# IEQ Management System for Building Energy

Jihoon Chung, Gabriel Jacoby-Cooper, Kelsey Rook

# 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[2]. 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

**Question:** *Which solution to improve indoor environmental quality and make an occupant feel comfortable uses the least amount of energy in their room?* 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℉
- Configurable equipment: window blinds, ceiling fan, air conditioning unit
- Power consumption of air conditioner: 530W
- Power consumption of fan: 48W

**Terms used from Ontology:** room, Indoor Environmental Quality, indoor, outdoor, air temperature, relative humidity, air speed, air quality, daylight, air quality index, air-conditioner, window blinds, energy

## Semantic Processes Involved:

(1) In the knowledge graph, loading BIM database, weather data, real-time sensor values including air temperature, relative humidity, airflow, air quality, etc., (2) Calculating an occupant's thermal comfort zone based on users' input data, and the loaded data, (3) *Reasoning to check a viable solutions how to change IEQ parameters*, such as pulling up/down blinds, opening/closing door, window, turning on/off the air conditioner, fan, electric heater, etc., (4) Suggesting an optimal solution to improve IEQ using minimal energy

**Usage scenario covered:** An occupant in his/her room, who feels discomfort and wants to find an optimal solution to enhance IEQ using minimal energy

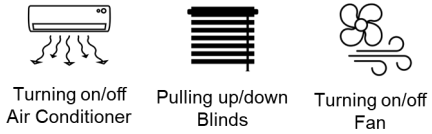
# Competency Question

## Description/Description + Ontology Usage:

Based on users' input data, the system would load BIM/weather/sensor data. *The ontology would be leveraged to find out how to improve IEQ by changing indoor environmental parameters.* For example, if the current air temperature is too hot for the user, it could be improved by decreasing air temperature. *Then, reasoning could be applied to identify which room components can be used to change the parameters.* For example, opening the window can be one of the viable solutions because it can decrease air temperature if the outdoor air temperature is lower than the indoor temperature.*Based on the information on power consumption for the components, the system could suggest the room component that consumes the least energy.*

**Sample Answer from Ontology:** Pull down blinds to block the sunlight and turn on a fan.

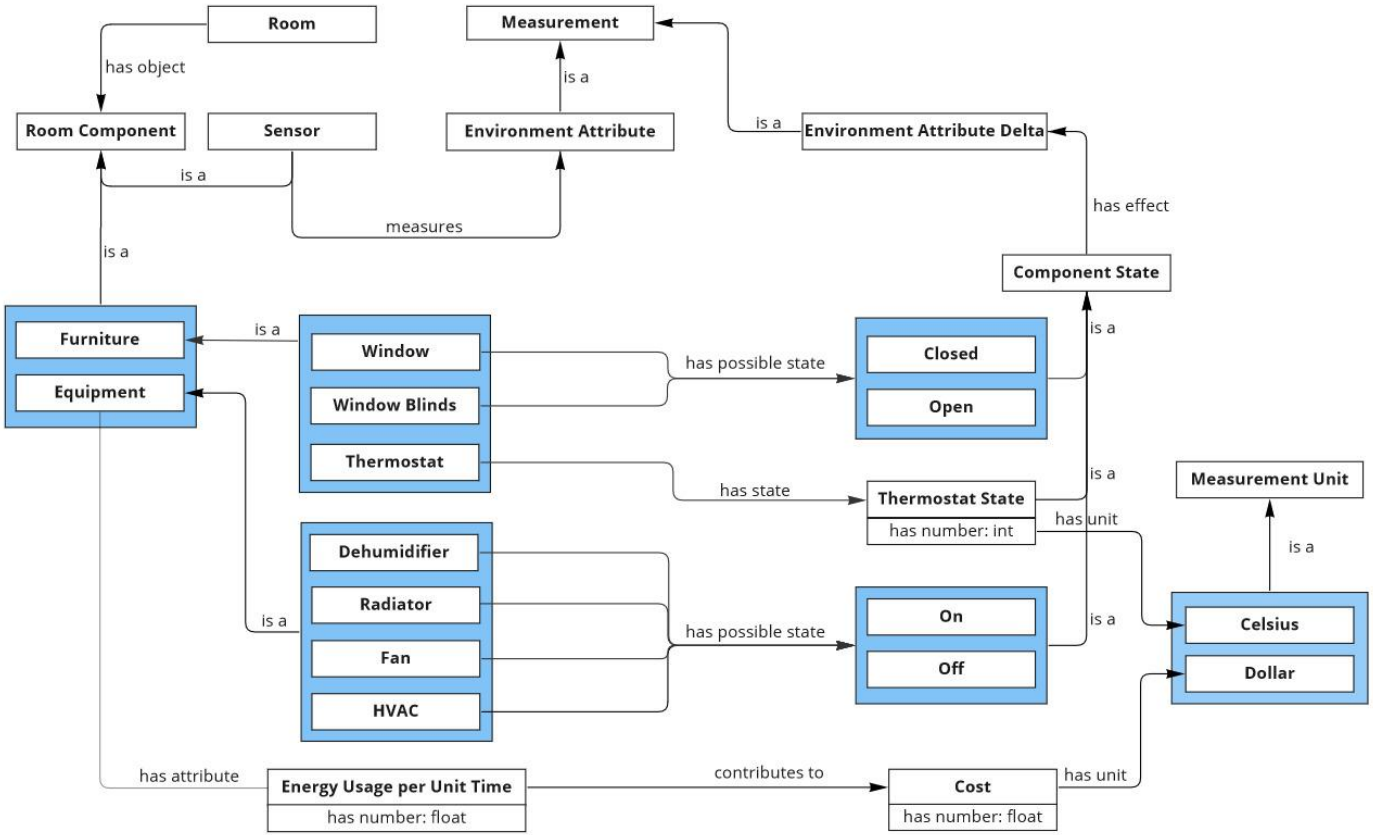
## Potential Solutions:



