1st Workshop on Performance Evaluation Methodology for Building Occupancy Sensing Systems for HVAC Controls

Workshop Meeting Minutes
June 26, 2019

Prepared by
Iowa State University
University of Alabama
ARPA-E SENSOR Teams

Agenda

1st Workshop on Performance Evaluation Methodology for Building Occupancy Sensing Systems for HVAC Controls

Kansas City Marriott Downtown, 200W 12th St Kansas City, MO 64105

Wednesday, June 26, 2019, 12:30 pm – 5:00 pm

12:30 PM **Buffet-Style Lunch**

1:00 PM **Welcome/Introductions; Overview of the ARPA-E SENSOR program,** Dr. Marina Sofos, *ARPA-E Program Manager*

1:25 PM **Workshop & Long Term Goals: Occupancy Sensor System Testing, Validation, Simulation & Standards Development,** Dr. Zheng O'Neill, *University of Alabama*, Dr. Kristen Cetin, *Iowa State University*,

1:30 PM **Overview of Iowa State University Approach:** Dr. Kristen Cetin, *Iowa State University*

1:40 PM **Overview of University of Alabama Approach:** Dr. Zheng O'Neill, *University of Alabama*

1:50 PM **Breakout Session Organization** Dr. Kristen Cetin, *Iowa State University*, Dr. Zheng O'Neill, *University of Alabama*

2:00 PM **Group Breakout Discussion: Part 1:** *Attendees breakout into groups based on interest and relevant backgrounds. Moderator-lead discussion will follow based on each group's topic.*

Group 1: Residential and Commercial Occupancy Sensor System Performance Testing Methods. *Moderators: Dr. Zheng O'Neill (University of Alabama) & Dr. Kristen Cetin (Iowa State University)* **PURPLE on your name badge**

Group 2: CO2 Occupancy Sensor System Performance Testing Methods *Moderator: Paul Kremer (Iowa State University)* **BLUE on your name badge**

3:15 PM **Coffee Break/Networking** Coffee and light snacks will be served

3:45 PM **Group Breakout Discussion: Part 2:** *Attendees breakout into groups based on interest and relevant backgrounds. Moderator-lead discussion will follow based on each group's topic.*

Group 3: Building Occupancy Simulation Methods. *Moderators: Dr. Jian Zhang (PNNL), Dr Bing Dong (Syracuse University)* **GREEN on your name badge**

Group 4: Occupancy-Based Controls *Moderator: Hwakong Cheng (Taylor Engineering)* **BLACK on your name badge**

5:00 PM **Workshop Summary & Next Steps**

Meeting Minutes: Breakout Sessions

After an introduction presentation by ARPA-E and two SENSOR teams from Iowa State University and the University of Alabama which are focused on performance evaluation of occupancy sensing systems, the workshop consisted of four breakout sessions, as listed in the agenda. The following is a summary of the discussion associated with each of the breakout sessions.

Group 1: Residential and Commercial Occupancy Sensor System Performance Testing Methods

This breakout session focused on one main question as follows, which was presented to the group at the beginning of the session, along with a list of variables the ISU and UA teams had developed:

Which variables that may affect the performance of a sensor system should be included in a test standard/guideline for occupancy recognition sensor systems? (e.g., lighting level, number of people, humidity, etc.)

a. *Which are most critical?*
b. *Should specific levels for critical variables be tested one at a time while holding other variable levels constant or in defined groupings supported by structured experimental design templates?*
c. *Which variables should be controlled or simply recorded (e.g. envelope infiltration rates, temperature, humidity, etc.) that we don't think will have much impact on the sensor systems under test?*

Additional Influential Variables: This discussion included what variables should/should not be tested for occupancy sensor systems. In addition to the list of variables provided by the SENSOR teams (attached), the following additional items were suggested to be considered:

- **Geometry of the space**: several participants recommended considering testing in at least two different shape/size spaces
- **Size of space**: Several voiced suggestions on the need to consider/clearly justify the size of the space in the testing; some suggested a minimum level/size space.
- **Height of ceiling:** Suggestion to consider height of ceiling and its relative height compared to the space size (sq ft)
- **Communication**: One of the variables suggested by the SENSOR teams in their initial list was "communication compatibility with BAS" – it was mentioned that this only represents a small percentage of existing buildings, thus it should be added to this that this should include communication with HVAC system through the thermostat
- **Vibration**: vibrations can occur in buildings; recommended to consider vibrations/movements of sensors and/or environment
- **Door size**: suggestion to also consider double doors in addition to single doors.
- **Robots**: Suggestion that in the future, it is likely more robots will be in buildings and may want to test the ability to distinguish between actual people and robots
- Duplicate sensors

- **People in adjacent spaces:** some sensors could accidentally detect people in adjacent spaces that are not the space monitored; suggested to consider this.
- **Thermal comfort criteria:** suggestion to consider radiant temperature, metabolic rate, occupant clothing level, and other thermal comfort criteria
- **Extreme conditions/parties**: Suggestion to consider special kinds of conditions that may confuse sensors, such as Mylar balloons/flashlights/party-related items
- **Glass walls and mirrors**: consider conditions that may confuse some sensor systems, including glass walls and mirrors
- **Sunlight**: suggestion to consider sunlight, including direct or diffuse or both kinds of conditions; some of this was captured in the suggested lighting level variable considered by the SENSOR teams (*the ISU team did not originally intend to use sunlight since it cannot be controlled; it intended to use artificial sources of light to induce glare-causing conditions*).

Ultimately there was agreement that there are a lot of variables to consider and that in the workshop we would not be able to identify a specific set of most important variables in the time available. Moderators suggested that a brief survey be developed and sent out to stakeholders to get feedback on the variables in the extensive list developed, that might be considered "most critical" by different stakeholders. The SENSOR teams are working on developing this ***survey*** and will send out to attendees of the workshop and other interested stakeholders, to obtain feedback from stakeholders' perspective.

Method for Choosing Variables to Consider: Upon discussion of getting stakeholder feedback on the most important variables to consider/evaluate, there was some discussion what should be used to ultimately decide what variables to use. The following were discussed:

- **Stakeholder feedback:** get feedback e.g. via survey, on what criteria are most important from different stakeholders' perspectives
- **Most impactful (based on physics):** pick the variables that, based on testing/theory, have the most impact on sensor systems
- **Controls impacts:** Given that this effort focuses on sensors connected to HVAC systems, evaluate criteria based on impacts on controls
- **Data-informed:** Suggestion to consider identifying the variables/level of variables to be tested based on the most common types of spaces/characteristics (e.g. RECS dataset, CBECS, etc.)
- **Divide by type of sensors system:** it was suggested that the variables to best tested would be determined separately, including one set of criteria for the Cat A and one for the Cat B types sensors.

Additional Evaluation Criteria: Additional considerations were suggested, not necessarily as variables to be tested, but as other criteria to consider in evaluating sensor systems:

- **Battery life**: suggestion to consider battery life in the evaluation criteria
- **Repeatability:** suggestion to repeat the tests several times and evaluate the repeatability of results of sensor systems
- **Accuracy over time**: some systems can take time to learn the environment (e.g. through data-driven learning algorithms); it was suggested that it would be beneficial to consider in the evaluation systems the ability of the system to accurately evaluate its environment

from the get-go as opposed to after a period of time of data collection. i.e., if a system takes a while to learn its environment and gain accuracy, then this may not be as beneficial as one that works well right after installation.

