Ontology Engineering 2022
Assignment 6

Use-Case Driven Knowledge Encoding Part 2

I. Use Case Description	
Use Case Name	IEQ Management System for Building Energy
Point of Contact	Jihoon Chung, Gabriel Jacoby-Cooper, Kelsey Rook
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, 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 (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.
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 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), which refers to a perceived experience of the building's indoor environment including thermal comfort, indoor air quality, acoustics, and control systems [3]. In a room, IEQ is affected by many factors: air temperature, mean radiant

	temperature, relative humidity, airflow, air quality, 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 (at least in the right external conditions, which can be broadly considered in the knowledge base and the ontology by integrating weather API data); 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 air temperature, mean radiant temperature, humidity, air speed, and clothing level, 2) occupancy behavior for IEQ, 3) indoor air quality A user will inform the IEQ management system of what quantifiable IEQ factors — thermal comfort and air quality — 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. Alternatively, to quantify IEQ, the application can use the Predicted Mean Vote (PMV) model and Air Quality Index (AQI) established by the US EPA. For the calculation, the PMV index requires air temperature, mean radiant temperature, air speed, relative humidity, clothing level, and metabolic rate [6-7]; the metabolic rate requires activity intensity, age, sex, height, and weight [8]; the AQI requires concentration of ozone (O3), particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO2), and nitrogen dioxide (NO2) [9]. The user can manually enter their desired temperature and humidity ranges, or the system can infer them through the PMV model based on sensor data as well as other information that the user provides, including clothing descriptions. As solutions to improve IEQ, several types of equipment affect thermal comfort in different ways: 1) fan increase air speed, 2) electric heater increase mean radiant temperature, 3) dehumidifier decrease humidity, 4) air conditioner increase or decrease air temperature, and 5) window blinds decrease mean radiant temperature.
Actors / Interfaces	The primary actors for this use case are occupants in a room who want to understand indoor environmental quality in the space and to improve his/her thermal comfort by changing thermostat settings, opening/closing windows, pulling up/down blinds, *etc.* Also, a facility manager can be the primary actor who wants to minimize energy consumption in a building and keep thermal comfort simultaneously. Other potential actors include users' profiles, building owners, weather APIs, Building Information Modeling (BIM) databases, demographic databases, wireless sensors, HVAC systems, windows, equipment, and existing ontologies. Such existing ontologies include the Occupancy Behavior Ontology (obXML), the Building Topology Ontology (BOT), the Building Information Ontology (ifcOWL), the Smart Appliances Reference Ontology (SAREF), the Semantic Sensor Network Ontology (SSN), the Air Quality Ontology (Calidad-Aire), the Quantities, Units, Dimensions, and Types (QUDT) ontology, and the Time Measurement Ontology (OWL-Time).

Pre-conditions	Physical sensors should be preinstalled in a room, or sensor data should be prepared. Additionally, building information and weather 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, *etc.* — should be updated
Triggers	The primary trigger for this use case is that the user launches the application, analyzes IEQ in the room, 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. The system shows a simulation result of how this solution can consume lower electricity compared to turning on the air conditioner. (Turning on the A/C would also negatively affect indoor air quality given the fact that the outdoor air quality is already "bad"). In this scenario, the office worker's IEQ comfort range is computed outside of the ontology based on contextual information (such as clothing descriptions) that she supplies.
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 perfectly satisfy all occupants' individual comfort zones, so the system falls back on energy use as a ranking factor.
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 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,
3		App	weather data, pre-registered demographic employees' data
4	User		Enters their thermal comfort zone and gets 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 windows, 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		Enters information about age, activity level, and clothing, which lets the application compute an estimated thermal comfort range automatically. Gets recommendations on 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 are 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)

