Ontology Engineering 2022
Assignment 3

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 an office
Requirements	Recommendations must take into account the temperature, humidity, luminosity, daylight, climate, building location/direction, window/door/window blinds, occupants' demographic, occupants' metabolic rate, thermostat settings of HVAC
Scope	The Scope of this use case is limited to a small office room that two to four people can use not only in the United States, but also other countries under different climates. The target population of this application is for individuals who regularly work in the offices. This use case is designed for office users or facility managers, and the language must be understandable to laypeople.
Priority	n/a
Stakeholders	Stakeholders include office occupants, facility managers, and building owners.
Description	According to reports written by U.S. Energy Information Administration, commercial building and residential building consumes 93% of electric energy in end-use section in 2021*, and 46.2% of primary energy use in the buildings is heating, cooling, ventilation, and lighting in 2014**. This energy is used for enhancing Indoor Environmental Quality (IEQ). In a room, IEQ is affected by many factors: temperature, humidity, air flow, air quality, luminosity, clothing, human activity, or occupant profile. The problem is that each building is under different environmental condition including weather, outdoor air quality, direction/location of building, etc., and each occupant has different clothing, occupant profile, and metabolic rate. Furthermore, potential solutions — air conditioner, electric heater, window blinds, window, door, fan, etc. — have an influence on IEQ in different ways. For instance, an air conditioner and a fan cool temperature down; however, the fan doesn't affect humidity unlike the air conditioner. Additionally, they consume different amount 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 and minimize energy use in an office by combining several sets of knowledge 1) thermal comfort based on temperature, humidity, air speed, metabolic rate, and clothing level, 2) occupancy behavior for IEQ, 3) indoor air quality, 4) interior illumination level. *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 **US Energy Information Administration. "Quadrennial Technology Review 2015", available at

	https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf
Actors / Interfaces	The primary actor for this use case is in an office who want to occupants 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 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 an office, or sensor data should be prepared.
Post-conditions	Any changes in user profile or properties of building elements — which is 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 office, and gets a recommendation.

III. Usage Scenarios

1. An office worker in San Diego, California, usually works in a huge 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. 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 are the optimal temperature & humidity for them.

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	Visualizes thermal comfort/discomfort zones on the 3D model
4	User		Clicks the thermal comfort zone and get recommendation how to improve IEQ
5		App	Finds a 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.

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 datasets 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 start 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

VI. Use Case and Activity Diagram(s)

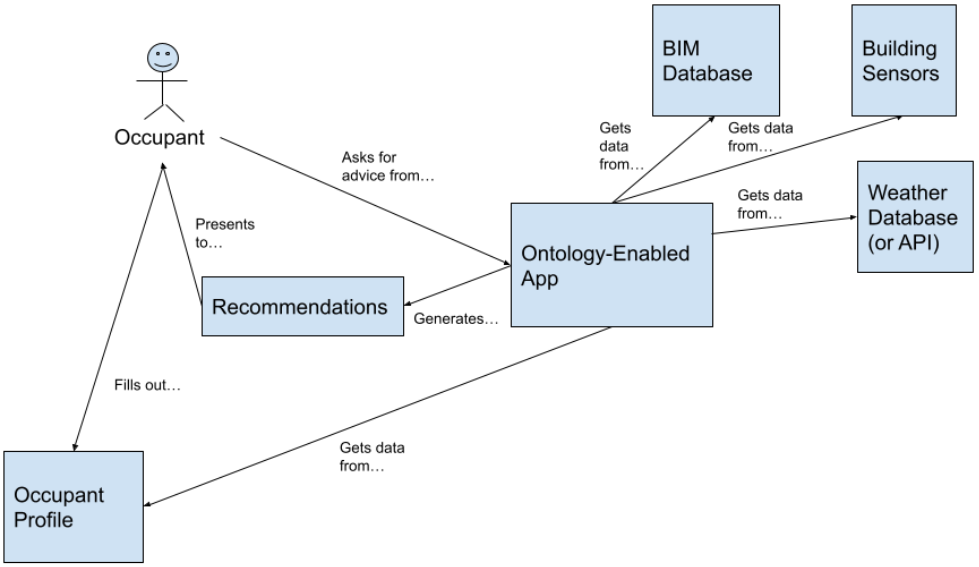

Figure 1: Use Case Diagram

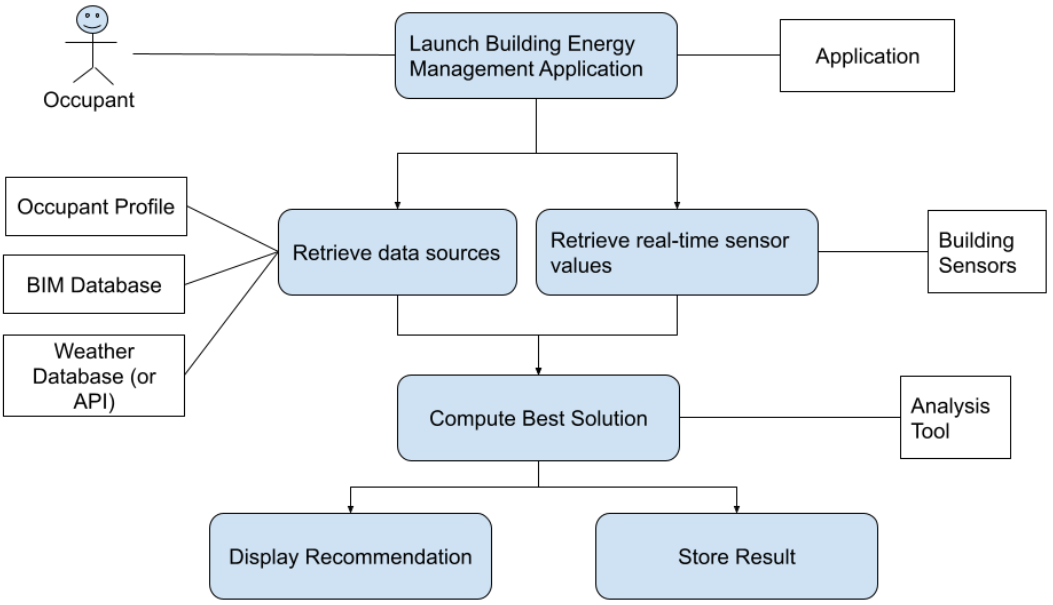

Figure 2: Activity Flow Diagram (Single User)

