IEQ Management System for Building Energy

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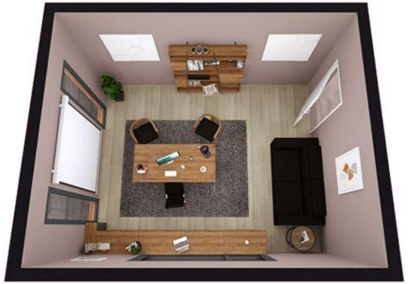
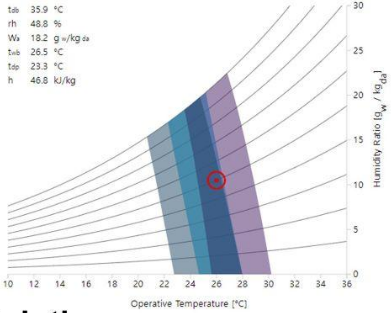
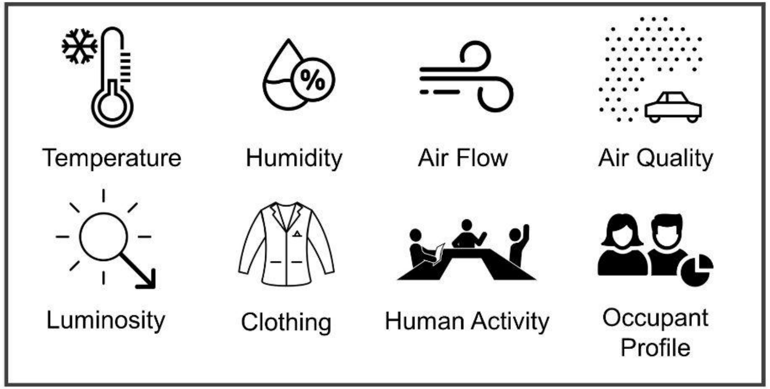
Target Space: Small Office (2~4 People)



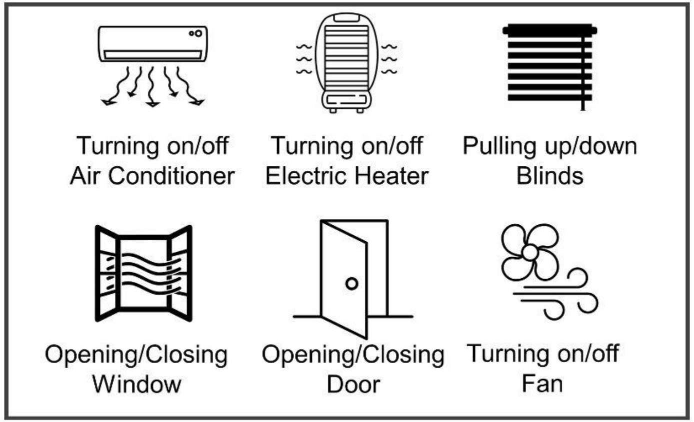
Example of Psychrometric



IEQ factors



Potential Solutions



Overview of Project

Problem: Different buildings are under different environmental conditions including weather, outdoor air quality, direction and location of the building, etc., and each occupant has different clothing and occupant profiles, which address their personal environmental preferences. Furthermore, potential solutions — air conditioners, electric heaters, window blinds, windows, doors, fans, etc. — have an influence on IEQ in different ways.

Scope: The scope of this use case is limited to a small room that two to four people can use in the United States. The target population of this application is individuals who regularly occupy the room. This use case is designed for users (specifically occupants of the building) or facility managers, and the language must be understandable to laypeople. In the case of low IEQ, room occupants may input the environmental changes they desire, and this system is able to suggest a solution to improve IEQ with minimal building energy use. However, this system cannot automatically manipulate opening/closing windows, HVAC systems, electric heaters, etc. In addition, this system is unable to apply to large spaces where comfort factors, such as temperature and humidity, are different depending on the location of occupant seats.

Stakeholders: Stakeholders include room occupants, facility managers, and building owners.

Who: Occupants of a building

What: IEQ management system to recommend how to manipulate windows, doors, electric heater, air conditioner, fan to improve IEQ in a room and minimize building energy use

Why: Commercial and residential buildings consumed 93% of electric energy in the end-use section in 2021[1], and 46.2% of energy use in buildings was for heating, cooling, ventilation, and lighting in 2014. This energy is used for enhancing Indoor Environmental Quality (IEQ)

How: An ontology was developed based on the Predicted Mean Vote (PMV) model and Air Quality Index (AQI) to quantify IEQ and suggest viable solutions.