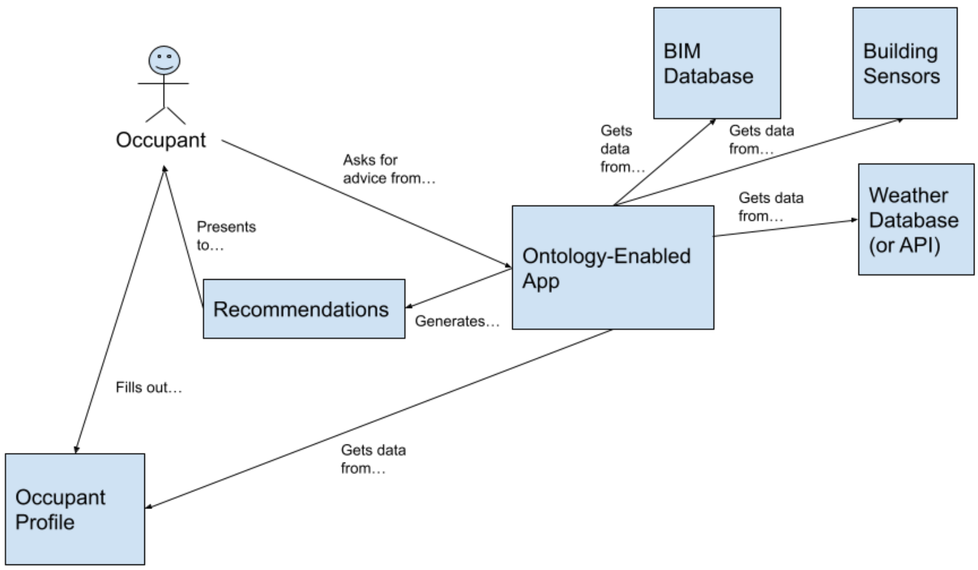


Figure 1: Use Case Diagram

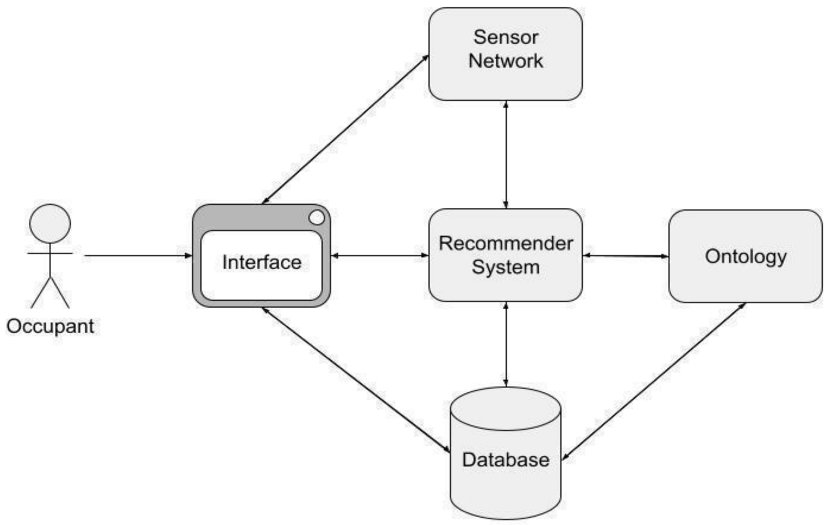


Figure 2: System Architecture

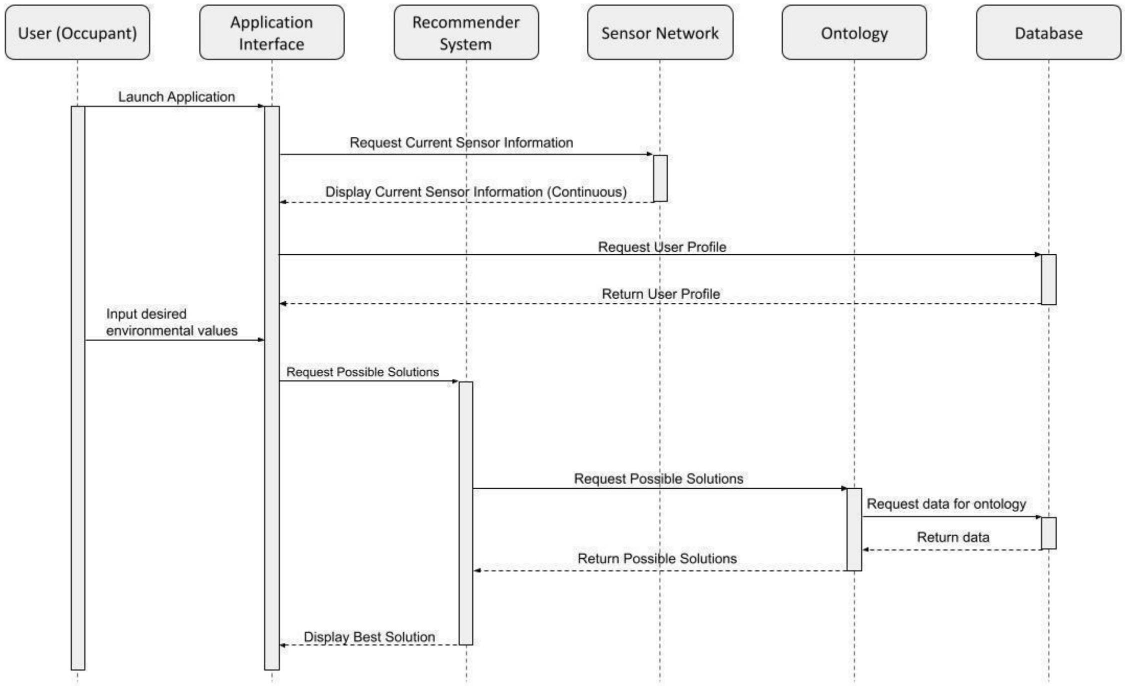


Figure 3: Activity Flow Diagram (Normal Flow)

VII. Competency Questions

1. **Question:** Which solution to improve indoor environmental quality and make an occupant feel comfortable uses the least amount of energy 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.
   Sample Answer from Ontology: Pull down blinds to block the sunlight and turn on a fan.
   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, the loaded data, and the PMV equation (see Appendix A, Appendix B, Appendix C, and Appendix D and Appendix B), (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

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.

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.

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.

Sample Answer from Ontology: Keep the thermostat setting at 75°F.

Terms used from Ontology: room, Indoor Environmental Quality, indoor, outdoor, air temperature, relative humidity, air speed, air quality, daylight, air quality index, air-conditioner, thermostat, electric heater, 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, the loaded data, and the PMV equation (see Appendix A, Appendix B, Appendix C, and Appendix D and Appendix B), (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: Three occupants in an office room, who are already comfortable

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. In this case, the current air temperature meets the three occupants' temperature preferences, and IEQ parameters don't need to be changed. Then, the system suggests to keep the thermostat setting, and the reasoning process is terminated.