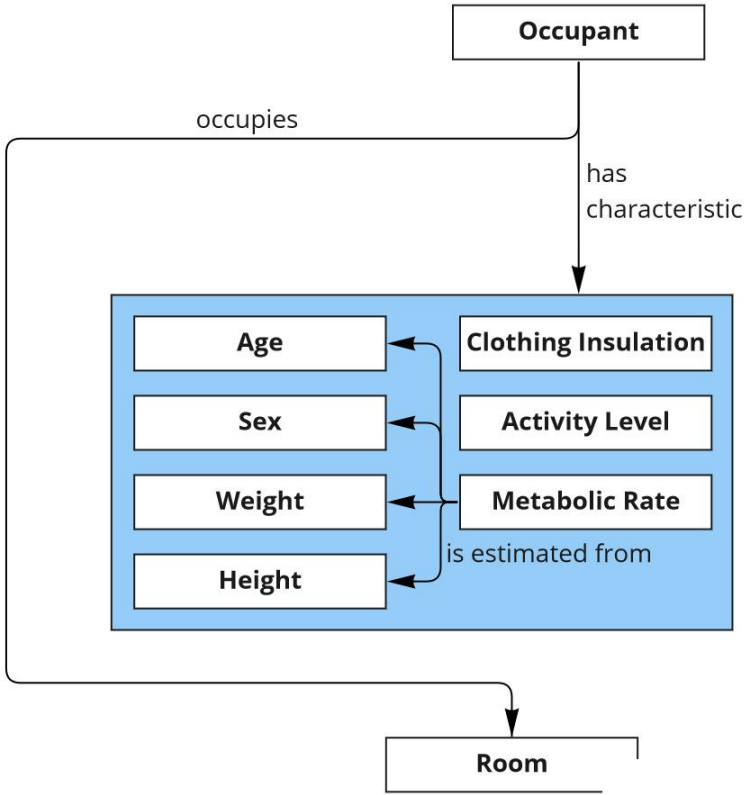

## Reasoning:

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.

