Ontology Engineering 2022
Assignment 4

Use-Case Driven Knowledge Encoding Part 2

I. Use Case Description	
Use Case Name	IEQ Management System for Building Energy
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Creation / Revision Date	September 2022
Associated Documents	See references.

II. Use Case Summary	
Goal	To assist occupants to improve indoor environmental quality (IEQ) and minimize energy use in a small room
Requirements	Recommendations must take into account the temperature, humidity, luminosity, daylight, climate, building location/direction, window/door/window blinds, occupants' environmental preference range and current comfort levels,, and thermostat settings of HVAC
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 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.
Priority	n/a
Stakeholders	Stakeholders include room occupants, facility managers, and building owners.

Description	According to reports written by the U.S. Energy Information Administration, commercial and residential buildings consumed 93% of electric energy in end-use section in 2021[1], and 46.2% of energy use in buildings were for heating, cooling, ventilation, and lighting in 2014[2]. This energy is used for enhancing Indoor Environmental Quality (IEQ), which refers to a perceived experience of the building's indoor environment including thermal comfort, indoor air quality, lighting, acoustics, and control systems [3]. In a room, IEQ is affected by many factors: temperature, humidity, air flow, air quality, luminosity, clothing, human activity, or an occupant's profile [4-5]. The problem is that 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. For instance, an air conditioner and a fan both cool temperature down; however, the fan doesn't affect humidity, unlike the air conditioner. Additionally, they consume different amounts of electric energy per unit time. In this project, we aim to develop an ontology that finds a viable solution to improve IEQ for occupants while minimizing energy use in a room by combining several sets of knowledge: 1) thermal comfort based on temperature, humidity, air speed, and clothing level, 2) occupancy behavior for IEQ, 3) indoor air quality, 4) interior illumination level. A user will inform the IEQ management system of what quantifiable IEQ factors (e.g., temperature, humidity, etc.) are currently causing them discomfort and to what degree, and the system will suggest the method for bringing those factors into an acceptable range that uses the least amount of energy.
Actors / Interfaces	The primary actor for this use case is occupants in a room who want to understand indoor environmental quality in the space and improve their thermal comfort by changing thermostat settings, opening/closing windows, pulling up/down blinds, etc. Also, facility managers can be the primary actor who wants to minimize energy consumption in a building and keep thermal comfort simultaneously. Others include user's profile, building owner, weather APIs, Building Information Modeling (BIM) database, demographic database, wireless sensors, HVAC, lights, windows, equipment, and existing ontologies, such as occupancy behavior ontology (obXML), Building Topology Ontology (BOT), building information ontology (ifcOWL), Smart Appliances Reference Ontology (SAREF), Semantic Sensor Network Ontology (SSN), air quality ontology (Calidad-Aire), Quantities, Units, Dimensions and Types (QUDT) ontology, time measurement ontology (OWL-Time).
Pre-conditions	Physical sensors should be preinstalled in a room, or sensor data should be prepared.
Post-conditions	Any changes in the user profile or properties of building elements — which are changed by users, such as window/door opening, turned-on/off lights, etc. — should be updated
Triggers	The primary trigger for this use case is that the user launches the application, analyzes IEQ in the roome, and gets a recommendation.

III. Usage Scenarios

1. An office worker in San Diego, California, usually works in a one-person office. During

summer, the office is too hot, 86°F, due to strong sunlight, and she wants to open the window; however, outdoor humidity is 83% and the air quality index is 273, ‘Bad’. Additionally, she can’t turn on the air conditioner because it’s too old and emits dust. As a result, her IEQ is considered low. The application may recommend pulling down blinds to block the sunlight and turn on the fan. Also, it suggests opening the door because corridor temperature, 74°F, is relatively cooler than room temperature. The system shows a simulation result of how this solution can consume lower electricity compared to turning on the air conditioner.

