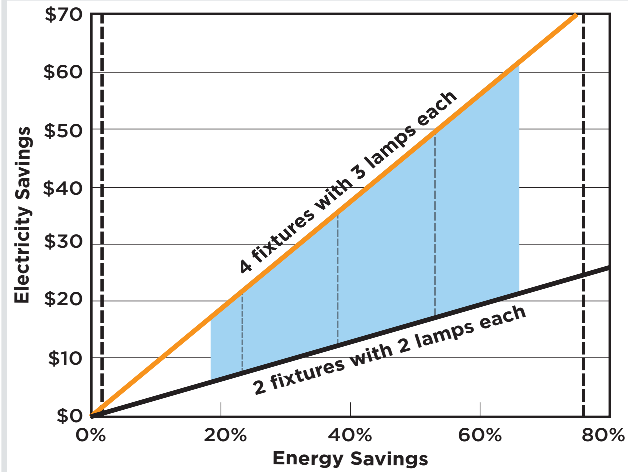

Figure 7. Energy savings vs. electricity savings with different lamping schemes.

If prioritizing the placement of sensors in a facility, choose areas where more lamps and more fixtures are located for higher energy savings.

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