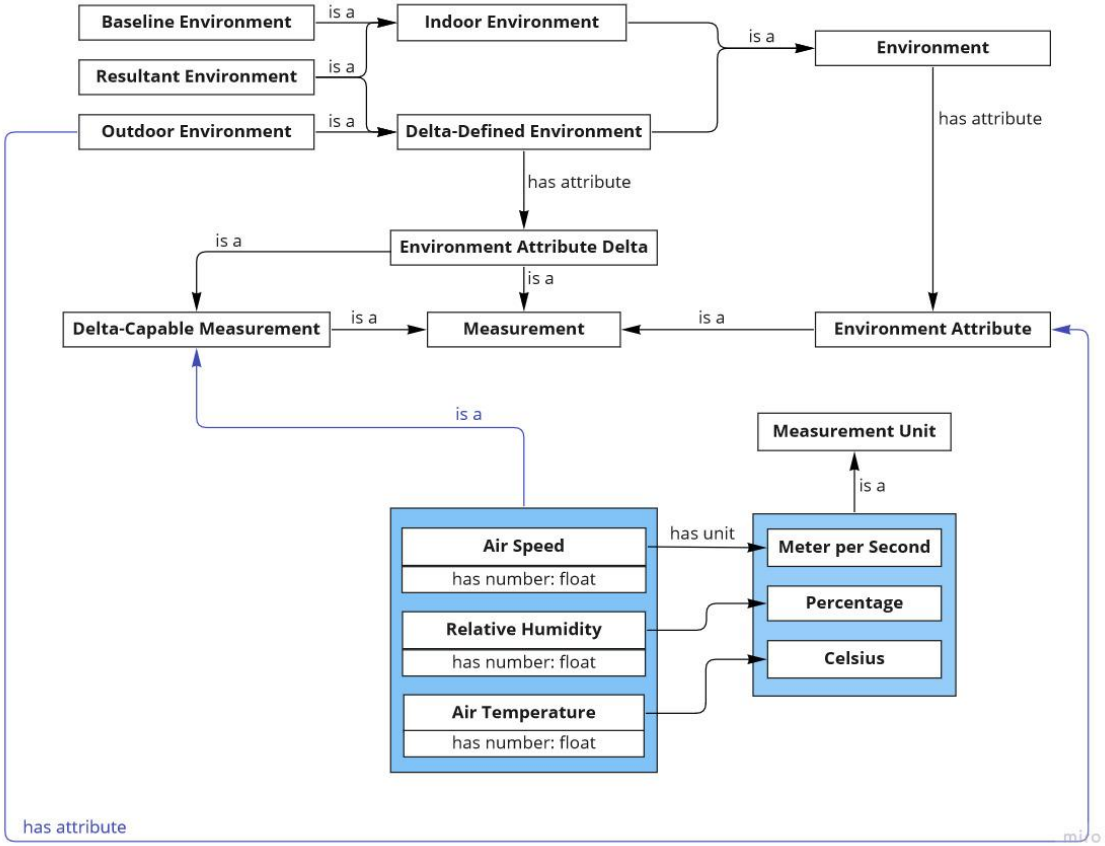
# Conceptual Model: Room and Components



# Conceptual Model: Occupant



# Conceptual Model: Environment and Attributes



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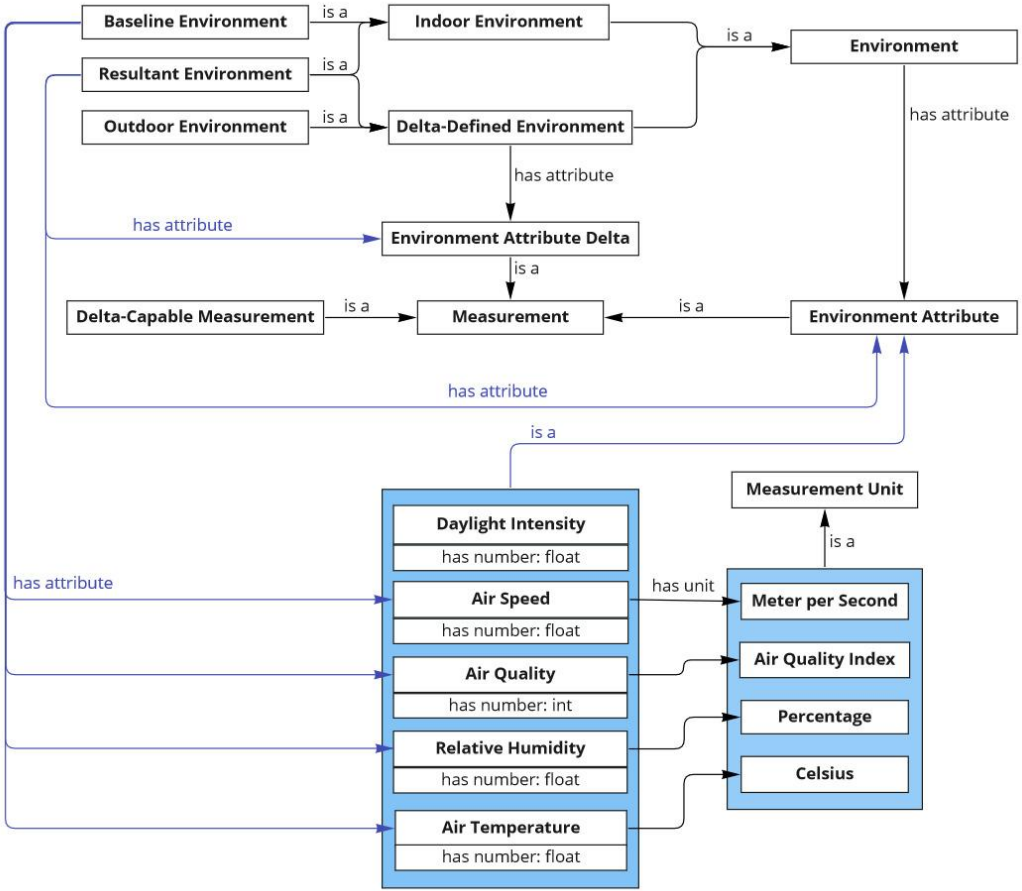