2. Three office workers in Chicago, Illinois, work in a school. During winter, it is difficult for them to find a suitable thermostat setting. The weather is extremely cold, 18°F. One of the workers, Michael, is 22 years old, male, and he feels warm. However, Jane, who is 53 years old, wants to increase the thermostat setting of a heater — even if she wears a thick sweater. The other worker, Tom, who is 42 years old, feels cold like Jane but dislikes the humid air from the air heater. The application may recommend keeping the thermostat setting, 75°F, and also turning on the electric heater in the room. The system shows how the three people have different thermal comfort zones and what the optimal temperature & humidity are for each of them. It’s not possible to satisfy perfectly all occupants’ individual comfort zones, so the system falls back on other ranking factors, such as energy usage.
3. A person is cleaning their home living room. The activity is physically intensive, so they feel too hot by about 8°F. The current outdoor temperature is 90°F, and the current indoor temperature is about 83°F. The humidity is low, measuring 25%. An air-conditioning unit is available, but there are no other climate-control options. Setting the A/C to 75°F uses a lot of energy, but the knowledge base and ontology aren’t aware of any other options, so the system falls back on suggesting this sub-optimal solution.

IV. Basic Flow of Events

Basic / Normal Flow of Events			
Step	**Actor (Person)**	**Actor (System)**	**Description**
1	User		Launches the application
2		App	Retrieves BIM database and real-time sensor values, weather data, pre-registered demographic employees’ data
3		App	
4	User		Clicks the thermal comfort zone and get recommendation how to improve IEQ
5		App	Finds the best solution among the potential solutions to enhance IEQ and minimize energy use.
6		App	Shows the solution and analysis results, such as opening/closing window, pulling down blinds, etc. Furthermore, displays how IEQ is enhanced in the room if the user follows the recommendation.
7	User		Follows the app’s recommendation
8		App	Updates the sensor value and status of building elements. Visualizes the current environment and reports the difference between simulated data and actual data.
9		App	Stores the result and utilizes it to improve the simulation

			performance in the future.

Basic / Normal Flow of Events			
Step	Actor (Person)	Actor (System)	Description
1	User		Launches the application Inputs available climate-control options, including fans, blinds, A/C units, etc.
2		App	Retrieves BIM database and real-time sensor values, weather data, etc.
3	User		Clicks the thermal comfort zone and get recommendation how to improve IEQ
4		App	Finds the best solution among the potential solutions to enhance IEQ and minimize energy use. Checks solution against predefined energy-use thresholds.
5		App	Shows potential solutions with high energy usage and explains that based on the thermal comfort inputs and available controls, there’s no way to achieve the desired IEQ result with lower energy usage.
6	User		Follows the app’s recommendation
7		App	Updates the sensor value and status of building elements. Visualizes the current environment and reports the difference between simulated data and actual data.
8		App	Stores the result and utilizes it to improve the simulation performance in the future.

V. Alternate Flow of Events

Alternate Flow of Events – Initial Application Set-Up Flow			
Step	**Actor (Person)**	**Actor (System)**	**Description**
1	User		Launches the application for the first time
2		App	Preliminary questions are asked of the occupants, the building, and sensors to initiate the system. - General information about the occupants - BIM database including building/furniture/sensor elements - Sensor IDs to match physical/digital sensors
3		App	Retrieves all the information and starts collecting data from the sensors
4		App	A preliminary report on the current status of all elements in BIM database and thermal comfort/discomfort zones

Alternate Flow of Events – Unresponsive Source			
Step	**Actor (Person)**	**Actor (System)**	**Description**
1	User		Launches the application
2		App	Current information for the building, sensors, and occupants is requested for loading the application

3		App	The interface with the application fails
4		App	The user is altered to the situation after 5 retries. The interface shows "The suggestion doesn't work"