- **Sensor degradation**: Some sensor systems stop performing well over time; suggestion to conduct testing to evaluate performance over time (e.g. accelerated testing)
- **Overlap of sensors:** It was mentioned that some systems, when installed, can have overlap between what is sensed by one sensor vs. another and that if there is overlap in how the sensors detect that space, this can cause errors; suggestion to consider this in testing.
- **Commissioning:** Mentioned that ease of commissioning would be an important criteria
- **Self-commissioning/Self-calibration**: mentioned that ideally sensors would benefit from self-commissioning

Testing criteria for all types of Cat A/B sensors: A good amount of discussion centered around what the criteria should be for all types of Cat A/B sensor systems. The following points were discussed:

- ***Tier systems for testing:*** There is a need to choose a short(er) list of variables/conditions that all sensors systems should be able to operate under. This could be a "tier 1" pass/performance evaluation. Then there could be a list of "tier 2" or "tier 3" variables that could also be tested if the sensor system(s) passed the first tier. The first tier would be a shorter list of variables that are considered to be most common/critical/needed to be known by a diversity of stakeholders
- ***Uniform/non-uniform testing depending on the sensor system type****:* Quite a bit of discussion occurred related to whether there should be a uniform set of variables/conditions that should be evaluated for all sensor system types. One side argued that different sensor systems, depending on the sensors used, will be more/less sensitive to different conditions (e.g. a camera sensor will not be sensitive to electromagnetic interference, but wave-based sensors will). Considering this the argument is that it doesn't make sense to test variables where a sensor system is not sensitive at all to a certain variable… The other side argues that if it testing is not the same variables for all types of sensors, then there is no apples to apples comparison of performance. No final conclusion was agreed upon during the meeting

Ultimately there were many more items to discuss. It was suggested by the moderators to set up follow up conference calls to discuss further items.

<u>Group 2: CO2 Occupancy Sensor System Performance Testing Methods</u>

In this breakout session, the discussion was based on four main questions, which were included in the question list (passed out in the meeting) and the D22.05 standard document for CO2 measurement. These include the following:

1. *Accelerated Testing: What is the preferred approach for accelerating sensor testing in a manner that will reliably provide important information with respect to sensor drift and long term performance?*

2. *Small Chamber Methods: To what degree should standard small chamber methods be referenced and used by this standard? (These small chamber methods for example specify requirements for uniformity of test concentration in the chamber space.)*

3. Reference Monitor Accuracy: With respect to the full range of sensors that could be evaluated with this standard (1 ppm), how accurate does the reference monitor need to be, and what level of stringency should be specified in terms of the traceable performance of the reference monitor?

4. Breadth of Standard Scope: What changes should we propose with respect to how broad we want the standard to be? (e.g., broaden the scope of the standard to provide for performance testing of CO2 sensors of varied form factors, serving varied market segments , and with varying underlying sensing technologies

The following items summarize the discussions in this session:

Influential factors: What are the major factors contributing to uncertainty in CO2 sensing?

- Moisture is an important issue; Moisture has a significant impact on the (true) value of CO2.
- Moisture and VOC both play an important role in uncertainty
- Temperature and pressure also impact CO2; pressure variation mimics height variation.

Testing parameter ranges: What are the appropriate ranges of the parameters to be evaluated? Are there any limits on how far these parameters can extend/can be evaluated to (e.g. on Page 11 of the D22.05 standard document, the RH values are very high. Is this needed?)

- At this moment, there are no specific studies focused on the limits/levels of these parameters.
- The post coil temperature of AHUs is normally much lower than the current specified value of 15C. We can lower the value the temperature range.

Accelerated aging: There are methods to study the performance of sensors after a certain number of cycles, but what about the performance due to accelerated aging, where the sensor system is exposed to extreme weather conditions? The aging can also occur from the stand point of the aging of the electronics.

- There is a need to create such a methodology. There was a previous study completed at ISU that conducted such an experiment. ARPA-E SENSOR team at ISU is also planning to conduct such an experiment

Sensor response time: Will the distance from the occupant to the sensor impact the performance? Can air velocity influence the performance of the sensor?

- The objective of Cat C is to measure the CO2 level, not the number of occupants from the CO2 value. To calculate the number of occupants, the distance from the sensor is an important parameter. The air velocity also impacts this.
- Teams are not required to put just a single sensor; they can place a grid of sensors in whatever configuration desirable; this will reduce the impact of the distance of the sensor from the occupant.

