# Saving Energy Nationwide in Structures with Occupancy Recognition (SENSOR) Program Overview

## B. PROGRAM OVERVIEW

### *1. Summary*

This program aims to dramatically reduce the amount of energy used for heating and cooling residential buildings (by 30%) via user-transparent sensor systems that accurately sense human presence (not merely motion). This program also aims to reduce energy usage in commercial buildings (also by 30%) by enabling ventilation control based on sensor systems that can accurately count the number of humans in a pre-determined zone. If these sensing technologies can be widely deployed with disruptively low price targets and failure rates, a significantly lower usage of energy will result without impact to comfort of the occupants of the space. Heating, cooling, and ventilation (HVAC) reduction is only one way energy can be saved; such human presence sensing and people counting will enable drastic improvements in the way buildings communicate with and respond to their occupants.

The accuracy, reliability, and cost requirements to deliver such substantial energy savings are far beyond the limits of sensor systems available today. However, ARPA-E believes that by building on recent trends in improved performance and reduced cost in low-power consumer electronics and wireless communication technologies, it is possible to achieve the required performance levels through a focused push in the SENSOR program. Supporting systems currently exist (i.e., thermostats/controls, variable air volume systems, etc.) that could utilize data from such sensor systems to achieve the program's energy reduction targets today, with only slight modifications. In order to ensure impact for the new sensor systems, significant adoption barriers must be identified and clearly understood, technical paths to overcome these barriers must be defined, and real-world performance of these technical solutions validated.

There are four areas of focus for this program, as described further in this FOA:

A. Human presence sensors for residential use (these deliver a binary "occupied or not occupied" signal to enable temperature adjustment (setbacks) between setpoints used for the normal comfort range vs those for an unoccupied residence;
B. People counting sensors for commercial use (these deliver the number of occupants in a specific defined HVAC zone to enable both temperature and ventilation setbacks);
C. Low-cost, stable, and easily deployable $CO_2$ sensors to enable adoption of ventilation setbacks;
D. Real-World testing and validation of A, B, and C in both laboratory controlled quasi-real world environments and actual field deployment tests throughout the program timeframe.

### *2. Background*

The amount of energy currently used to heat, cool, and ventilate buildings is enormous – equivalent to 13 quad BTUs (Quadrillion British Thermal Units) of energy; the *entire* United States energy consumption was 97.5 quad BTUs in 2015. 37% of all energy used in commercial buildings is used for heating, cooling, and ventilation (HVAC)[1]. Much of this is wasted, and is being used when buildings are either not occupied at all, or occupied well under the maximum levels they are designed for.

Human presence sensing and people counting have significant potential to generate energy savings in a number of ways. Currently, simple motion sensing is used to control lighting to save energy (albeit with high failure rates when occupants are not in motion.) These failures have minimal drawbacks (aside from transient user annoyance): lights can easily be set to the proper state immediately by the occupant, with relatively little impact to comfort, productivity, and safety. This would not

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[1] Data adapted from EIA's Commercial Building Energy Consumption Survey (CBECS 2012) data and EIA's Residential Energy Consumption Survey (RECS 2008) data

be true for an HVAC scenario, where a thermostat would have to be manually reset and a potential for thermal inertia would result in extended discomfort. More seriously, such failures could set ventilation to an inappropriately low setting and result in $CO_2$ or other volatile organic compound (VOC) increases that could impact productivity, comfort, and potentially health – all *invisibly* without notice to the occupant. Thus, sensor systems used for HVAC control require significantly better accuracy than what movement sensors can provide, and must address the user adoption issue of "invisible failure".

Individual sensor system applications and requirements will vary based on the building type and use case. For the purposes of this Funding Opportunity, the market has been divided into two high-level categories, Residential and Commercial. The technical distinction between these two high-level categories is one where only temperature setbacks are used (Residential – Category A), requiring only binary occupancy information, and one where ventilation control can be added (Commercial – Category B), where the number of people within each HVAC zone is needed to properly tailor the ventilation settings. ARPA-E does not want to limit technology applications to any specific niche of the market, and strongly encourage submissions with technologies that have the flexibility to provide excellent savings across a range of building types in order to maximize impact, thus Categories A and B are technology agnostic.

Here, a "Sensor system" is defined as the sensor(s) needed to determine the desired output data as well as the hardware to transmit these data to an existing type of control system. The sensors themselves include the actual sensing modality hardware, a power source, a communication source, any onboard computation hardware that is needed such that the sensor is self-contained, and packaging. An example for the residential use case could be a small number of sensors that all communicate directly to the control system (i.e. thermostat); an example for the commercial use case could be a distributed network of several very low power, distributed wireless sensing points that all communicate back to a hub, which transmits the people count data to a control system. There are many more configurations that could be possible depending on the specific sensor modality chosen. This FOA, defines a set of requirements for a system to be successful in delivering energy savings, regardless of the specific sensing modality or sensor network configuration. ARPA-E encourages an emphasis on retrofit installations, technologies capable of multiple deployment scenarios, and testing and validation.

## Category A: Residential (Human Presence Sensors)

The ability to control heating and cooling set-points directly has been available for over a hundred years, and well predates electronics, even for programmable versions[2]. It is perhaps shocking that the potential energy usage benefits of this technology have yet to be fully realized in residential or commercial buildings, despite the semiconductor revolution and significant advances in HVAC control strategies.

When programmable thermostats using solid-state controls became available, they were heralded as true differentiators in terms of HVAC energy savings, *potentially* enabling HVAC energy usage reductions of 20-30% (see references in Table 1, See Section I.E of the FOA). However, after several years of wide commercial availability and usage, multiple studies in different geographic areas conducted at different times found that they were conclusively not saving energy; in fact, in some cases users even *increased* their energy usage[3,4]. As a result of the lack of energy reduction by programmable thermostats, the Environmental Protection Agency announced a decision to sunset the Energy Star program for this technology in 2009. This impacted both the Energy Start Homes Program and LEED for Homes; both programs discontinued award points for this product. [5]

Since that time, research has shown that the deleterious impact of user interfaces is much more important than originally appreciated.[6] This issue does not seem to be improving as newer, "smarter" thermostats grow increasingly more complicated. A disruptive change in this area is needed, and it must *fundamentally* solve this issue, not merely provide an iteration with regard to existing thermostat user interface design. The need for human input and continuing attention clearly must be *removed* in a way that is user-acceptable, and this challenge could be solved and validated with the technology envisioned within this FOA.

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[2] Bernan, Walter. On the History and Art of Warming and Ventilating Rooms and Buildings, London, 1845

[3] Peffer,T., et al., Building and Environment **46** (12) 2011

[4] Malinick, T., et al., ACEEE Summer Study on Energy Efficiency, **7** 2012 (pp 162-173 and references therein)

[5] U.S. Environmental Protection Agency. Summary of Research Findings from the Programmable Thermostat Market. Memo to Manufacturers on Programmable Thermostat Specification Review. 2003, Washington, D.C.: U.S. Environmental Protection Agency.