VI. Use Case and Activity Diagram(s)

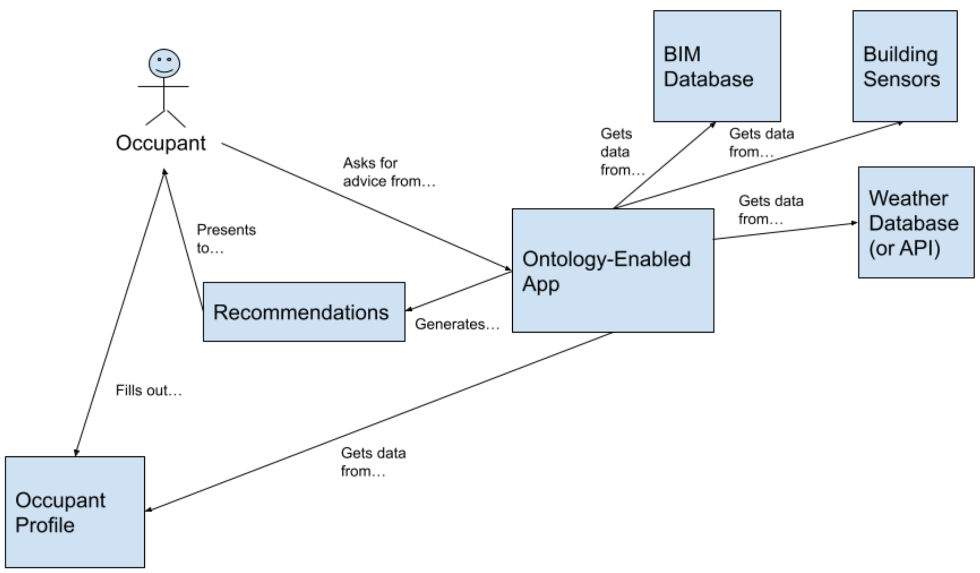

Figure 1: Use Case Diagram

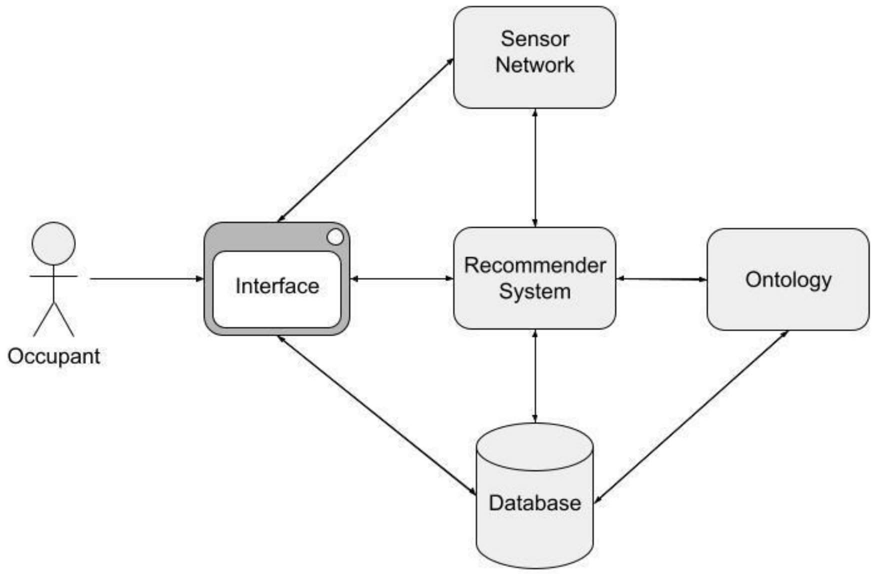

Figure 2: System Architecture

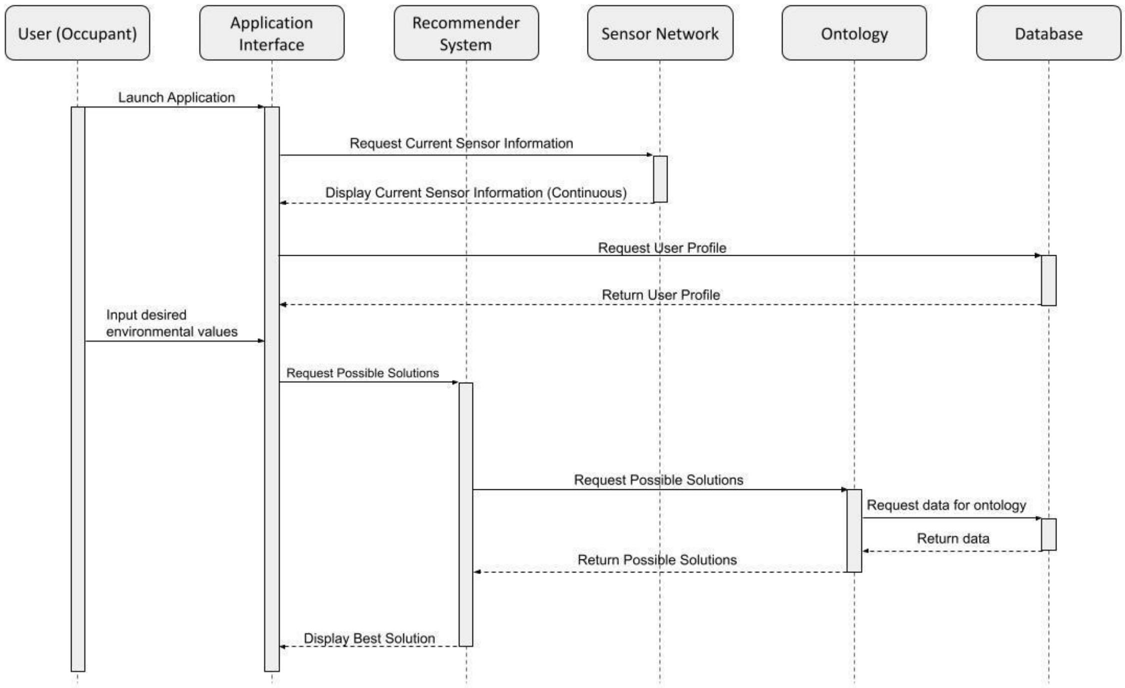

Figure 3: Activity Flow Diagram (Normal Flow)

VII. Competency Questions

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.
   Answer: Pull down blinds to block the sunlight and turn on a fan.
   Determining the answer: (1) In the knowledge graph, load BIM database, weather data, pre-registered demographic employees’ data, real-time sensor values including temperature, humidity, air quality, etc., (2) Calculate an occupant’s thermal comfort zone based on the loaded data, (3) Query to find a solution how to change IEQ parameters using potential solutions, such as pulling up/down blinds, opening/closing door, window, turning on/off the air conditioner, fan, electric heater, etc. (4) Suggest the best solution to improve IEQ and

minimize energy use. (5) Show results on how the solution enhances the environment and reduces the energy consumption in the office.

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. 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.

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 HVAC thermostat setting is 75°F, which is the current indoor temperature.. An electric space heater is available but currently switched off.

   Partial Answer: Keep the thermostat setting at 75°F and turn on an electric space heater.

   Determining the answer: (1) In the knowledge graph, load BIM database, weather data, real-time sensor values including temperature, humidity, airflow, air quality, etc., (2) Calculate occupants' thermal comfort zone based on the loaded data, (3) Query to find a solution how to change IEQ parameters using potential solutions, such as pulling up/down blinds, opening/closing door, window, turning on/off the air conditioner, fan, electric heater, etc. (4) Suggest the best solution to improve IEQ and minimize energy use. (5) Show results on how the occupants have different thermal comfort zones and what is the optimal temperature & humidity for them.

   Reasoning: A temperature value that's within the comfort range of all three occupants is 77°F. The only available option for raising the temperature is to turn on the electric space heater since changing the HVAC thermostat can only lower the temperature.