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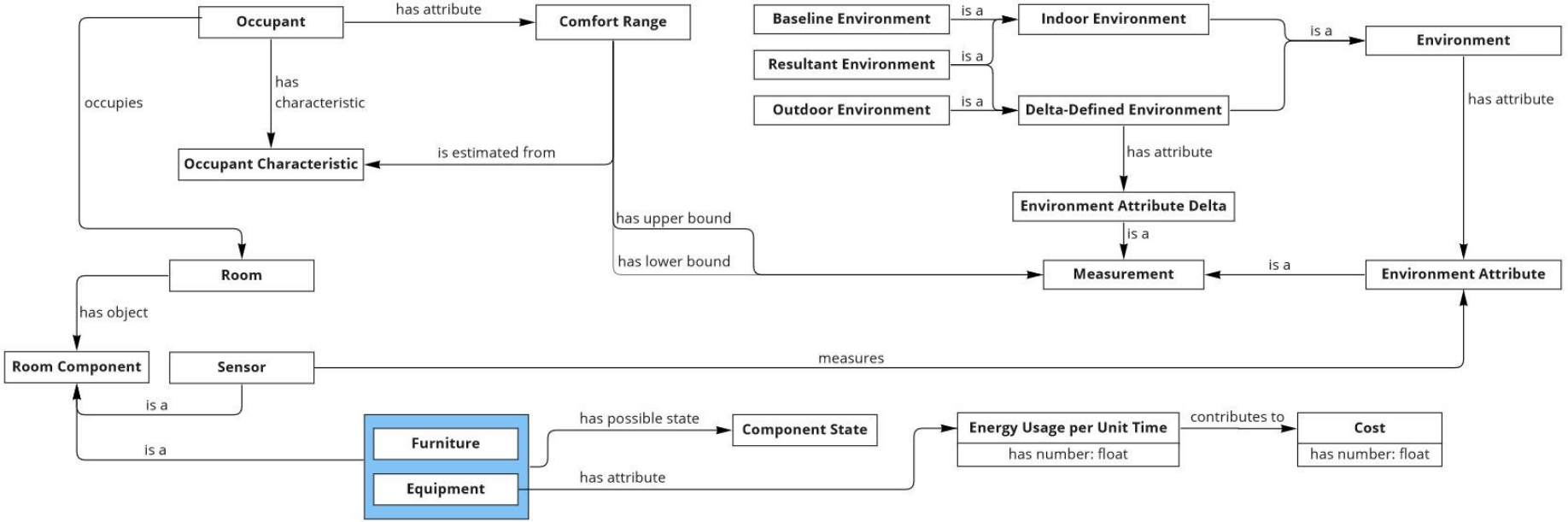