Manufacturer Acceptance: Are manufacturers receptive to this suggested sensor standard?

- Several representatives from different companies and in general they agreed to the need of sensor guideline.

Performance Matrix: Are the performance matrices defined as before or after shipping/handling? If sensors ship under extreme weather conditions, they can influence the performance of the sensors.

- The performance matrix is based on starting from production to installation and commissioning. So, everything is included in this.
- Maybe we need some methodology to evaluate such parameters.

Choosing a sensor to test: How should a (specific) sensor be chosen to test:

- For ARPA-E SENSOR teams, Cat C, since systems are not commercially available yet will have to test the one prototype(s) that is provided; timeline has been defined such that they (Cat C) can scale product. After creating the prototype, teams should focus on scaling towards mass production. Eventually such teams can be tested beyond just prototype.
- For commercially available products, can randomly select sensors and evaluate their performance.

Evaluation Metric: Which one is more proper, sensor cost/area or sensor cost/number of sensors:

- Specific to ARPA-E efforts, since Cat C has the capability to implement as many sensor as are need to evaluate CO2, area metric (cost/area) would be better, however this is not same for all type of sensors

Feasibility of Category C requirements: For a single office, the whole sensor system is required to cost ~$20. Will it be possible to achieve this?

- The cost has been specified in such a way so that it does not include labor and has to have automated connectivity to controls, such that after installation, operation costs are zero, thus the whole $$ can be used for sensor development.

Evaluation of stress/vibrations: What are the impacts of parameters such as stress and vibration? In the future of wearable CO2 sensors this may be considered

- There are some test methods available to evaluate the extreme conditions. Consider this as a future effort that is needed.
- A 'drop test' something similar could be used to evaluate this.

Outside CO2 levels: Is outside CO2 variation important/considered in this effort?

- Yes this is important
- As outside temperature impacts CO2, we can test at least freezing temperatures to evaluate the effect on CO2 due to freezing.

Differentiating variable/fixed air speed methods: Do we need different methods for testing CO2 levels for HVAC systems with variable vs. fixed air speed?

- Yes, need to define how much specificity required. We could include fan characteristics or use air change rate.

Reporting granularity: How much granularity is needed in results? Can we report all the data and the cumulative results?

- The results can vary, and based on this, we would need data and methods used for testing. This also gives better approximation of the result.
- Need to decide where's the limit of testing methods?

Group 3: Building Occupancy Simulation Methods

During this session the moderators provided a powerpoint presentation summary of the methodologies being proposed for the building occupancy simulation and energy modeling task associated with the ARPA-E SENSOR Category D efforts. A brief summary of these methods is provided here:

University of Alabama Approach: This project includes a task to assess the energy savings from existing advanced occupancy-sensor-driven HVAC controls with considerations of possible sensor errors and their impact on energy savings through using the DOE prototype EnergyPlus models. Simulated scenarios will include four commercial prototypes (medium offices, large office, one hotel, and one school) and one single family home prototype in all U.S. climate zones.

Iowa State University Approach: This project is developing occupancy simulation tools for three types of buildings, including a residential building (based on ATUS data), academic building (based on ISU-simulator). These tools allow for uses to provide input into the building and occupancy types and produce a schedule with can be imported into energy simulation software. The team is also developing validated energy models of the buildings that will be used for laboratory and field testing for use in evaluating the energy savings.

The following discussion occurred during this session:

(1) Limitations of common modeling assumptions to support dynamic occupancy-based controls

a. Simplified thermal zoning where thermal zones with same space type and orientation are typically combined
b. Standard occupancy profiles that are typically used for zones with the same space type which is not necessary a good representation of reality
c. Limited availability of occupancy data or research from literature review that provide representative and stochastic occupancy profiles and are able to differentiate the thermal zones in different building types.

(2) Modeling advanced VAV controls that are supported by occupancy sensing

a. Thermostats setbacks
b. Requirements in Standard 90.1, Standard 62.1 (detailed Ventilation Rate Procedure, Simplified Ventilation Rate Procedure), Guideline 36, and their future editions.