[1] US Energy Information Administration. “U.S. energy consumption by source and sector, 2021”, available at https://www.eia.gov/totalenergy/data/monthly/pdf/flow/total-energy-spaghettichart-2021.pdf
[2] US Energy Information Administration. “Quadrennial Technology Review 2015”, available at https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf

Competency Question 1

Question: Which solution to improve indoor environmental quality and make an occupant feel comfortable uses the least amount of energy? The outdoor air temperature is 86°F, the humidity is 83%, daylight is 110,000 lux through the window, and the outdoor air quality index is 273, 'Bad'. The indoor air temperature is 82°F. The occupant says that it's 9°F too hot for their comfort but that the current humidity level is acceptable. The available, configurable equipment includes currently open blinds that block the window, a ceiling fan that's currently switched off, and a window-mounted air conditioning unit.

Parameters:

- Outdoor air temperature: 86℉
- Humidity: 83%
- Daylight: 110,000 lux
- Outdoor air quality index: 273, "Bad"
- Indoor air temperature: 82℉

Answer: Pull down blinds to block the sunlight and turn on a fan.

Reasoning:

Of the three configurable factors (i.e., the blinds, the fan, and the A/C unit), the blinds have no energy usage, the fan has minimal energy usage, and the A/C has significant energy usage. Lowering the blinds in a ventilated room (which can be determined with the BIM data) would lower the indoor temperature by about 3°F. Turning on the fan would lower the indoor temperature by about 6°F. (This value is determined by a hardcoded rule that takes into account the qualitative nature of the fan, including its size, which can be learned by asking the user in the application.) The A/C can be set to reduce the indoor temperature by any desirable amount. The combination of lowering the blinds and turning on the fan can reach the desired comfort temperature without the large energy usage that comes with turning on the A/C. Turning on the A/C is even more undesirable because it would bring the harmful particulate matter that's contributing to a "bad" outdoor air quality into the room.

Competency Question 2

Question: What IEQ parameters, such as temperature, humidity, airflow, etc., make the multiple occupants feel comfortable in an office room? There are three occupants who prefer temperatures in the range of 73˚F to 77˚F, 74˚F to 78˚F, and 75˚ to 78˚F, respectively. All other factors are already ideal. The outdoor temperature is 18˚F. The current A/C thermostat setting is 72˚F, which is the current indoor temperature. An electric space heater is available but currently switched off.

Parameters:

- Outdoor air temperature: 18°F
- Indoor air temperature: 72°F
- A/C thermostat setting: 72°F
- Electric space heater: switched off

Answer: Keep the thermostat setting at 72˚F and turn on the space heater

Reasoning:

The “nearest” (and therefore achievable with the least energy usage) temperature value that’s within the comfort range of all three occupants is 75˚F. The only available option for raising the temperature is to turn on the electric space heater since changing the A/C thermostat can only lower the temperature.

Competency Question 3

Question: What IEQ parameters, such as temperature, humidity, airflow, etc., make the multiple occupants feel comfortable in an office room? They are working on their seats quietly. The occupants' profiles are 26-year-old female Jane (height: 5' 2", weight: 121 lbs, sweat pants, long-sleeve sweatshirt: 0.74 clo, the blue area in the figure), 59-year-old female Megan (height: 5' 8", weight: 136 lbs, wearing Trousers, long sleeve-shirt: 0.61 clo, the grey area in the figure), and 46-year-old male John (height: 6' 1", weight: 189 lbs, wearing sweatpants, Jacket, Trousers, long-sleeve shirt: 0.96 clo, the purple area in the figure). The outdoor weather is 56°F, relative humidity is 28%, air-speed is 1.6m/s. Indoor temperature is 70° F, relative humidity is 34%, and air-speed is 0.8m/s. Air-conditioner is broken, window is opened, and an electric heater is available

Parameters:

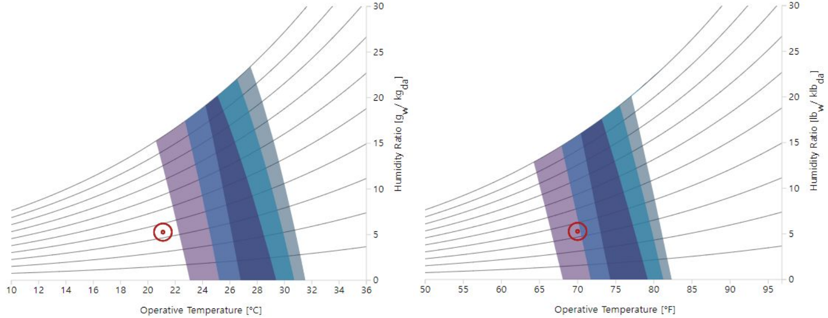
- Occupant 1: Jane (26-year-old male; height: 5' 2"; weight: 121 lbs; sweat pants; long-sleeve sweatshirt: 0.74 clo)
- Occupant 2: Megan (53-year-old female; height: 5' 8"; weight: 136 lbs; wearing Trousers; long sleeve-shirt: 0.61 clo)
- Occupant 3: John (42-year-old male; height: 6' 1"; weight: 189 lbs; wearing sweatpants, Jacket, Trousers, long-sleeve shirt: 0.96 clo)
- Outdoor air temperature: 56°F
- Outdoor relative humidity: 28%
- Outdoor air-speed: 1.6m/s
- Indoor air temperature: 70°F
- Indoor relative humidity: 34%
- Indoor air-speed: 0.8m/s
- Windows: opened

Competency Question 3

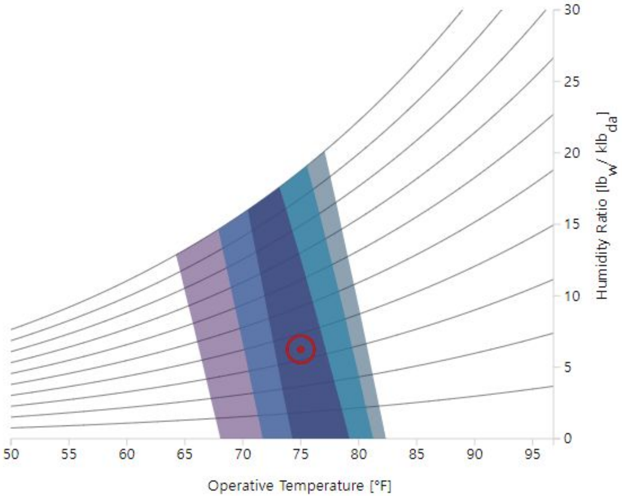
Answer: Closed windows, turning on an electric heater, and recommend Jane to wear an outer

Reasoning:

The current indoor air temperature and relative humidity (the red dot in the figure) are out of the three people's comfort zones (the blue, grey, and purple area in the figure). The windows should be closed because of the low outdoor temperature and high air-speed. However, even if the windows are closed, and indoor air-speed becomes 0.1m/s, the red dot could still be **out of Jane's and Megan's comfort zones** An additional process is needed to further increase indoor air temperature. **The air-conditioner is broken, and we should turn on an electric heater to increase the indoor temperature.** If the electric heater is turned on, and the air temperature becomes 75°F, All the occupants feel comfortable in the office room, as shown in the figure.



Psychrometric Chart before Closing Windows (left, air-speed: 0.8m/s) and after Closing Windows (right, air-speed: 0.1m/s)



Psychrometric Chart before turning on equipment (left, air-speed: 0.1m/s, air temperature: 70°F) and after turning on (right, air-speed: 0.1m/s, air temperature: 75°F)

Competency Question 4

Question: What IEQ parameters, such as temperature, humidity, airflow, etc., make the multiple occupants feel comfortable in a living room during summer? The occupants' profile is a 26-year-old son typing something on his laptop (metabolic rate: 1.1, the blue area in the figure), a 59-year-old mother dancing (metabolic rate: 3.4, the grey area in the figure), and a 32-year-old daughter cleaning the house (metabolic rate: 2.7, the purple area in the figure). The outdoor weather is 89°F, relative humidity is 70%, air-speed is 1.2m/s, and outdoor air quality index is 181, 'Unhealthy'. Indoor temperature is 85°F, relative humidity is 67%, and air-speed is 0.8m/s **Air-conditioner (power consumption: 543W), a fan (power consumption: 48W), and a dehumidifier (power consumption: 300W) are available.**

Parameters:

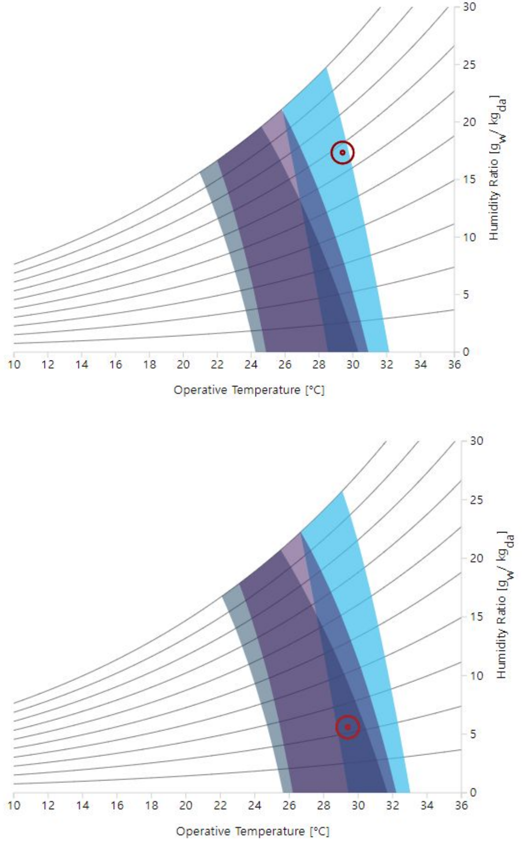
- Occupant 1: son (26-year-old male; metabolic rate: 1.1)
- Occupant 2: mother (59-year-old female; metabolic rate: 3.4)
- Occupant 3: daughter (32-year-old female; metabolic rate: 2.7)
- Outdoor air temperature: 89°F
- Outdoor relative humidity: 70%
- Outdoor air-speed: 1.2m/s
- Outdoor air quality index: 181, 'Unhealthy'
- Indoor air temperature: 85°F
- Indoor relative humidity: 67%
- Indoor air-speed: 0.8m/s
- Power consumption of the air-conditioner: 543W
- Power consumption of the fan: 48W
- Power consumption of the dehumidifier: 300W

Competency Question 4

Answer: Close the window and turned on the fan and dehumidifier

Reasoning:

Window sensors show that the windows are opened; but, they should be closed due to low outdoor air quality. Because they didn't input their clothing level in the system, the system uses a default summer clothing value of 0.5 which is the same as the value of 'typical summer indoor clothing'. The three people have gaps in comfort ranges of temperature and humidity due to the different activity levels, and the current air temperature and relative humidity (the red dot in the figure) are only in the son's comfort zone (the blue area in the figure). If the indoor air-speed is 1.5m/s and the relative humidity is 22%, IEQ will meet the three people's comfort requirements, as shown in the figure. In this case, two options are available: turning on the air-conditioner or turning on a fan & dehumidifier. The power consumption of the air-conditioner is 543W, while the dehumidifier consumes 300W and the fan consumes 48W. Thus, turning on the dehumidifier and fan is more appropriate.



Psychrometric Chart before turning on equipment (left, air-speed: 0.8m/s, relative humidity: 67%) and after turning on (right, air-speed: 1.5m/s, relative humidity: 22%)

Competency Question 5

Question: In a small gym, three people are working out. 22-year-old male Jason walking on a treadmill lifting 45kg bars (metabolic rate: 4.0, wearing shorts & short-sleeve shirt: 0.36 clo, the blue area in the figure), 44-year-old male Bob seated with heavy limb movement (metabolic rate: 2.2, wearing typical summer indoor clothing: 0.5 clo, the grey area in the figure), and 52-year-old female Sarah walking on a treadmill with 3 mph (metabolic rate: 3.8, wearing a short-sleeve shirt: 0.57 clo, the purple area in the figure). What IEQ parameters, such as temperature, humidity, airflow, etc., make the multiple occupants feel comfortable in a gym? Indoor temperature is 82°F, relative humidity is 38%, air-speed is 0.1m/s, and outdoor air quality index is 38, 'Good'. Outdoor temperature is 80°F, relative humidity is 34%, and air-speed is 1.1m/s. An air conditioner (power consumption: 1350W) and floor fan (power consumption: 48W) are available.