3. **Question:** What IEQ parameters, such as temperature, humidity, airflow, etc., make the multiple occupants feel comfortable in an office room? The occupants' profiles are 26-year-old female Jane (height: 5' 2”, weight: 121 lbs, wearing knee-length skirt: 0.54 clo), 59-year-old

female Megan (height: 5' 8", weight: 136 lbs, wearing Trousers, long sleeve-shirt: 0.61 clo), and 46-year-old male John (height: 6' 1", weight: 189 lbs, wearing sweat pants, long-sleeve sweatshirt: 0.74 clo). The outdoor weather is 56°F, relative humidity is 28%, air-speed is 1.4m/s. Indoor temperature is 69°F, relative humidity is 34%, and air-speed is 0.1m/s. Air-conditioner is broken, and an electric heater is available

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

Determining the answer: (1) In the knowledge graph, load BIM database, weather data, real-time sensor values including temperature, humidity, airflow, air quality, etc., (2) Calculate an occupant's thermal comfort zone based on the loaded data, (3) Query to find a solution how to change IEQ parameters using potential solutions, such as pulling up/down blinds, opening/closing door, window, turning on/off the air conditioner, fan, electric heater, etc. (4) Suggest the best solution to improve IEQ and minimize energy use. (5) Show results on how the solution enhances the environment and reduces the energy consumption in the office.

Reasoning: Because of the low outdoor temperature and high air-speed, windows should be closed. Air-conditioner is broken, and we should turn on an electric heater to increase the indoor temperature. The problem is that Jane could still feel discomfort even if the electric heater is used. The only option is to increase Jane's clothing level by wearing an outer.

4. **Question:** Partial Answer: What IEQ parameters, such as temperature, humidity, airflow, etc., make the multiple occupants feel comfortable in a living room? The occupants' profile is a 26-year-old son typing something on his laptop (metabolic rate: 1.1), 59-year-old mother dancing (metabolic rate: 3.4), and 32-year-old daughter cleaning the house (metabolic rate: 2.7). The outdoor weather is 75°F, relative humidity is 25%, air-speed is 1.2m/s, and outdoor air quality index is 181, 'Unhealthy'. Indoor temperature is 77°F, relative humidity is 42%, and air-speed is 0.8m/s. Air-conditioner, a fan, and a dehumidifier are available.

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

   Determining the answer: (1) In the knowledge graph, load BIM database, weather data, real-time sensor values including temperature, humidity, airflow, air quality, etc., (2) Calculate an occupant's thermal comfort zone based on the loaded data, (3) Query to find a solution how to change IEQ parameters using potential solutions, such as pulling up/down blinds, opening/closing door, window, turning on/off the air conditioner, fan, electric heater, etc. (4) Suggest the best solution to improve IEQ and minimize energy use. (5) Show results on how the solution enhances the environment and reduces the energy consumption in the house.

Reasoning: Because of low outdoor air quality, the windows should be closed. The three people have large gaps in comfort ranges of temperature and humidity due to the different activities. In this case, two options are available to meet the three people's comfort requirements: turning on the air-conditioner or turning on a fan and dehumidifier. The power consumption of the air-conditioner is 543W, while the dehumidifier consumes 300W and the fan consumes 50W. Thus, turning on the air-conditioner is appropriate.

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), 44-year-old male Bob seated with heavy limb movement (metabolic rate: 2.2, wearing typical summer indoor clothing: 0.5 clo), and 52-year-old female Sarah walking on a treadmill with 3 mph (metabolic rate: 3.8, wearing short-sleeve shirt: 0.57 clo). 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 air quality index is 38, 'Good'. Outdoor temperature is 80°F, relative humidity is 34%, and air-speed is 1.1m/s

   Partial Answer: Opened windows and turn on a fan

   Determining the answer: (1) In the knowledge graph, load BIM database, weather data, real-time sensor values including temperature, humidity, airflow, air quality, etc., (2) Calculate an occupant's thermal comfort zone based on the loaded data, (3) Query to find a solution how to change IEQ parameters using potential solutions, such as pulling up/down blinds, opening/closing door, window, turning on/off the air conditioner, fan, electric heater, etc. (4) Suggest the best solution to improve IEQ and minimize energy use. (5) Show results on how the solution enhances the environment and reduces the energy consumption in the gym.