- Minimum zone VAV airflow for hydronic and electric reheat terminal boxes that are depended on the sensed number of people.
  - Cooling minimum
  - Heating minimum
  - Dead band minimum
  - System ventilation flow

c. Limitation of Building Energy Modeling tools to support these controls

(3) There is a need to upgrade modeling rules to capture savings of occupancy-based HVAC controls in performance rating methods or code compliance (Standard 90.1 Appendix G and Chapter 11 Energy Cost Budget).
(4) Impacts of these assumptions above on the magnitude of savings for cost effectiveness analysis of individual designs, utility program, and policy analysis.
(5) Modeling stochastic sensed occupancy variations.
(6) Modeling OBC-based controls as a Grid-Interactive Efficient Buildings measure.

Additional details of these topics are listed below:

Detail Zoning:
A more detailed zoning method was introduced, including a detail zoning method based on some detail zoning assumptions. In this case, we have to further divided zones into more thermal zones.

- How much detail should we considered in zoning?
  - Lay out the building into different types of rooms.
  - Zoning depends on the purpose of the building.
  - Sometimes, you are zoning for one purpose, but in reality, it will be used as another type of purpose.

- What is the comfort indication when saving the energy?
  - Currently, we are not use thermal comfort as the evaluation metrics.
  - It could be considered as part of our control intent.
  - Need to consider thermal comfort while achieving the energy saving, even it's not the primary purpose of this project.

- Occupancy Profile:
  - Occupancy profiles can be generated based on LBNL simulator.
  - Currently, most schedule are fixed.
  - The ground truth to get the occupancy data could suffer from high cost and privacy issues, especially for room level information. (e.g., wifi signals and mobile phone signals for the building level).
  - We expect to see energy saving from stochastic and dynamic occupancy schedules.

- How to define reasonable occupancy schedules?
  - Refer to ATUS data to figure out a typical schedule for occupancy (different kind of people). Some literature and ongoing efforts in this area
  - For residential buildings, can consider plug-loads, lighting, etc. linked to occupancy

  - Residential simulation protocol - randomize a variety building for end uses. Find the correlation between them.

OBC Simulation Plan

- Where is the energy saving coming from for OBC?
  - Ventilation – For VAV system, there are two ways to control. 1). Reset the minimum damper position. 2). Reduce the AHU OA in-take.
  - Thermostat – temperature setback (thermal comfort is important in temperature setback).
  - Currently, we are discussing zone level and system level ventilation. However in more detail, there is a design level system ventilation for the VAV system. In that scenario, the system would try to maintain the low load condition with acceptable low IAQ, while there is still has people in the room. For ASHRAE 62.1, there is an assumption to be made instead of checking the critical conditions in each zone. However, at the operation level, a detailed calculation method should be used, include checking the ventilation efficiency dynamically to decide the overall ventilation.
- When occupancy sensors have faults (positive or negative), how much is the impact to thermal comfort?
  - Sensor failure test. (e.g., a sensor failure is occurred, then the failure mode is introduced). In EnergyPlus, use simulation to understand the impact from the sensor failure.

How to deal with the change of use of space?

- In current simulation, we are not considering the use of the space is totally changed.
- Guideline 36 – if the building owner decided to change the purpose of use, it would be easier and cheaper to re-program the box.

Thermal comfort

- Relative humidity is important to the thermal comfort.
- People are more sensitive to the RH than the temperature band.
- Most buildings only have temperature sensor, and no RH sensor would be installed.
- Control the window blinds.

Group 4: Occupant-Based Controls

In this breakout session, the following questions were discussed. These focused on the technical and market barriers to Occupant-Based Control (OBC), and the saving opportunities of OBC.

1) What are the technical barriers? What are the integration challenges? How do we communicate sensing system with different control systems, like DCV, Nest thermostats, and etc.?

2) How to evaluate performance of OBC, how to calculate the saving potentials of OBC?