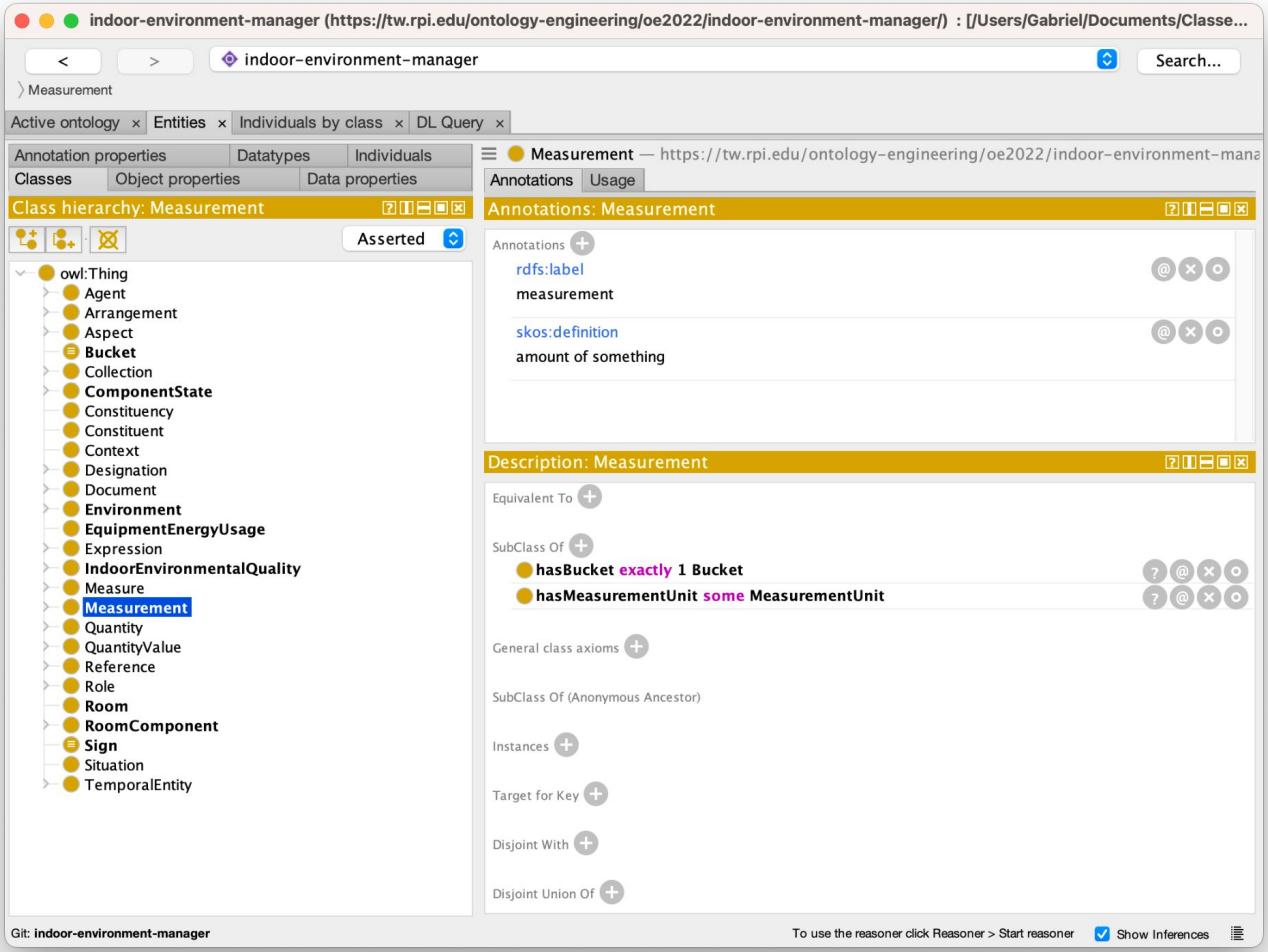
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indoor-environment-manager
Search...
Measurement
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Individuals by class
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Class hierarchy: Measurement