   Reasoning: Although temperature and humidity are similar to indoor temperature and humidity, outdoor air-speed is faster than indoor air-speed. Additionally, indoor 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. An additional process is needed to further increase indoor air-speed. Turning on a fan is a better option than turning on air-conditioning in terms of energy use.

VIII. Resources

Knowledge Bases, Repositories, or other Data Sources

Data	Type	Characteristics	Description	Owner	Source	Access Policies & Usage
ASHRAE Global Thermal Comfort Database	*Downloadable in multiple formats*		*sets of objective indoor environmental measurements and subjective evaluations by occupants from bulidigns*	*ASHRAE*	[*https://github.com/CenterForTheBuiltEnvironment/ashrae-db-II*](https://github.com/CenterForTheBuiltEnvironment/ashrae-db-II)	*open*
ASHRAE Global Occupant Behavior Database	*Downloadable in multiple formats*		*34 field-measured building occupant behavior datasets collected from 15 countries and 39 institutions across 10 climatic zones*	*ASHRAE*	[*https://ashraeobdatabase.com/#/*](https://ashraeobdatabase.com/#/)	*open*
flEECe, an Energy Use and Occupant Behavior Dataset for Net Zero Energy Affordable Senior Residential Buildings	*Downloadable in multiple formats*		*energy and occupant behavior attributes for 6 affordable housing units over nine months in Virginia, USA*	*Frederick Paige, Philip Agee*	[*https://osf.io/2ax9d/*](https://osf.io/2ax9d/)	*open*

ROBOD, Room-level Occupancy and Building Operation Dataset	*Downloadable in multiple formats*		*dataset consisting of indoor environmental conditions, Wi-Fi connected devices, energy consumption of end uses, HVAC operations, and outdoor weather conditions*	*Ono et al.*	*https://figshare.com/articles/dataset/ROBOD_Room-level_Occupancy_and_Building_Operation_Dataset/19234530/7*	*open*
Datasets for Occupancy Profiles in Student Housing for Occupant Behavior Studies and Application in Building Energy Simulation	*Downloadable in multiple formats*		*Dataset of occupantts' entering and exiting activities with 1960 daily occupancy schedules*	*Nikdel et al.*	*https://data.mendeley.com/datasets/hx5mp695tv/1*	*open*
ECO data set (Electricity Consumption & Occupancy)	*Downloadable in multiple formats*		*dataset of non-intrusive load monitoring and occupancy detection collected in 6 Swiss households over a period of 8 months*	*A Research Project of the Distributed Systems Group*	*https://www.vs.inf.ethz.ch/res/show.html?what=eco-data*	*open*
COD: A Dataset of Commercial Building Occupancy Traces - Stony Brook Univ.	*Downloadable in multiple formats*		*Dataset of occupancy traces in a commer*	*Liu et al.*	https://zenodo.org/record/996587	*open*

			cial office building spanning 9 months and covering room-level occupancy for three different spaces			
Fitness-gym and Living-room Occupancy Estimation Data	*Downloadable in multiple formats*		*Dataset of environmental information and corresponding occupancy level of two different locations, such as a fitness-gym and a living-room.*	*Vela et al.*	https://data.mendeley.com/datasets/kjgrct2yn3/3	*open*