Retrofitting of HVAC systems with OBC

- Often older VAV boxes in an existing building is 20+ years old, and may be unable to implement OBC.

- Practical outdoor air controls are not good; the ability of tuning outdoor air controls to the correct number of people in the building is limited.
- Outdoor air measurement could be an issue
- Many existing systems bring in more outdoor air than necessary.
- VAV boxes have an opening for the minimum flow rate for ventilation higher than requirements from current standards. By taking occupancy counting into account, we might eliminate some of these issues

Occupant Sensing

The purpose of sensing is to allow for the HVAC controls to know the presence/number of people in a space.

- It is challenging integrating lighting-based occupancy sensors with HVAC control. Thermal zoning is different than lighting zones. Is it feasible, or is it labor-cost? There might be a real need to integrate any sensor network into HVAC control. Maybe it is a software issue.
- Need to make sure that fresh air, even though delivered to the thermal zone, actually is delivered to the occupant. Different rooms have different opening, doors, and windows, and whether doors and windows are open or not will also influence the air distribution in the rooms, i.e. air distribution in a room is time-varying.
- Another question is how occupant breathe fresh air in real world, and this may influence how diffuser supply air into the room. This is something that sensing might help better understand/evaluate.

Market barriers

- A market barrier might come from the lack of a clear understanding how the sensor performs, and how complex it is to integrate the sensor with existing system, and how reliable it is.

Evaluating the performance of OBC

- It is not clear which building will benefit mostly from OBC. Because the integration of OBC into existing HVAC systems may add additional complexity to the operation and maintenance of systems, and certainly will add to the cost. This should be considered when evaluating the saving potentials. This requires real case studies to demonstrate a certain level of energy or cost savings.
- There may not be not enough funding to do a field study of OBC in various buildings with different systems. You can do some testing, but we need to be careful. Others might take your results and misuse that.
  - In this program, we can develop a testing prototype to guide people to do more testing of different cases, and then we could start another program on the control side things and do more testing.
- What is your baseline, what other technologies are you competing with?
  - Need to establish the baseline.
  - We will do he functional testing first to make sure the system works, and then add OBC to the system. The comparison is between the system without OBC and the case with OBC.

   - Alabama's simulation will give a nationwide saving estimation using DOE's prototype buildings.
- In some cases, it would not be cost effective to upgrade to a DCV system with occupant sensors.
- OBC should be based on what? Number of people or bioeffluent?
- Can we have sensors to be used by the HVAC and lighting system at the same time for OBC?

CO_2 sensors

- People might think CO_2 is the problem, and do not understand how CO_2 is supposed to work and the theory behind this.
- Occupancy sensors that just show the number of people might be a great way to address this problem.

Residential side

- What is the communication methodology? Is it a dedicated or using the house's wifi? Will the residents be comfortable with this?
- Need to consider the pathway to integrate with thermostat.
- Sometimes, residents will look at privacy only.
- Other aspect is how we can get people to do this.
- We can divide into different scenarios. If the occupants pay the electricity utility, who has the control of the system? Owner or tenant? Energy or comfort? We might have different strategies for different scenarios. And from the commercial side, we may have something, not just energy savings, but something like indoor productivity that could trigger the maintenance to improve this.
- Should the project also be considering the zoning of home, and using an OBC in conjunction with the zoning space, and providing technologies to support that?
- With regard to the OBC collecting the occupant behavior data, if the thermostat is online, these occupant behavior data might be shared in an unsafe way. What is the prototype standard to protect these data because this might be people's concern.
   - In this program, we have IRB approvals to look at if we are protecting personal identification information, and it can be patterns of other types of issues.
   - We do apply some protections like the camera will not collect and store full picture but some basic pixels that can be interpreted by machine learning algorithms. There is still some concerns about the people that run the system at the back end.
- Residential OBC application
   - A thermostat integrated with occupancy sensor with OBC functions
   - Smart thermostat certification from EPA with standard OBC algorithms
   - Open plug & play with occupancy sensor