[6] Meier, A., et al., Building and Environment **46** (12) 2011

### Categories B and C: Commercial (People Counting Sensors and CO2 Sensors)

For the case of commercial buildings, there is an additional energy savings opportunity over that of temperature setbacks: ventilation. Most large buildings are outfitted with variable speed fans for controlling the amount of ventilation delivery ("VAV" or variable air volume systems, often found in HVAC systems with economizers), and these fan speeds can be adjusted to use more or less energy, depending on the ventilation needs[7]. It is difficult for these systems to be utilized largely because this would require the certain knowledge of the number of people occupying the space at any time, which is not available. Therefore, many buildings are strikingly over-ventilated. Recent concerns about indoor air quality ("IAQ") have driven up ventilation rates even more despite the increased energy usage and cost associated with this strategy. The limiting case of a highly occupied building defines the settings, as described by ASHRAE standards driven by IAQ[8]. However, if the number of people in the space could be determined, IAQ could be ensured even at reduced fan speed set points, and the building confirmed to be in continuous accordance with ASHRAE ventilation standards. Ventilation is an exciting energy savings opportunity, as it can be changed quickly and doesn't suffer from the thermal lag of extended temperature set-points.

IAQ concerns are identified as a potentially critical user adoption barrier for ventilation control, because ventilation is "invisible". Building managers and end users have no timely, affordable, and easy to deploy method to detect that the system is performing as it should to meet standards, and thus deliver an environment that promotes comfort, productivity, and even health. IAQ markers such as $CO_2$ can be measured, but current technology is expensive, requires wired installation, and is plagued with calibration issues such that costly manual calibration needs to be performed every year. The drive toward more ventilation and not less is likely to continue as the understanding of IAQ impacts grows[9]. On the other hand, advanced building standards such as LEED platinum are challenging to meet without adequate ventilation control. If $CO_2$ could be measured reliably and cheaply on demand wherever an end user desired, it could be used as an *indicator* that ventilation rates are set to appropriate levels, and thus enable existing VAV systems to be used in conjunction with the people counting sensor technology described in this FOA. To this end, $CO_2$ sensor development is included in Category C as a partial solution and adoption enabler, even if this sensing modality cannot be used alone to deliver an occupancy count. If a submission intends to use $CO_2$ sensing as an actual *occupancy count* modality, this would follow the requirements of Category B. If a submission intends to deliver $CO_2$ sensors as an adoption enabler as discussed above, this would follow the requirements of Category C.

### Category D: Testing and Validation (both Residential and Commercial)

Finally, there is a key need in this application space for testing and validation research. Because building spaces, usage patterns, and HVAC systems vary widely, as do climates, validating the energy savings from a particular technology in the building space can be challenging. ARPA-E knows of no existing tools that can fully assess and validate presence sensor and people counting technologies as described in this FOA. In order to enable widespread adoption of such technologies for both retrofit and new building scenarios, a way to validate energy saving claims must be developed and implemented.

Testing and validation research must deliver a clear means for assessing the energy saving impact of both the residential and commercial (Categories A and B) technologies in a wide variety of floorplans. To this end, both a simulation tool and real-world field trials must be completed for multiple building types. A method for determining ground truth must be established and used to compare against novel sensor systems in both the residential and commercial spaces.

## C. PROGRAM OBJECTIVES

The principal objective of the SENSOR program is to reduce energy used by HVAC systems in buildings by 30% for both residential and commercial buildings, which could total 2-4 Quads of energy consumption in the U.S. (Section I.F of the FOA provides a detailed accounting of the available savings, including breakdown across different sectors and types of buildings.)

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[7] J. Zhang, G Liu, MR Brambley, RG Lutes, PNNL # 22072, 2013

[8] Standards 62.1 & 62.2 – The Standards For Ventilation And Indoor Air Quality – ANSI/ASHRAE Standards 62.1 and 62.2 are the recognized standards for ventilation system design and acceptable IAQ

[9] Recent studies have indicated that productivity suffers at $CO_2$ levels currently considered benign (~ 650 to <1000 ppm) MacNaughton, Et al., Int. J. Environ. Res. Public Health **12** 2015, 14709-14722

In pursuit of this objective, the SENSOR program will develop new classes of sensor systems: human presence sensors (for residential use), people counting sensors (for commercial use), and low-cost $CO_2$ sensors (as a critical enabling technology for VAV actuation in commercial buildings). These sensor technologies seek to minimize or eliminate the need for human intervention, and thus the SENSOR program represents a fundamentally new approach to energy savings in HVAC, which has been pursued for decades but has thus far proven elusive.

All newly developed sensor systems under the program must meet aggressive cost, performance, and usability requirements in order to gain the acceptance and penetration levels necessary for a 30% reduction in HVAC energy consumption. The SENSOR program will subject all technologies to rigorous testing to demonstrate performance in relevant deployment scenarios. In addition, testing and validation research will deliver tools for accurately assessing the real-world impact of these new sensing technologies.

Section I.F of the FOA shows how deployment in even just a few key market areas is adequate to reach the energy and cost savings goals of this program. These areas, chosen as they have lower barriers to adoption than the others, must drive the program’s technical and testing/validation pathways. For residential buildings, these market areas are detached and attached single family housing, and for commercial buildings, these market areas are office buildings, lodging, education, and public assembly. Finally, Section I.F details the method used to derive the price metrics presented in Section I.E of the FOA.

## D. TECHNICAL CATEGORIES OF INTEREST

The SENSOR program will fund transformational R&D on building sensor systems in four categories:

A. Human presence sensors for residential use
B. People counting sensors for commercial use
C. Low-cost, stable, and easily deployable $CO_2$ sensors to enable commercial adoption
D. Real-world testing and validation for both residential and commercial validation

Submissions addressing Categories A, B, and/or C must be included in one ~~Concept Paper~~ Full Application, and Submissions addressing Category D must be included in a separate ~~Concept Paper~~ Full Application. For example, this could include a residential solution that includes full, real-world field testing and validation development (Categories A and D – two distinct ~~Concept Papers~~ Full Applications; a complete commercial solution with both people counting and $CO_2$ sensors and development of a real-world field testing and validation protocol (Categories B, C, and D – two ~~Concept Papers~~ Full Applications); a sensor system for people counting and $CO_2$ detection (Categories B and C – one ~~Concept Paper~~ Full Application), or other combinations. Applicants submitting to Categories A, B, and C but not submitting to Category D must still perform controlled laboratory-based hardware testing (see Section I.E of the FOA), but they will not be required to submit their technologies for testing and validation by Category D teams. Teams submitting in Category D only will develop simulation tools and real-world field testing protocols for human presence or people counting technologies in general. Collaboration between Categories A, B, C and Category D teams are strongly encouraged but not required.

