Saving Energy Nationwide in Structures with Occupancy Recognition (SENSOR)

About 13% of all energy produced in the United States today is used to heat, cool, and ventilate buildings, with much of it wasted—used when buildings are unoccupied or not fully occupied. The projects that comprise ARPA-E's Saving Energy Nationwide in Structures with Occupancy Recognition (SENSOR) program seek to develop user-transparent sensor systems that accurately quantify human presence to dramatically reduce energy use in commercial and residential buildings.

By reducing energy used for heating, ventilation, and air conditioning (HVAC) by as much as 30%, SENSOR projects could produce savings of 2-4 quadrillion BTUs across the U.S. power system. Project teams will develop sensing technologies that minimize or eliminate the need for human intervention while pursuing aggressive cost, performance, privacy, and usability requirements in order to gain the acceptance and penetration levels needed to achieve this 30% reduction in HVAC energy consumption.

Technical Categories:

- Category A: Human presence sensors for residential use
- Category B: Occupant-counting sensors for commercial use
- Category C: Low cost, stable, easily deployable CO_2 sensors for commercial use
- Category D: Testing and validation for residential and commercial applications

PROJECT DESCRIPTIONS

Duke University – Durham, NC

Detecting Human Presence Using Dynamic Metasurface Antennas (DMA) (Category A) – $404,878

The Duke University team will develop a residential sensor system that uses a dynamic meta-surface radar antenna design to identify the presence of occupants. Because microwaves emitted by radar easily bounce off many surfaces inside a home, the sensor will be able to detect very small movements, including people breathing, even in rooms outside its line of sight. Using rapidly advancing computational techniques, the sensor system will adapt to different homes, taking into account characteristic changes in both home structure and floor layout. Thanks to its simplicity, the sensor can be made more affordably than phased-array approaches and can be easily deployed in a variety of settings.

Endeveo, Inc. – Boston, MA

Hotspot Enabled Accurate Determination of Common Area Occupancy Using Network Tools (HEADCOUNT) (Category A) – $1,223,320

The Endeveo team and its partners will develop residential occupancy sensing technology that monitors small changes in the radio waves given off by existing Wi-Fi routers and access points to determine the presence of people. By processing changes in wireless data called Channel State Information and using machine learning techniques, they aim to accurately detect small movements such as human respiration in the area covered by the network. The team will develop algorithms that allow the sensor to distinguish between humans and pets, as well as cope with day-to-day events like opening doors or moving furniture. While the sensor uses devices' Wi-Fi radio signals to probe the environment, it will not require internet access to function.

State University of New York at Stony Brook – Stony Brook, NY

SLEEPIR – Synchronized Low-energy Electronically-chopped PIR Sensor for Occupancy Detection (Category A) – $1,000,000

The State University of New York at Stony Brook team and its partners will develop an advanced, low-cost occupancy sensor for residential homes by building upon commercially available pyroelectric infrared (PIR) sensor technology to detect human presence. Stony Brook's innovation relies on the use of an "optical chopper" which temporarily interrupts the flow of heat to the sensor and allows the device to detect both stationary and moving individuals. The team will evaluate several approaches for the chopper, such as new low-power liquid crystal technology with no moving parts. The team will apply new signal processing techniques and machine learning to the infrared data, enabling differentiation between pets and people, and potentially sleep vs. active states.

Syracuse University – Syracuse, NY

MicroCam: A Low Power and Privacy Preserving Multi-modal Sensor Platform for Occupancy Detection (Category A) – $1,200,000

The Syracuse University team and its partner will develop a low cost, high accuracy residential occupancy sensor that can operate independently for several years on typical alkaline batteries. The device will pair a low-resolution optical camera (which inherently preserves privacy) with an infrared sensor, microphone, and low-power processor to understand its surroundings and determine human presence. Algorithms will be developed to analyze and combine data from these sensors to enable occupancy sensing that would be impossible by each sensor alone. The collected data will be processed locally, so that the device will not require connections to the internet or "cloud" to function.

United Technologies Research Center – East Hartford, CT

PEOPLE: Platform to Estimate Occupancy and Presence for Low Energy Buildings (Category A) – $1,956,775

The United Technologies Research Center team and its partners will develop a low cost residential occupancy sensor that uses radar sensing technology to determine human presence in residential environments. The envisioned system will be able to detect movements as small as the respiration of individuals, enabling it to distinguish between humans, pets, or background objects. The sensors will be low power and easily adaptable to multiple types of floor plans.

University of Colorado Boulder – Boulder, CO

Battery-free RFID Sensor Network with Spatiotemporal Pattern Network Based Data Fusion System for Human Presence Sensing (Category A) – $2,000,000

The University of Colorado Boulder team and its partners will develop an occupancy detection system employing a wirelessly powered sensor network that communicates using radio-frequency identification (RFID) related technology. The sensors will use privacy-preserving microphones and low-resolution cameras to detect human presence, relaying the information back to a central hub that also monitors patterns of activity in the home's electricity use. Because the sensor system can be powered wirelessly, it can be deployed without costly and invasive rewiring. The sensor data will be combined in computationally efficient ways to enable high accuracy human presence detection.