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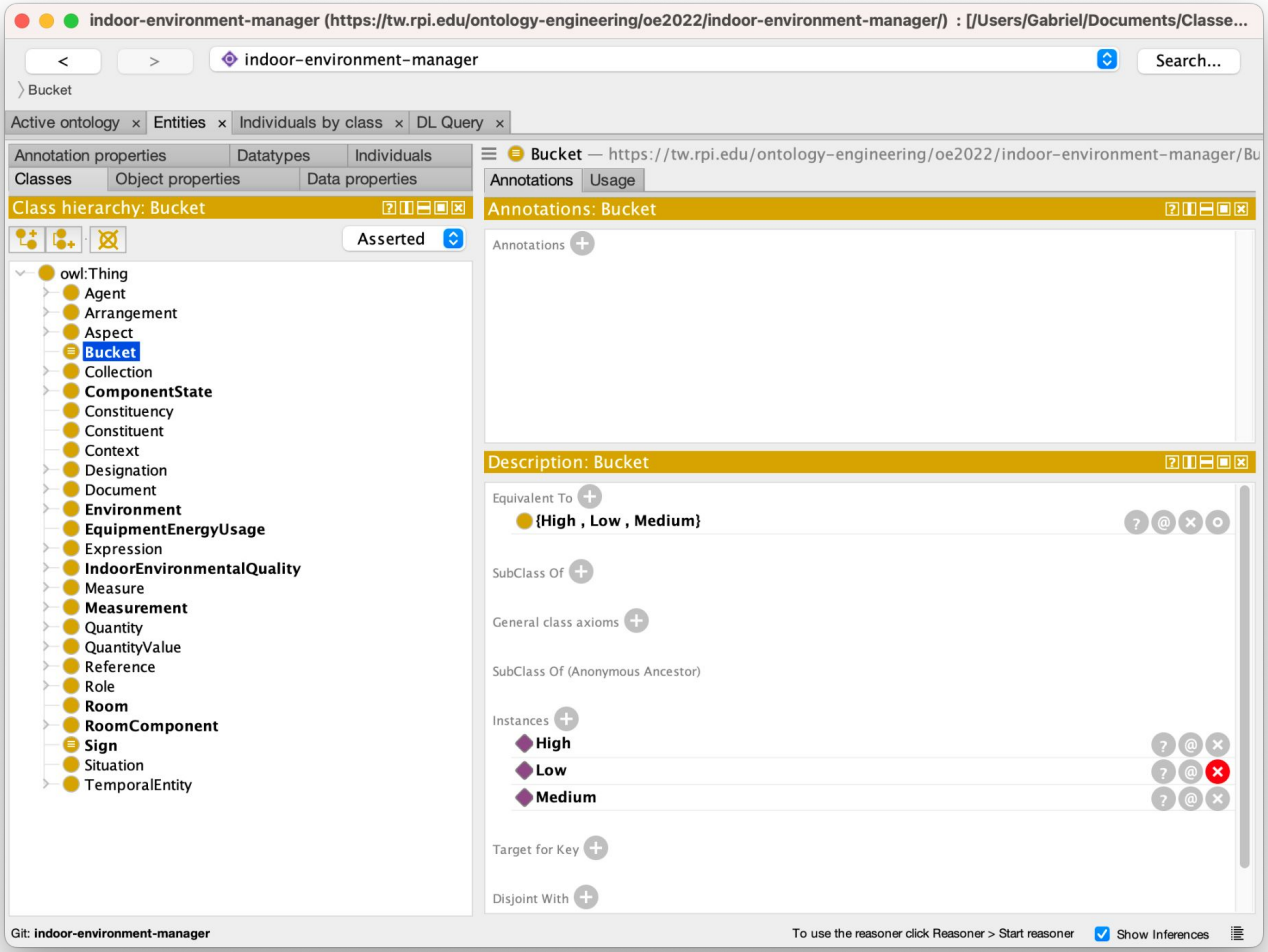
skos:definition
amount of something
Description: Measurement
Equivalent To
SubClass Of
hasBucket exactly 1 Bucket
hasMeasurementUnit some MeasurementUnit
General class axioms
SubClass Of (Anonymous Ancestor)
Instances
Target for Key
Disjoint With
Disjoint Union Of
Git: indoor-environment-manager