**Category A: Human presence sensors for residential use**

*Must deliver a binary “occupied or not occupied” signal to enable temperature setbacks in residential buildings.*

SENSOR seeks technical solutions that can detect the presence of a human body in a residence of a wide variety of types, structures, or geometries, and discriminate between that of a human or pet (cat or dog). A number of existing sensor solutions available on the market (for example, passive infrared “PIR” and/or ultrasonic modalities) attempt to provide rough presence detection of a moving, warmer-than-background item through use of motion detectors integrated with a timing delay circuit. Such movement-based sensor systems typically detect the passing of people through a threshold (door or window) or across a certain field of view, and thus infer indirectly whether a space is occupied or not[10,11]. Such modalities will not be acceptable for the sensors described in this FOA. Here, true presence sensing is required – that of a moving *or* non-moving body – in order to reduce the false-negative rate to acceptable levels, as described in Section I.E of the FOA.

“Geofencing” (GPS accessing) or Bluetooth tracking technologies that track the presence of a device such as smartphone have been seen in this application area. This has limited functionality, as it requires the occupant to carry an item and ensure

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[10] Lu J., *et al.*, Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems, Zurich, Switzerland Nov. 03-05, 2009 (pp 211-224)

[11] Duarte, et al., Energy and buildings **67** (2013) 587-595.

that it is powered up with the proper communication protocol enabled. This may act as a partial solution for a small controlled subset of users with non-critical systems, but would miss the detection of people not having the device on their person, powered up, in the right communication configuration. Here the interest is in technologies that detect the actual human body, with no "beacon" requirements, in order to reach the widest adoption at lowest cost. To this end all proposed solutions must not require any "beacons" – this includes the presence of a particular item by the person (say, a smartphone), a wearable item, or the like.

Some other sensor configurations have potential for presence counting.[12] Beyond those mentioned above, pressure sensitive rug tiles, image capture technologies, RF and radar systems, and audio systems have been investigated for other uses, such as security or retail tracking. In general, there are significant drawbacks with respect to price, commissioning concerns, and/or challenges with accuracy. For example, many visible camera-based technologies work by comparing captured frames against a background frame, and thus effectively work as movement sensors, resulting in high false-negative rates when a body is not in motion.

Due to the market desire for a solution and the difficulty of obtaining this solution, some researchers have implemented a "data fusion" scheme, and combining information from multiple types of sensors is a growing effort.[13,14] The greater availably of very low cost and low power distributed sensing networks, based on hardware incorporating communication and significant computation abilities, coupled with novel work in the algorithm space, could have great promise for this sensor fusion area. ARPA-E encourages work in this field and believes there is promise in the data fusion space, as long as any proposed work meets the metrics in this FOA.

It is noted that data from *all* of these sensor systems must be readily available to multiple types and styles of thermostats – thus, an existing open source (encryptable) communication scheme for the sensor output (noting that any *internal* algorithms limited to the sensor system do not need to be open source). In addition, Applicants must submit a plan showing that the proposed technologies will address end-user privacy concerns. Finally, hardware that would not require a residence to have an existing WiFi system is encouraged; the percentage of American homeowners with broadband access (not all with WiFi connectivity) in 2015 was 67%, and is actually decreasing slightly with time, due mostly to price and the growing use of "smartphone-only" connectivity[15].

In order to address issues of security and privacy, as well as ensure the lowest barriers to adoption, sensors in Categories A, B, and C must be "self-contained" regarding computation. No "cloud" computation or communication will be acceptable, and the only communication/data link "external" to the sensor system will be between the sensors and/or sensor hub to the control system. *The only communication required must be between sensor nodes, hubs (if used), and control system*. There are multiple types of communication schemes that could be used, and flexibility in this space is acceptable for this program as long as the scheme is open-source, encryption enabled, and well defined, such that a building automation system could easily incorporate it (or already has it).

**Category B: People counting sensors for commercial use.**

*Must deliver the number of occupants in a specific defined HVAC zone to enable both temperature and ventilation setbacks*

Some sensor configurations have been investigated for presence and people counting.[16] Beyond those mentioned above, and as discussed for Category A, there are systems that show promise for people counting, for example pressure sensitive rug tiles, image capture technologies, RF and radar systems, and audio systems. Each has individual challenges for a cost-effective people counting technology, most notably price, commissioning concerns, and/or challenges with accuracy.

Also as described for Category A, "geofencing" GPS and Bluetooth detection of smartphones has been proposed as a solution in this area, but again, requiring a beacon is out of scope for this FOA. Failures could easily occur when a device is left in a different area, out of power, or without communication enabled. User adoption needs require no additional badges or items to be worn or carried. ARPA-E encourages the field of data fusion for people counting.

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[12] Labeodan et al., Energy and Building **93** (2015) 303-314.

[13] Zhou, et al., CISBAT 2013 - September 4-6, 2013 - Lausanne, Switzerland

[14] Zhang, et al. Build Simul (2012) 5: 179-188.

[15] Horrigan, J B and Duggan, M., Pew Research Center, "Home Broadband 2015", 2015

[16] Labeodan et al., Energy and Building **93** (2015) 303-314.

A significant amount of research has been performed to identify whether $CO_2$ sensors can be used to count the number of occupants and preemptively increase the amount of ventilation to a highly occupied zone. The findings conclude that due to the diffusion time and the transient airflow patterns within a building, even state-of-the-art $CO_2$ sensors, regardless of cost, cannot alone be used to accurately assess the level of occupancy or used to predict the level of occupancy in a building.[17] ASHRAE specifically recommends against placing $CO_2$ sensors in air returns for this purpose.[18] Regardless, as Category B is technology agnostic, submissions will be considered using $CO_2$ as the counting modality for this section, but these challenges would have to be addressed.

As noted above, sensors must be “self-contained” regarding computation, and the only communication/data link “external” to the sensor system will be between the sensors and/or sensor hub to the control system.

**Category C: Low-cost, stable, and easily deployable $CO_2$ sensors to enable commercial adoption**

*Must provide accurate, easily accessible $CO_2$ data to enable adoption of ventilation setbacks in commercial buildings*

As previously discussed, $CO_2$ sensing where an end-user desires is critically important for the deployment and acceptance of any ventilation control technology in a commercial environment. ASHRAE has guidelines stating that for especially densely populated rooms, the $CO_2$ must be monitored and the ventilation system must react to increased levels of $CO_2$ within any given room.[19] Currently, systems respond by either always running at high ventilation levels, or HVAC systems can be equipped with expensive $CO_2$ detection and integration for those particular rooms that are expected to have large density of occupants for extended amount of time, although current sensing modalities suffer from baseline drift and need frequent manual (and thus expensive) recalibration.