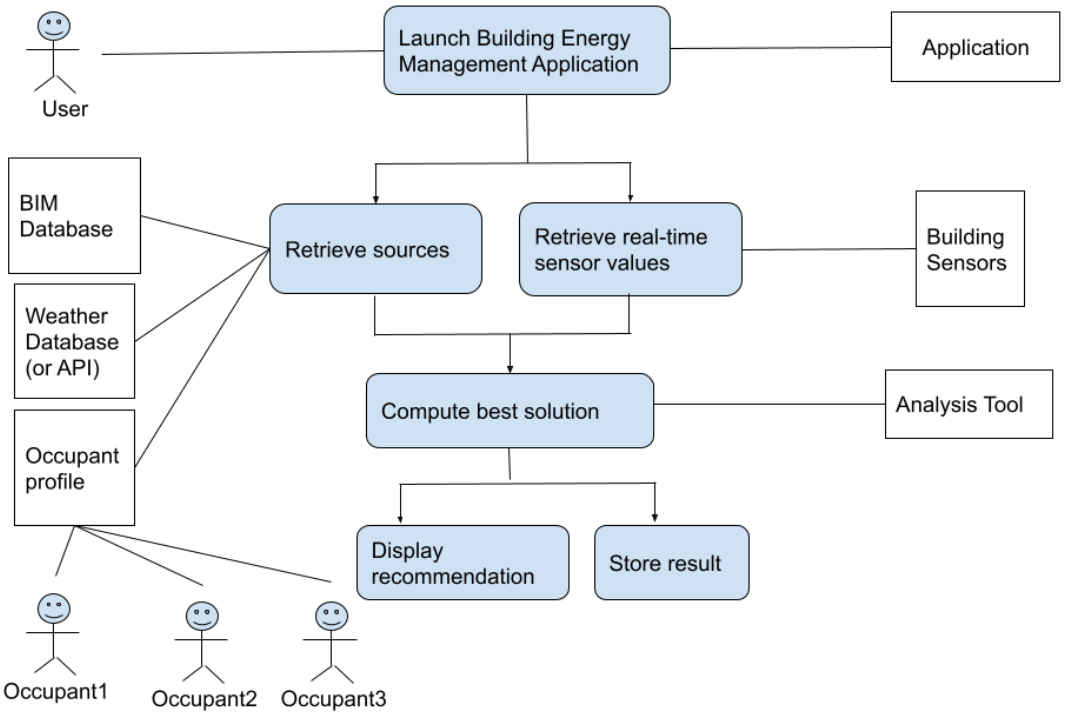

Figure 3: Activity Flow Diagram (Multiple Users)

VII. Competency Questions

1. **Question:** Which solution is relevant to improve indoor environmental quality and make an occupant feel comfortable? The outdoor air temperature is 86°F, the humidity is 83%, daylight is 110,000 lux, and the outdoor air quality index is 273, 'Bad'. The corridor temperature is 74°F.

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

   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, 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.

2. **.Question:** What IEQ parameters, such as temperature, humidity, airflow, etc., make the multiple occupants feel comfortable in an office room? The occupants' profile is a 22-year-old male, 53-year-old female, and 42-year-old male. The outdoor weather is 18°F. The current thermostat setting is 75°F.

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

   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, 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.

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*			*ASHRAE*	*https://github.com/CenterForTheBuiltEnvironment/ashrae-db-II*	*open*
ASHRAE Global Occupant Behavior Database	*Downloadable in multiple formats*			*ASHRAE*	*https://ashraeobdatabase.com/#/*	*open*
flEECe, an Energy Use and Occupant Behavior Dataset for Net Zero Energy Affordable Senior Residential Buildings	*Downloadable in multiple formats*			*Frederick Paige, Philip Agee*	*https://osf.io/2ax9d/*	*open*
ROBOD, Room-level Occupancy and Building Operation Dataset	*Downloadable in multiple formats*			*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*			*Nikdel et al.*	*https://data.mendeley.com/datasets/hx5mp695tv/1*	*open*
ECO data set (Electricity Consumption & Occupancy)	*Downloadable in multiple formats*			*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*			*Liu et al.*	https://zenodo.org/record/996587	*open*
Fitness-gym and Living-room Occupancy Estimation Data	*Downloadable in multiple formats*			*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*	*n/a*	*open*
Occupancy Profile ontology	*OWL, RDF/XML, CSV*	*Ontology for occupancy profile*	*BIMERR*	*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/*	*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/*	*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/*	*n/a*	*open*
ifcOWL ontology	*OWL, RDF/XML, CSV*	*Ontology for Building Information Modeling*	*Building Smart International*	*https://standards.buildingsmart.org/IFC/DEV/IFC4/ADD2_TC1/OWL/index.html*	*n/a*	*open*
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*	*BIMERR*	https://bimerr.iot.linkeddata.es/def/building/	*n/a*	*open*

		entities in the building domain				
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*