To use the reasoner click Reasoner > Start reasoner
Show Inferences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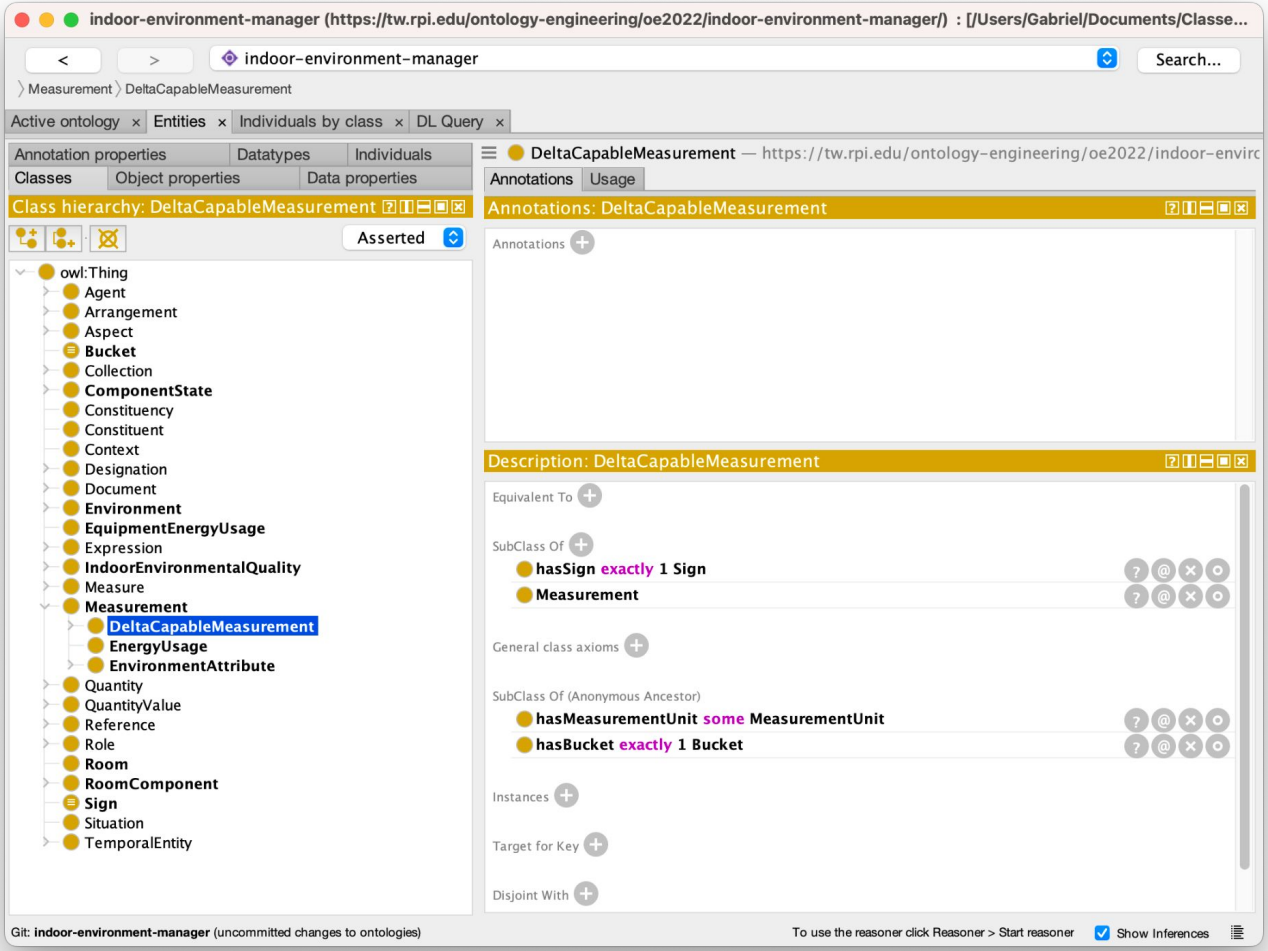
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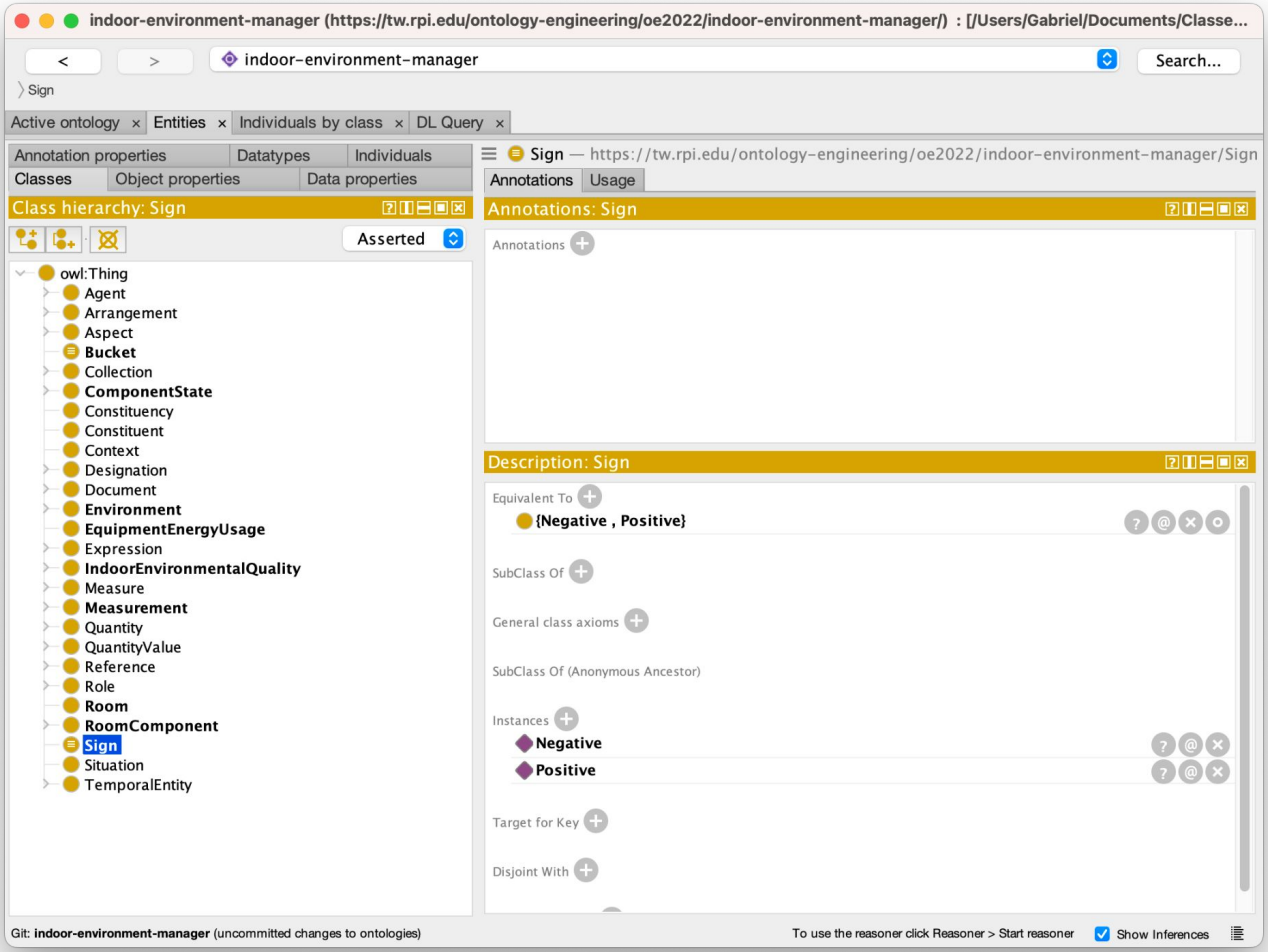
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# Sample Question