Here, ARPA-E seeks the development of $CO_2$ sensors that solve the problems with baseline drift as well as can be deployed easily and affordably where an end user requires. As described in the metrics section below, this will require a truly disruptive change regarding sensing modality. The cost metrics alone are challenging to meet with any technology that would require wired installation, and a low-power, wireless, easy-to-deploy sensor is not an incremental change in this area.

As noted above, sensors must be “self-contained” regarding computation, and the only communication/data link “external” to the sensor system will be between the sensors and/or sensor hub to the control system.

**Category D: Testing and Validation for Both Residential and Commercial Validation**

*Laboratory controlled, quasi-real world environments, and actual field deployment tests for technologies from Categories A, B, C, and others in the market throughout the program timeframe.*

Finally, this FOA includes provision for developing and implementing the testing and validation of potential occupancy sensor and people counting technologies. There is no accepted global method for testing and validating such sensors, and this has been a key barrier for adoption in these fields, especially as some unrelated technologies in the energy efficiency market have had difficulty validating claimed energy savings, increasing the perceived risk of adoption of such technologies. ARPA-E sees the development of greatly improved testing and validation methodologies as a key need for this program.

Emphasis will be placed on demonstrating that sensors can meet the acceptable failure rates as defined in the metrics below (see Section I.E of the FOA), as well as validate the energy saved in real-world retrofit scenarios. This must be done while demonstrating the flexibility of occupancy sensors and people counting technologies in three clearly distinct types of building geometries. For residential spaces, this could mean older homes built in the ~1940s, housing stock from the 1970-80s with distinctly different floor plans, a modern very open-plan home, and the like; for commercial spaces, this could be satisfied by demonstrating the technology in an open office scenario with conference rooms, a closed individual office scenario with conference rooms, or an academic building with classrooms and an auditorium mixed with offices. The commercial space must use building examples from at least two distinct sub-markets (for example, office and lodging, office and academic, etc.) ARPA-E intends that this part of the program will develop tools and field testing protocol that can be utilized by this sensor-driven HVAC energy reduction field in general. ARPA-E strongly encourages but does not require teams in this area to collaborate in various ways with any stand-alone sensor hardware teams.

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[17] Cali, et al., Building and Environment **86** (2015) 39-49.

[18] Schell, et al., Demand Control Ventilation Using $CO_2$, ASHRAE Journal February 2001, pg 1.

[19] ASHRAE 60.1

Applicants are encouraged to review the “priority market segments” detailed in Section I.F of the FOA for guidance on preferred relevant building environments and use cases for testing.

## E. TECHNICAL PERFORMANCE TARGETS

This FOA defines separate high-level technical metrics for residential and commercial building sensor systems as described below. Successful submissions will provide preliminary analyses of their sensing modalities that provide a path and detailed explanation toward achieving these metrics.

**Program structure and schedule**

Table 1 below gives a rough guide for the timeline for each section of this FOA; this is followed by a discussion of program performance targets.

**Table 1. SENSOR Program Structure and Schedule**

| | Year 1 | | | | Year 2 | | | | Year 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A: Residential -- presence sensing** | | | | | | | | | | | | |
| Simulation and savings baseline | 🟦 | 🟦 | | | | | | | | | | |
| Hardware development | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | |
| Lab-based hardware testing | | | | | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| **B: Commercial -- people counting** | | | | | | | | | | | | |
| Simulation and savings baseline | 🟩 | 🟩 | | | | | | | | | | |
| Hardware development | | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | |
| Lab-based hardware testing | | | | | | | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 |
| **C: Commercial -- $CO_2$ sensing** | | | | | | | | | | | | |
| Hardware development | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | |
| Lab-based hardware testing | | | | | | | 🟫 | 🟫 | 🟫 | 🟫 | 🟫 | 🟫 |
| **D: Testing and Validation** | | | | | | | | | | | | |
| System-level testing protocol and simulation development | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | | | | |
| System-level controlled lab testing | | | | | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | | | |
| System-level Field Trial Testing and Simulation Validation | | | | | | | | 🟫 | 🟫 | 🟫 | 🟫 | 🟫 |

**Metrics**

The particular needs and requirements for these sensor technologies to be successful and make an impact in these markets are addressed in the following sections. As sensors differ in deployment requirements, fields of view, communications/hour, etc., we have written these metrics to be technology agnostic. This means that the sensors, at early stages, will have to be simulated using tools that include control schemes and building simulations. There are no specific requirements as to the method and tools used for doing this, as long as they are well described and documented.

For illustration regarding these failure metrics we provide an example of simple analyses with simplifying assumptions to establish a baseline for the level of detail required to be included in submissions in Section I.G of the FOA. We emphasize that more complex and accurate simulations with more “real-life” data using multiple deployment scenarios will be required as the program progresses. In general, submissions should incorporate milestones at the 6 month mark providing extensive baseline simulations of required performance and at the 2 year mark provide simulations that incorporate actual detector system measurements showing clear progress towards the final metrics of the program.

*Category A: Residential occupancy*

For the residential market, there is a particular sensitivity to perceivable “false negatives” – when a sensor does not detect that the space is inhabited such that the temperature setbacks are triggered, which risks making the occupant becoming uncomfortable, and thus harming the user adoption of the technology. The Program requirement is 2 or fewer of these “failure events” a year, and a more detailed explanation of this requirement can be found in Section I.G of the FOA. “False positives”, on the other hand, reduce the energy saved by having the temperature setbacks reversed when the domicile is unoccupied, and are less detrimental to user adoption. As long as the energy saved can be shown to be at least 30%, there is more flexibility for error for this case. This “Energy Savings” metric indicates energy savings directly resulting from deployment of the human presence sensors or people counters in a real-world scenario, using existing control systems. These metrics must be met including households occupied by both humans and pets.[20]

The price metric calculation can be found in Section I.F of the FOA. Other requirements relate to the specific needs to ensure large-scale adoption.

**Table 2. Metrics and Requirements: Category A**

| | | |
|---|---|---|
| **Category A Performance Metrics:** | | |
| Demonstrated Energy Savings | | ≥ 30% |
| Number of Failures (false negatives)/year, 95% confidence | | ≤ 2 |
| Minimum Maintained & Recalibration Requirement | | ≥ 3 years |
| Price Metrics: | | |
| Residential Price: | ≤ 0.06 $/sqft | Total sensor system price including installation/commissioning |
| **General Requirements for all Hardware:** | | |
| No Beacons Required | For example, smartphones or any other wearable tech | |
| Communication Protocol for output to Control System | Open-source and secure | |
| Privacy concerns addressed | Deliver plan for addressing privacy (or perceived privacy) barriers to deployment and use (For example, demonstrating adherence to wiretapping laws in all states) | |
| Security and Flexibility | No cloud computation – all computation to occur locally at sensors or within local sensor system | |
| Ease of self-commissioning | A plan must be presented. Example: inclusion of simple screen, app, LED indicators, or the like available to a user such that the system can be easily self-tested upon startup, and the number of occupants validated; “peel, stick, and button press” technology that does not require skilled labor for placement or installation | |
| Testing and Validation | | |