External Ontologies, Vocabularies, or other Model Services *(partial)*

Resource	Language	Description	Owner	Source	Uses	Access Policies & Usage
obXML	*OWL, RDF/XML, CSV*	*Ontology for occupant behavior*	*LBNL BTUS*	[*https://behavior.lbl.gov/?q=obXML*](https://behavior.lbl.gov/?q=obXML)	*n/a*	*open*
Occupancy Profile ontology	*OWL, RDF/XML, CSV*	*Ontology for occupancy profile*	*BIMERR*	[*https://bimerr.iot.linkeddata.es/def/occupancy-profile*](https://bimerr.iot.linkeddata.es/def/occupancy-profile)	*n/a*	*open*
Brick Ontology	*OWL, RDF/XML, CSV*	*Ontology for physical and virtual assets in building*	*Brick Consortium, Inc.*	[*https://brickschema.org/ontology/*](https://brickschema.org/ontology/)	*n/a*	*open*
Building Topology Ontology (BOT)	*OWL, RDF/XML, CSV*	*Ontology for describing topological concepts of a building*	*W3C*	[*https://w3c-lbd-cg.github.io/bot/*](https://w3c-lbd-cg.github.io/bot/)	*n/a*	*open*
Smart Applications REFerence ontology (SAREF)	*OWL, RDF/XML, CSV*	*Ontology for Internet of Things*	*ETSI*	[*https://saref.etsi.org/core/v3.1.1/*](https://saref.etsi.org/core/v3.1.1/)	*n/a*	*open*
ifcOWL ontology	*OWL, RDF/XML*	*Ontology for Building*	*Building Smart*	*https://standards.buildingsmart.org/IFC/DEV/IFC4/A*	*n/a*	*open*

	, CSV	*Information Modeling*	*International*	[DD2_TC1/OWL/index.html]()		
IEA-EBC Annex 66		*Ontology for occupant behavior*	*EBC*	[https://annex66.org/]()	*n/a*	*open*
Building Ontology	*OWL, RDF/XML, CSV*	*Ontology for representing main topological relationships that exists between entities in the building domain*	*BIMERR*	[https://bimerr.iot.linkeddata.es/def/building/]()	*n/a*	*open*
Digital Construction Ontologies		*Ontology for providing the essential concepts and properties of construction and renovation projects*	*Torma and Zheng*	[https://digitalconstruction.github.io/v/0.3/index.html]()	*n/a*	*open*
Time Ontology in OWL		*Ontology to contextualize time measurement and time instant*	*W3C*	[https://www.w3.org/TR/owl-time/]()	*n/a*	*open*
Semantic Sensor Network (SSN)		*Ontology for describing sensors and their observations, involved procedures*	*W3C*	[https://www.w3.org/TR/vocab-ssn/]()	*n/a*	*open*
Calidad-Aire (Air Quality Ontology)	*OWL, RDF/XML, CSV*	*Ontology for the description of air quality data in a city.*	*Lafuente and Corcho*	[http://vocab.linkeddata.es/datosabiertos/def/medio-ambiente/calidad-aire/index-en.html]()	*n/a*	*open*
W3C Geospatial Ontologies		*ontology to represent geospatial concepts and properties*	*W3C*	[https://www.w3.org/2005/Incubator/geo/XGR-geo-ont-20071023/]()	*n/a*	*open*

IX. References

[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

[3] ASHRAE Terminology. “indoor environment quality (IEQ)”, available at

https://xp20.ashrae.org/terminology/index.php?term=indoor%20environment%20quality%20(IEQ)
[4] Luo, Maohui, Zhe Wang, Kevin Ke, Bin Cao, Yongchao Zhai, and Xiang Zhou. "Human metabolic rate and thermal comfort in buildings: The problem and challenge." Building and Environment 131 (2018): 44-52.
[5] Hasson, Rebecca E., Cheryl A. Howe, Bryce L. Jones, and Patty S. Freedson. "Accuracy of four resting metabolic rate prediction equations: effects of sex, body mass index, age, and race/ethnicity." Journal of Science and Medicine in Sport 14, no. 4 (2011): 344-351.