Boston University – Boston, MA

Scalable, Dual-Mode Occupancy Sensing for Commercial Venues (Category B) – $998,728

The Boston University team will develop an occupancy sensing system to estimate the number of people in commercial spaces and monitor how this number changes over time. The sensor combines the data from panoramic cameras and low-resolution thermal door sensors using innovative fusion algorithms to accurately count humans in rooms of different shapes and sizes. The data fusion system will take advantage of off-the-shelf sensors to reduce cost, while the system's scalable design will support venues of various sizes.

Cornell University – Ithaca, NY

Indoor Occupant Counting Based on RF-backscattering (Category B) – $1,500,000

The Cornell University team will develop a system using a combination of "active" RFID readers and "passive" tags. Instead of requiring occupants to wear tags, the tags, as coordinated landmarks, will be distributed around a commercial area to enable accurate people counting by sensing perturbations in radio waves traveling through the space. The distributed tags will operate without need for a power source. Extraction of body traits and algorithms by advanced imaging can further improve the accuracy and reliability of people counting in a complex room layout.

Rensselaer Polytechnic Institute – Troy, NY

Reflected Light Field Sensing for Precision Occupancy and Location Detection (Category B) – $2,375,228

The Rensselaer Polytechnic Institute team and its partners will develop a system for counting occupants in a commercial space using multiple, low-cost, time-of-flight (TOF) sensors, which measure the distance from objects using the speed of light to create a 3D map of human positions. This TOF system could be installed in the ceiling or built into lighting fixtures for easy deployment. Several sensors distributed across a space will enable precise mapping, while preserving privacy by using low-resolution images. System software will reduce errors by incorporating motion and position information, even between sensor "blind spots" to improve accuracy.

Scanalytics, Inc. – Milwaukee, WI

Floor Sensors for Occupancy Counting in Commercial Buildings (Category B) – $851,957

The Scanalytics team will develop pressure-sensitive flooring capable of sensing a large area with high-resolution and fast response time. This floor covering will enable the precise counting of people in commercial environments like stores, offices, and convention centers. To obtain the highest precision and reduce the overall system cost, data from the floor sensors will be fed into a processing algorithm that will intelligently determine the number of people in a space for many varied floor plans and use cases.

Matrix Sensors, Inc. – San Diego, CA

Stable, Low Cost, Low Power, CO_2 Sensor for Demand-controlled Ventilation (Category C) – $1,530,000

The Matrix Sensors team and its partner will develop a low-cost CO_2 sensor module that can be widely used to enable better control of ventilation in commercial buildings. The team's innovation consists of a solid-state sensor based on a type of material called a metal-organic framework (MOF), which captures and releases CO_2. The MOF is deposited as a thin film atop a sensor that can detect the change in mass brought by the absorbed CO_2, allowing it to determine the concentration of the gas in the air. If successful, the sensor would be exceedingly easy to deploy at a cost dramatically lower than today's commercially available systems.

N5 Sensors, Inc. – Rockville, MD

Digital System-on-chip CO_2 Sensor (Category C) – $1,530,000

The N5 Sensors team and its partners will develop and test novel semiconductor-based CO_2 sensor technology that can be placed on a single microchip. Using N5's low-power technology to determine CO_2 concentrations through absorption and desorption, combined with the ability to process data on the same integrated circuit package, the project team hopes to drastically reduce the cost of CO_2 sensors in commercial applications with an easily deployed "peel-and-stick" device.

Purdue University – West Lafayette, IN

Building-integrated Microscale Sensors for CO_2 Level Monitoring (Category C) – $1,533,407

The Purdue University team will develop a new class of small-scale sensing system that uses an ensemble of resonant mass and electrochemical sensors to detect the presence of CO_2. The team will take advantage of low-cost circuit boards and off-the-shelf devices like commercial solar panels and batteries to reduce the cost of their system, enabling extremely easy to deploy, low-cost sensors.

Iowa State University – Ames, IA

Simulation, Challenge Testing & Validation of Occupancy Recognition & CO_2 Technologies (Category D) – $736,210

The Iowa State University team will develop a comprehensive testing protocol and simulation tools to evaluate the energy savings and reliability of occupancy recognition sensor technologies for commercial and residential buildings. ISU’s field test protocols will allow them to determine occupancy recognition sensor effectiveness and reliability in both laboratory and real-world conditions for residential and commercial applications. Laboratory test facilities will provide controlled environments to collect hard data on these technologies’ performance. Their approach will test multiple sensor technologies across Categories A, B, and C, including occupancy recognition and CO_2 measurement technologies.

University of Alabama – Tuscaloosa, AL

Quantification of HVAC Energy Savings for Occupancy Sensing in Buildings Through an Innovative Testing Methodology (Category D) – $1,496,655

The University of Alabama team and its partners will design a new testing and validation protocol for advanced occupancy sensor technologies in categories A, B, and C. The team’s evaluation regime will include eight levels of diversity to generate strong testing results, while its simulation tools will take advantage of data analytics with built-in machine learning algorithms to accurately determine energy savings. In addition, the team’s focus on working within existing industry standards will help inform projects’ eventual transitions to commercialization.