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[20] In 2012, 36% of households had a dog, and 30% of households had a cat : 2012 US Pet Ownership and Demographics Sourcebook, via the AVMA

| | |
|---|---|
| Ensuring adoption diversity | Ensure a varied number of skin colors, body types, and physical ability levels (i.e. use of wheelchairs and the like) are adequately represented in both simulation and laboratory-scale testing scenarios |
| Ensure adoption flexibility | Validation protocols must be developed for at least three distinct scenarios in the residential sector, including household pets, for both the simulation and laboratory-scale testing scenarios. |

*Category B: Commercial people counting*

For the commercial market, accuracy of people counting is described using a different method. Here, “failures” for the commercial scenario are miscounts *10% lower* than the true count, with a 95% probability of no more than 4 failures per year. This strict requirement is crucial for ensuring that ventilation meets ASHRAE standards[21], which state that a +/- 10% error is in line with the balancing tolerance included with the standard for ventilation requirements. Miscounts higher will reduce the amount of energy saved via over-ventilation, but do otherwise not pose any risk, and are captured in the “Energy Savings” metric (similar to false-positives in Category A).

In order to satisfy these requirements, similar procedures are used as for the residential case. It is encouraged, but not required that Concept Papers provide initial preliminary simulations that justify the feasibility of the proposed technical approach to achieve the energy savings and failure rate metrics. This will be required with Full Application submissions, please see Section IV of the FOA. A very simple methodology is also shown in Section I.G of the FOA.

**Table 3. Metrics and Requirement: Category B**

| | | |
|---|---|---|
| **Category B Performance Metrics:** | | |
| Demonstrated Energy Savings | | ≥ 30% |
| Commercial: Number of Failures (10% lower than true count)/year, 95% confidence | | ≤ 4 |
| Minimum Maintained & Recalibration Requirement | | ≥ 3 years |
| Price Metrics: | | |
| **Commercial** Price: | ≤ 0.08 $/sqft | Total sensor system price including installation/commissioning |
| **General Requirements for all Hardware:** | | |
| No Beacons Required | For example, smartphones or any other wearable tech | |
| Communication Protocol for output to Control System | Open-source and secure | |
| Privacy concerns addressed | Deliver plan for addressing privacy (or perceived privacy) barriers to deployment and use (For example, demonstrating adherence to wiretapping laws in all states) | |
| Security and Flexibility | No cloud computation – all computation to occur locally at sensors or within local sensor system | |
| Ease of self-commissioning | A plan must be presented. Example: inclusion of simple screen, app, led indicators, or the like available to a user such that the system can be easily self-tested upon startup, and the number of occupants validated; “peel, stick, and | |

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[21] Standard 62.1-2016, Table 8.2

| | |
|---|---|
| | button press" technology that does not require skilled labor for placement or installation |
| Testing and Validation | |
| Ensuring adoption diversity | Ensure a varied number of skin colors, body types, and physical ability levels (i.e. use of wheelchairs and the like) are adequately represented in both simulation and laboratory-scale testing scenarios |
| Ensure adoption flexibility | Validation protocols must be developed for at least three distinct scenarios in the commercial sector for both the simulation and laboratory-scale testing scenarios |

*Category C: Commercial $CO_2$ sensing*

As described in previous sections, $CO_2$ sensors can be used in conjunction with commercial sensor systems as needed in order to achieve end user adoption. These sensors must meet the price requirements of the commercial sensor systems, with the following technical requirements, which resolve issues with calibration and drift over time:

**Table 4. Metrics: Category C**

| | | |
|---|---|---|
| Price Metrics: | | |
| Commercial Price: | ≤ 0.08 $/sqft | Total sensor system price including installation/commissioning |
| CO2 Sensor Metrics: | | |
| Sensor Range and Precision | Dynamic range 400-2000 ppm, 30 ppm precision | |
| Drift | < 10 ppm / year | |
| Lifetime | ≥ 3 years | |
| Selectivity | < 5 ppm change for common gasses such as $N_2$, $H_2O$, and VOCs commonly found inside buildings | |
| Time response | < 1 minute | |

*Category D: Testing and Validation*

Testing and validation protocols, simulation tools, and real-world field testing are needed to enable adoption of the sensing technologies in this FOA. Here, these must be developed and deployed for both residential and commercial cases, with three distinct use cases in each. For residential spaces, this could mean older homes built in the ~1940s, housing stock from the 1970-80s with very different floor plans, a modern very open-plan home, and the like; for commercial spaces, this could be satisfied by demonstrating the technology in an open office scenario with conference rooms, a closed individual office scenario with conference rooms, or an academic building with classrooms and an auditorium mixed with offices. The commercial space must use building examples from at least two distinct sub-markets (for example, office and lodging, office and academic, etc.) ARPA-E intends that this part of the program will develop tools and field testing protocol that can be utilized by this sensor-driven HVAC energy reduction field in general.

As described in Table 1 above, there are three components to this Category. A simulation tool including three distinct use cases for both residential and commercial scenarios will be developed; this simulation tool will be tested in controlled laboratory environments where ground truth is independently measured (A significant overlap with the laboratory-scale testing for Categories A and B, which would be convenient for collaboration, is noted); and finally, the last five quarters consist of testing human presence and people counting sensor systems in the field, using the testing protocols developed (field testing arrangements would be developed in earlier quarters prior to deployment).

**Table 5. Testing and Validation: Category D**

| Testing and Validation | |
|---|---|
| Testing Accuracy | Sufficient to clearly validate the performance metrics for Categories A and B, including both energy savings and failure rates. A method for establishing initial ground truth must be fully described. |
| Ensuring adoption diversity | Ensure a varied number of skin colors, body types, and physical ability levels (i.e. use of wheelchairs and the like) are adequately represented in both simulation and real world testing scenarios. |
| Ensure adoption flexibility | Validation protocols must be developed for at least three distinct scenarios in the residential sector, including household pets, for both the simulation and real world testing scenarios. For the commercial sector, simulations and real world testing for two distinct sub-markets must be developed and performed, with at least 3 distinct floor plans included in total. (For example, a large open office layout including conference rooms; a closed door office layout including conference rooms; a medium-range lodging hotel-type layout.) A set of occupancy data must also be developed that tests these different scenarios such that they represent real-world use. |

## F. TECHNICAL SUPPLEMENT: CALCULATIONS OF ENERGY SAVINGS, IMPACT AND PRICE METRIC DEVELOPMENT

Based on ARPA-E evaluation of existing studies using simulations or experimental systems with testing, ARPA-E has determined that a potential savings of 30% of baseline HVAC usage is a viable target for both the Commercial and Residential sectors. There are many factors that must be considered in the determination of the exact level of energy savings. A sample of published work addressing many of these (including both theoretical and experimental scenarios) is provided in Table 6 below. Provided high accuracy human sensing and people counting data as envisioned by this FOA, HVAC control systems will potentially respond with even better precision and time granularity than even the best case scenarios in Table 6, and thus a 30% energy savings goal appears to be reasonable and achievable.