- “What action produces a resultant indoor environment that has a ‘medium negative’ temperature delta from the current indoor environment?”
  - There’s a currently closed window in the room.
  - The current outdoor environment has a “medium negative” temperature delta from the current indoor environment.
  - Opening a window produces a resultant indoor environment with the same qualitative temperature delta from the current indoor environment as the current outdoor environment.
    - (Note that the numeric range of an indoor-outdoor temperature delta is different from that of an indoor-indoor temperature delta, even when they share the same qualitative bucket.)
  - Therefore, opening the window will produce a resultant indoor environment that has a “medium negative” temperature delta from the current indoor environment.

# Description Logic Constructs

- **Enumerations**
  - Bucket ≡ {High, Low, Medium}
  - Sign ≡ {Negative, Positive}
- **Intersections**
  - EnvironmentAttributeDelta ≡ DeltaCapableMeasurement ⊓ EnvironmentAttribute
- **The Kitchen Sink** (for-all, union, & negation!)
  - DeltaDefinedEnvironment: ∀ hasAttribute.(EnvironmentAttributeDelta ⊔ ¬EnvironmentAttribute)

# What We've Done

- Modeled environments
- Modeled qualitative buckets
- Discussed "bucket math"
  - For example, what's the "sum" of three "low" buckets?

# What We Haven’t Yet Done

- Defined numeric bucket ranges
- Implemented “bucket math”
  - *49* different mappings for best-case/worst-case analysis!
- Connected room objects and sensors to measurements