Parameters:

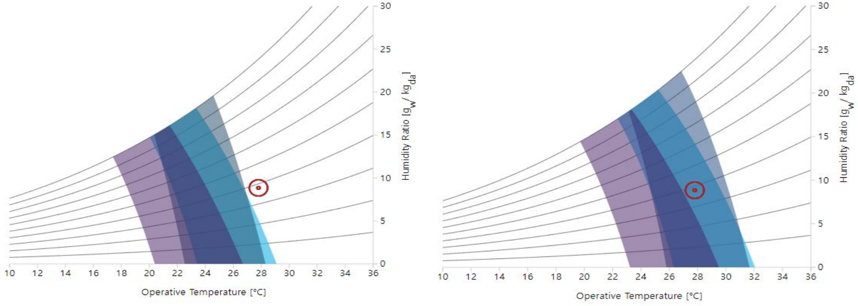
- Occupant 1: Jason (22-year-old male; metabolic rate: 4.0; wearing shorts & short-sleeve shirt: 0.36 clo)
- Occupant 2: Bob (44-year-old male; metabolic rate: 2.2; wearing typical summer indoor clothing: 0.5 clo)
- Occupant 3: Sarah (52-year-old female; metabolic rate: 3.8; wearing a short-sleeve shirt: 0.57 clo)
- Outdoor air temperature: 80°F
- Outdoor relative humidity: 34%
- Outdoor air-speed: 1.1m/s
- Outdoor air quality index: 38, 'Good'
- Indoor air temperature: 82°F
- Indoor relative humidity: 38%
- Indoor air-speed: 0.1m/s
- Power consumption of the air-conditioner: 1350W
- Power consumption of the fan: 48W

Competency Question 5

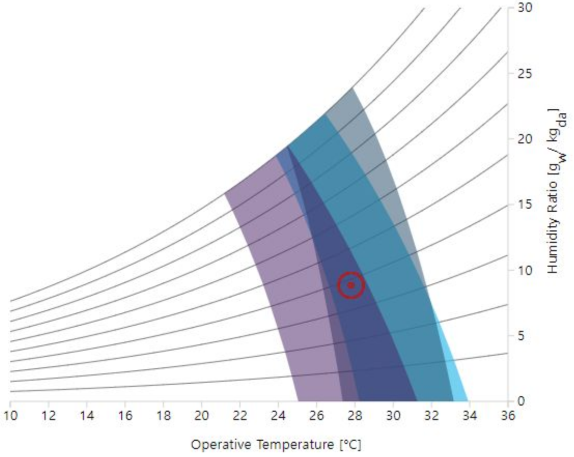
Answer: Opened windows and turn on a floor fan

Reasoning:

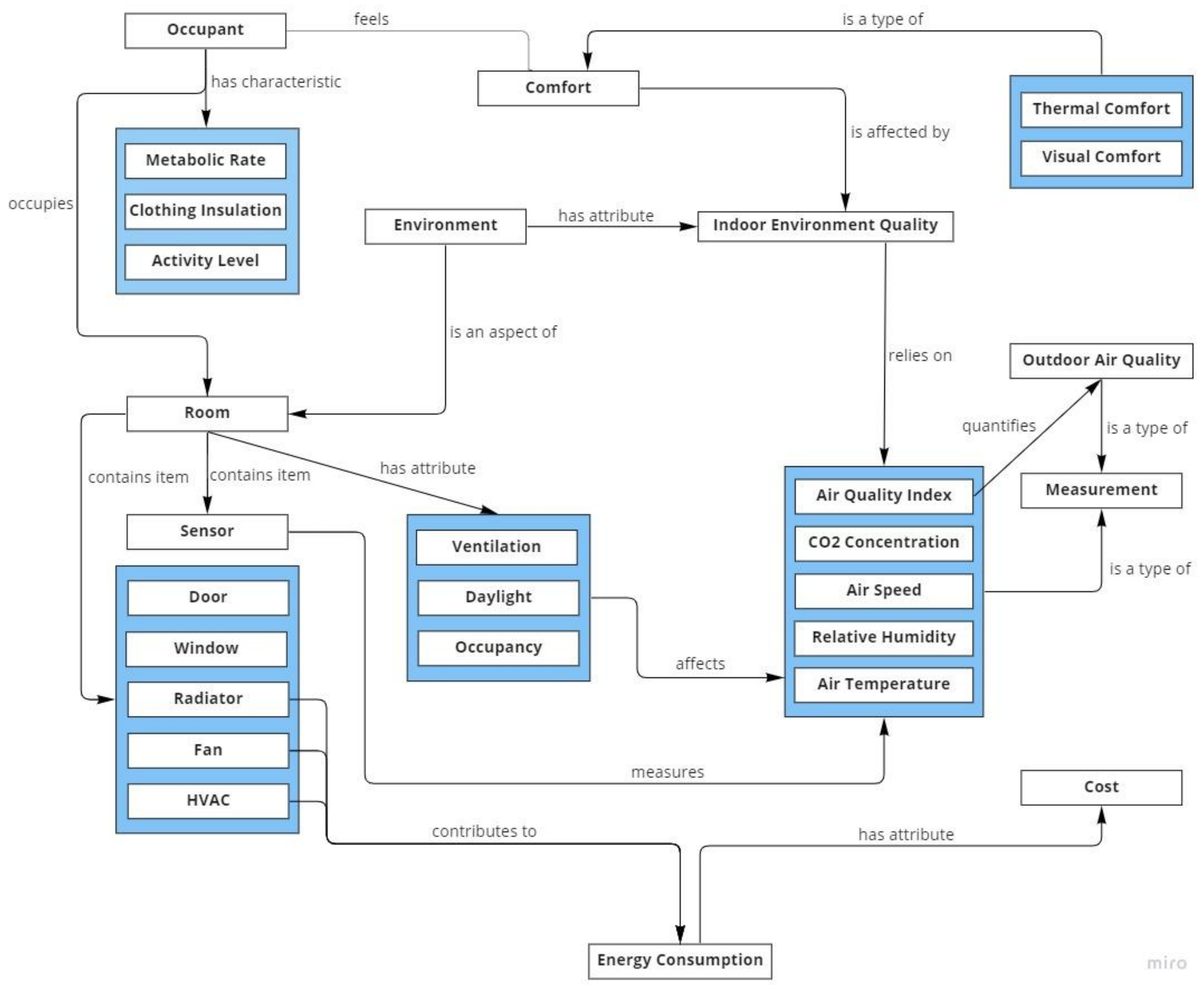
Although temperature and humidity are similar to indoor temperature and humidity, outdoor air-speed (1.1m/s) is faster than indoor air-speed (0.1m/s). Additionally, outdoor air quality is good, and opening windows can be a good choice. Even if indoor air-speed becomes 0.9m/s, Sarah could still feel discomfort. In hte figures, the purple areas represent Sarah's comfort zones, and the current air temperature and relative humidity (the red dot) are out of Sarah's comfort zones (the purple area). An additional process is needed to further increase indoor air-speed. Turning on the fan (power consumption: 48W) is a better option than turning on the air-conditioner (power consumption: 48W) in terms of energy use. If the fan is turned on, and the air-speed becomes 2m/s, all the occupants can feel comfortable, as shown in Figure 8.



Psychrometric Chart before Opening Windows (left, air-speed: 0.1m/s) and after Opening Windows (right, air-speed: 0.9m/s)



Psychrometric Chart after Opening Windows and Air-Speed is 2m/s



Conceptual Model

- Motivation behind conceptual model
- How does this model address our competency questions?

Resources

Databases:

- ASHRAE Global Thermal Comfort Database (https://github.com/CenterForTheBuiltEnvironment/ashrae-db-II)
- ASHRAE Global Occupant Behavior Database (https://ashraeobdatabase.com/#)
- ROBOD, room-level occupancy and building operation dataset (University of Singapore, https://figshare.com/articles/dataset/ROBOD_Room-level_Occupancy_and_Building_Operation_Dataset/19234530/7)
- fIEECe, an Energy Use and Occupant Behavior Dataset for Net Zero Energy Affordable Senior Residential Buildings (https://osf.io/2ax9d/)

Ontologies:

- obXML (https://behavior.lbl.gov/?q=obXML)
- Occupancy Profile ontology (https://bimerr.iot.linkeddata.es/def/occupancy-profile/#Driver)
- Brick Ontology (https://brickschema.org/ontology)
- Smart Appliances Reference Ontology (SAREF, https://ontology.tno.nl/saref/)
- ifcOWL Ontology (https://standards.buildingsmart.org/IFC/DEV/IFC4/ADD2_TC1/OWL/index.html)
- Semantic Sensor Network (SSN, https://www.w3.org/TR/vocab-ssn/)
- Calidad-Aire (Air Quality Ontology, http://vocab.linkeddata.es/datosabiertos/def/medio-ambiente/calidad-aire/index-en.html)