**Table 6. Select publications demonstrating theoretical and limited deployment of occupancy sensors**

| Target Sector | Savings Estimate | Technical Study Details | Source |
|---|---|---|---|
| Residential | 27.92% of HVAC load | Simulation: Theoretical Rule-based control strategies for Temperature and PMV | Homod, RZ, Sahari KSM. EnergyBuild 60 (2013). |

| | | | |
|---|---|---|---|
| Residential | 28% of HVAC load | One wired movement sensor in every room + a wired door switch on each exterior doorway to the home. | Lu, J, et al., “The Smart Thermostat: Using Occupancy Sensors to save energy in homes”, SenSys '10 Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems, Zurich, Switzerland Nov. 03-05, 2009, Pages 211-224 |
| Residential | 10-30% of HVAC load | Programmable Thermostat – theoretical performance | U.S. Environmental Protection Agency. Summary of Research Findings from the Programmable Thermostat Market. Memo to Manufacturers on Programmable Thermostat Specification Review. 2003, Washington, D.C.: U.S. Environmental Protection |
| Commercial | 37% of HVAC load | Energy Plus Simulations – Including various climate breakouts | J. Zhang, G Liu, MR Brambley, RG Lutes, PNNL- 22072, 2013 |
| Commercial | 10-15% of HVAC load | Wired entryway and motion sensors, 10 commercial Offices over a 10 week period | Agarwal, et al, “Occupancy-driven energy management for Smart Building Automation”, BuildSys 2010 November 2, 2010, Zurich, Switzerland. Copyright c 2010 ACM 978-1-4503-0458-0/10/11/02 |
| Commercial | 14% of HVAC load | Wired Cameras, Large multi-function building | Erickson, et al., Proceedings of the 1st ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings (BuildSys) 2009 |
| Commercial | Overall > 20% Aggressive cases 35-75% of HVAC load | Modelling of large Office Building in multiple climate scenarios using accurate scheduling | Fernandez, et al., PNNL-21569, 2012 |

### *Magnitude of Impact by Sector and Type of Building*

Here, the potential energy savings possible via the full adoption of the proposed technology is demonstrated, and further break down the HVAC market to demonstrate how adoption will be driven. While HVAC usage represents the largest opportunity for energy savings at the present time, appealing secondary markets for occupancy sensing and people counting technologies would be for plug-loads[22], enhancing building security and higher productivity, and enabling building space optimization – a rapidly growing and very high value field. Finally, enabling demand response to be adopted in the residential sector could be a very significant additional benefit, where various demand response schemes could be adjusted to only

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[22] In commercial spaces, the Dept. of Energy CBECS database showed an overall growth of 115% per year over the 2003-2012 time period (CBECS 2003, CBECS 2012), with much higher growth in specific sectors

occur when a home had no occupants. This is an example of how true occupancy sensing and people counting will potentially revolutionize the way buildings communicate with and respond to their occupants.

Using a 30% reduction in HVAC energy usage in buildings as described above, the potential energy savings impacts are significant. Tables 7 and 8 below show total energy usage and potential savings for both the residential and commercial sectors, divided into several sub-sectors. All calculations are performed at an adoption rate of 100%. Certain sectors are highlighted in green that appear to present the lowest barriers to adoption, and these sectors to drive the testing and validation plans for this FOA are encouraged.

**Table 7. Residential Energy Usage and Potential Savings, in quad BTUs [From CBECS, 2012]**

| **Housing Unit Type** | ALL U.S. RESIDENTIAL BUILDING STOCK | |
|---|---|---|
| | Total Energy Usage | 30% ENERGY SAVINGS |
| Single-Family: Detached | 5.163 | 1.549 |
| Single-Family: Attached | 0.372 | 0.112 |
| Multi-Family: 2-4 Unit Buildings | 0.473 | 0.142 |
| Multi-Family: 5 or More Unit Buildings | 0.682 | 0.205 |
| Mobile Homes | 0.363 | 0.109 |
| **Total All Building Usage** | **7.053** | **2.116** |
| **Total Priority Segments only** | **5.535** | **1.660** |

For the residential case, the energy savings are straightforward and result from the usage of moderate temperature setbacks (for example, 62/78 F). This would equal over a quad and a half of savings for the single family housing sector, a key target for this FOA.

For the commercial case, an additional breakdown (“weighted for VAV”) in which this technology is only applied to buildings that are estimated to have VAV systems (based on 2012 CBECS estimates) is added. This is a conservative estimate; as building stock is replaced, the percentage of buildings with VAV systems will stand to increase with time, however, this gives us a “lower bound” target for commercial savings estimates that ARPA-E believes is reasonable to estimate a potential impact range.

The impact range forecasted for this program is based upon the targeting of specific key sectors in which occupancy sensing represents a realistic option (based on both potential savings and prospective ease of implementation). The rows highlighted in green in Tables 7 and 8 identify key sectors in which ARPA-E foresees early or especially impactful adoption of advanced sensor technology, with lower barriers to entry. Cumulatively they represent approximately 2.6 quadrillion BTUs (“quads”) of energy savings in a 100% adoption scenario, or ~ 2.1 quads of savings if only those commercial buildings with current VAV systems installed adopt advanced sensors (based on a 30% savings target per building).

**Table 8. Commercial Energy Usage and Potential Savings, in Quad BTUs [From CBECS, 2012].**

| | | Current VAV Buildings Only | | | Current VAV Buildings Only |
|---|---|---|---|---|---|
| **Principal Building Activity** | ALL U.S. COMMERCIAL BUILDING STOCK | | | | |
| | **Total HVAC Energy Usage** | | | **30% HVAC Energy Savings** | |
| Education | 0.81 | 0.38 | | 0.24 | 0.11 |
| Food sales | 0.09 | 0.01 | | 0.03 | 0.00 |
| Food service | 0.25 | 0.07 | | 0.07 | 0.02 |
| Health care-inpatient | 0.50 | 0.40 | | 0.15 | 0.12 |
| Health care-outpatient | 0.20 | 0.16 | | 0.06 | 0.05 |
| Lodging | 0.36 | 0.12 | | 0.11 | 0.03 |
| Mercantile/ Retail | 0.87 | 0.10 | | 0.3 | 0.03 |
| Office | 1.37 | 0.67 | | 0.41 | 0.20 |
| Public assembly | 0.54 | 0.25 | | 0.16 | 0.08 |
| Public order and safety | 0.10 | 0.05 | | 0.03 | 0.01 |
| Religious worship | 0.17 | 0.08 | | 0.05 | 0.02 |
| Service | 0.22 | 0.04 | | 0.07 | 0.01 |
| Warehouse and storage | 0.27 | 0.05 | | 0.08 | 0.01 |
| Other/ Vacant | 0.24 | - | | 0.07 | - |
| **Total All Building Usage** | **5.98** | **2.38** | | **1.80** | **0.71** |
| **Total Priority Segments only** | **3.08** | **1.42** | | **0.92** | **0.43** |

Single-family home and large/medium office sector segments are identified as the greatest drivers of savings, as they have the largest potential impact footprint and the best existing infrastructure to support the implementation of these human presence and counting sensors (programmable thermostats, high penetration of VAV systems in a cyclically occupied building). Outside of this, other high value early market adopters include the education and public assembly sectors, which also have large energy footprints and wide variations in occupancy throughout an average day, lending themselves to high savings potential if people sensing is correctly implemented. Finally, the lodging sector has already begun experimenting with human presence in hotel room spaces, and could benefit greatly from having improved (and lower cost) capabilities on this front. It is crucial that proposed technologies demonstrate impact in multiple types of floorplans for the residential sector, and multiple types of segments for the commercial sector.

### Price Metric Development

Identifying the key barriers to the adoption of occupancy-sensing and people counting technologies is crucial. One of the most important barriers to user adoption is price – inclusive of hardware, installation, and commissioning. Other barriers are the accurate validation of energy savings, concerns about privacy (true or perceived), legal restrictions (such as wiretapping or other public privacy laws), and security. These others barriers are addressed Sections I.D and I.E of the FOA, and a set of guidelines included to ensure the technologies proposed to this FOA will address these issues. A thorough description of the desired price metrics are described here.

Price considerations must include not just the price of the hardware, but installation, commissioning, and upkeep. Here, price targets are defined simply by a one year return on investment (ROI) considering an average energy cost, delivering a 30% reduction in HVAC energy usage. A path toward meeting these targets must be shown at scale (scale = 1 million units or more). The cost of the control “system” (a thermostat), or the ability to interface to an existing control system (programming a VAV system) has also been subtracted out. These numbers are general guidelines, but given the aggressive one-year ROI, there is still quite a bit of room for customer acceptability.

After taking these criteria into account the price targets that will be utilized for the purposes of this FOA are $0.08/sqft for commercial applications, and $0.06/sqft for residential applications. An overview of how these numbers were calculated is provided below in Table 9 for reference.

These price targets are technology limiting. Any wired installations require semi-specialized labor that drives up cost significantly. Technical platforms that do not require wired installation (say, a long-life battery powered distributed sensor network), that could be self-installed and need little to no commissioning, with little to no maintenance; such a system could have the potential of reaching the price metrics in this FOA are encouraged. Even if a wall-powered hub was required, or fewer distributed, non-line of sight sensors were required, as long as the power budget was so low as to still enable a 30% energy savings, such a system could be transformative and not require high installation costs.

**Table 9. Calculation of Price Metrics for Residential and Commercial Sensor Systems**

| Commercial Price Build | | | Residential Price Build | | |
|---|---|---|---|---|---|
| Input Variable | Estimate | Reference Info | Input Variable | Estimate | Reference Info |
| Building Size (sqft) | 15,552 | Average commercial building size, based on CBECS 2012 data | House Size (sqft) | 2000 | Average residential single family home size based on RECS data |
| Total Value to Customer | $ 2,700 | Based on 30% savings, $0.10/kwh, $0.03/therm, 1 Year Payback requirements | Total Value to Customer | $ 260 | Based on 30% savings, $0.10/kwh, $0.03/therm, 1 Year Payback requirements |
| Cost to integrate Sensors into existing infrastructure | $ 1,500 | Generalized number for software adjustment to existing VAV system control box to enable sensor based control | Wifi Programmable Thermostat Cost | $ 140 | Median of commercially available models on Amazon.com |
| Allowable Sensor Price | $ 1,200 | Amount of total value remaining to customer after integration | Allowable Sensor Price | $ 120 | Amount of total value remaining to customer after cost of Thermostat is removed |
| Sensor Target per square ft (excludes labor) | **$ 0.08** | $/SF required to yield a 1 year payback after non-sensor costs are accounted for | Sensor Target Per SF | **$ 0.06** | $/SF required to yield a 1 year payback after non-sensor costs are accounted for |

## G. TECHNICAL SUPPLEMENT: EXAMPLE CALCULATIONS OF PERFORMANCE

*Residential failures per year metric*

The residential failures per year metric is driven by the need to assure high adoption rates, with the perception of discomfort to be clearly avoided. The metric as stated in Table 2 is quite stringent: 2 failures per year at the end of the program. Failure in the context of residential dwellings is defined as the possibility occupants finding themselves in an uncomfortable environment due to the detector system misreporting the presence of occupants. This is a system-level goal, driven by the occupancy sensors giving the correct output. There may be systems using multiple redundant networked sensors, or systems using very few to one – these would all result in very different individual sensor metrics. Regardless of what is used, the sensor system itself must send information to the control system that is in accordance with the metrics in Table 2.

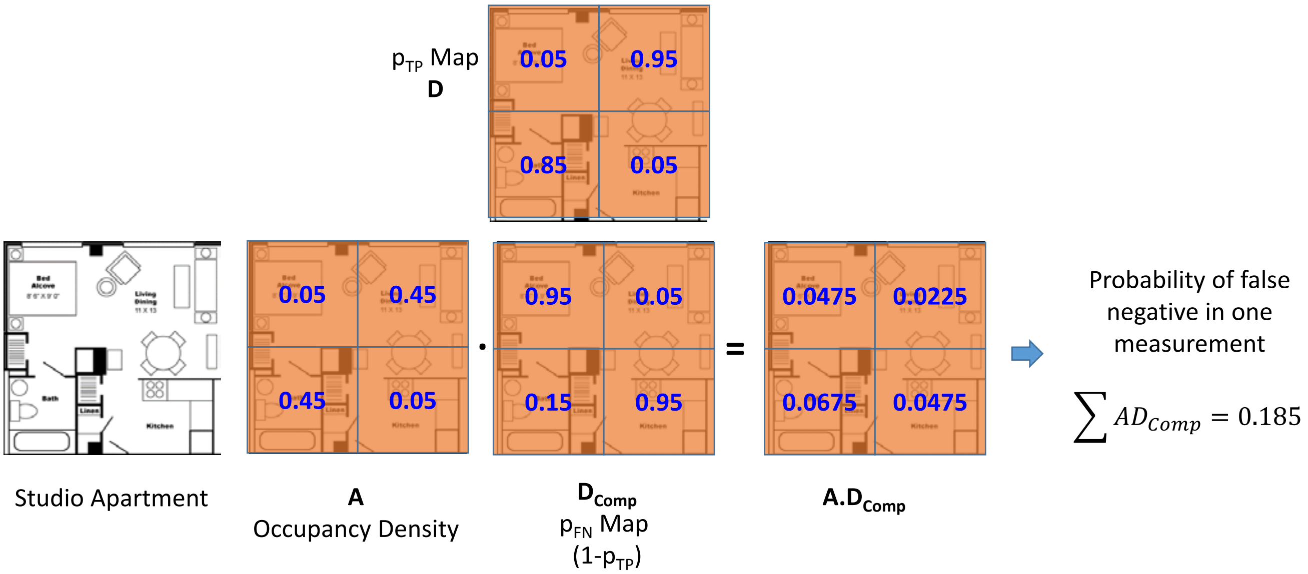

***Figure 1. Schematic illustrating the estimation of the probability for false negatives for a single measurement.***

As illustration the following analysis is provided. Given a floor plan of a representative extremely simple residential dwelling, knowledge of the spatial occupancy density ($A(x,y)$) at some point in time and the spatial detectivity of the detector system ($D(x,y)$) the probability of false negative $p_{FN}$ could be calculated at this time as (see also Figure 1):

$$p_{FN}(t) = \sum_{x,y} A(x,y) \cdot (1 - D(x,y))$$

***Schematic illustrating the estimation of the probability for false negatives for a single measurement.***

A more detailed calculation would calculate these probabilities for each time $t$ (appropriately weighed by the probability of occupants being present at that time) and calculate the probability for different number of failures in a year. In what follows, to simplify the model, assume that this probability is constant in time, that the proper time interval to consider is half an hour and that the dwelling is occupied half of the time. Under these assumptions the number of measurements $n$ is 365 x 24 x 0.5 x 2 = 8760, so that the probability of having no more than $K$ failures can be calculated as:

$$P(k \leq K) = \sum_{k=0}^{K} \binom{n}{k} p^{n-k} (1-p)^k$$

Now the probability can be estimated of having no more than K failures per year as a function of the detector system probability of true positives $p_{TP}$. Figure 1 shows such a calculation where the probability of a current detector with an average of 1 failure per week is shown for reference. This calculation shows that the requirement for the probability of detection ($p_{TP}$) for a system to have 95% probability of having no more than 2 failures per year would be in the order of 0.9995.

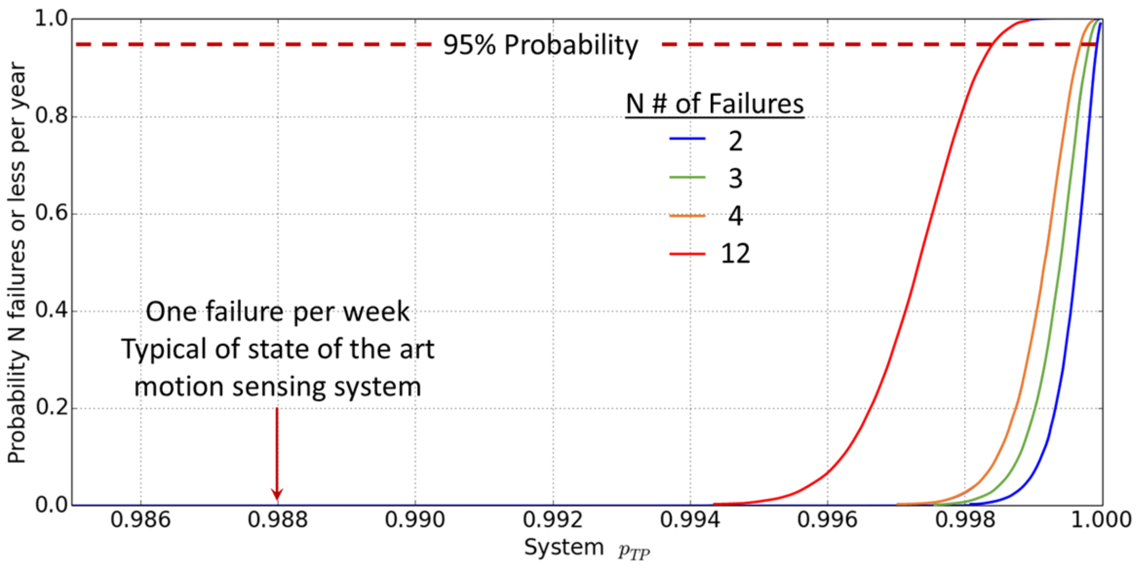

***Figure 2. Plot of the probability of $N$ failures or less per year as a function of system probability of true positives (under assumptions given in the text)***

These calculations are offered as an illustration of the stringent requirements imposed by the metrics in this FOA. The ultimate test for satisfying the requirement is achieving the 2 failures per year rate. The testing and validation part of this FOA includes simulation work demonstrating a path toward achieving the metric. This will require an initial 6 month simulation with reasonable estimates and more thorough baseline data than that demonstrated here in this simple example, and a 2nd year simulation informed by experimental measurements in suitable conditions (representative dwelling, verified occupancy model, sensor measurements, etc.). Models used by the Applicants may have significantly different assumptions than the ones presented here, in which case a detailed explanation is expected, but the end prediction of the models must justify the final metric of 95% probability of no more than 2 failures per year.

*Commercial failures per year metric*

For the commercial use case, the number of occupants will be used to identify the optimal ventilation rate for an HVAC zone. As an example of a simple preliminary analysis, similar to the above residential case, consider a detector system with a Gaussian distribution response for a room occupied by $m$ individuals. This can be represented as a normal distribution with mean ☐ equal to m and standard deviation ☐proportional to $m$,:

$$N(\mu, \sigma), \qquad \mu = m, \qquad \sigma = am$$

Under this assumption, the probability that the detector system will report a number of occupants fewer than 10% of the true value can be computed as a function of $a$ which is detector system dependent. Note also that under these assumptions this probability is independent of $m$ and the spatial configuration of the HVAC zone, which may not be the case in general. Similar to the residential case, assuming the detector system reports every half an hour, the 95% probability of the detector system achieving the goal of no more than 4 failures per year could be calculated: this would require a probability of detection of 0.998. Models used by the Applicants may have significantly different assumptions and dependencies than the simple ones presented here, in which case a detailed explanation is expected, but the end prediction of the models must justify the final metric of 95% probability of achieving no more than 4 failures per year. Applicants are encouraged to reference the above parameters and the effects changes in number of occupants in the zone, spatial configuration of occupants within the zone, occupant trajectories, structural variations within a zone, and other transients within the environment have on the proposed system’s ability to achieve the 95% confidence interval.

The above analyses of the presence and occupant counting offered here are illustrations only, and Applicants are free to present other analyses with different assumptions as long as a detailed justification for their methodology is included in the submission.

## H. SUPPLEMENT: RESEARCH INVOLVING THE USE OF HUMAN OR ANIMAL SUBJECTS

Any research funded under this FOA that involves the use of human or animal subjects will be subject to all applicable requirements with respect to those activities, and it will be the responsibility of each award recipient to ensure compliance with those requirements.