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, air speed, 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 Figure 4), 59-year-old female Megan (height: 5' 8", weight: 136 lbs, wearing Trousers, long sleeve-shirt: 0.61 clo, the grey area in Figure 4), 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 Figure 4). 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, and an electric heater is available

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

Terms used from Ontology: room, Indoor Environmental Quality, indoor, outdoor, air temperature, relative humidity, air speed, air quality, occupant profile, age, sex, height, weight, clothing insulation, metabolic rate, air-conditioner, electric heater

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, the loaded data, and the PMV equation (see Appendix A, Appendix B, Appendix C, and Appendix D and Appendix B), (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: Three occupants in an office room, who are doing same activity, feel discomfort and want to find an optimal solution to enhance IEQ using minimal energy

Description/Description + Ontology Usage: Based on users' input data, the system would load BIM/weather/sensor data, and the PMV equation, the current PMV value, and lower and upper bound of the comfort zone can be calculated for the three occupants. The ontology would be leveraged to find out how to improve IEQ by changing indoor environmental parameters. For example, PMV value is too low, and it can be improved by increasing air temperature or relative humidity, or decreasing air speed. Then, reasoning could be applied to identify which room components can be viable to change the parameters. For example, an electric heater can be one of the viable solutions because it only increases air temperature. Based on the information on power consumption for the components, the system could suggest the room component that consumes the least energy.

Reasoning: The current indoor air temperature and relative humidity (the red dot in Figure 4) are out of the three people's comfort zones (the blue, grey, and purple area in Figure 4). 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 Figure 5.

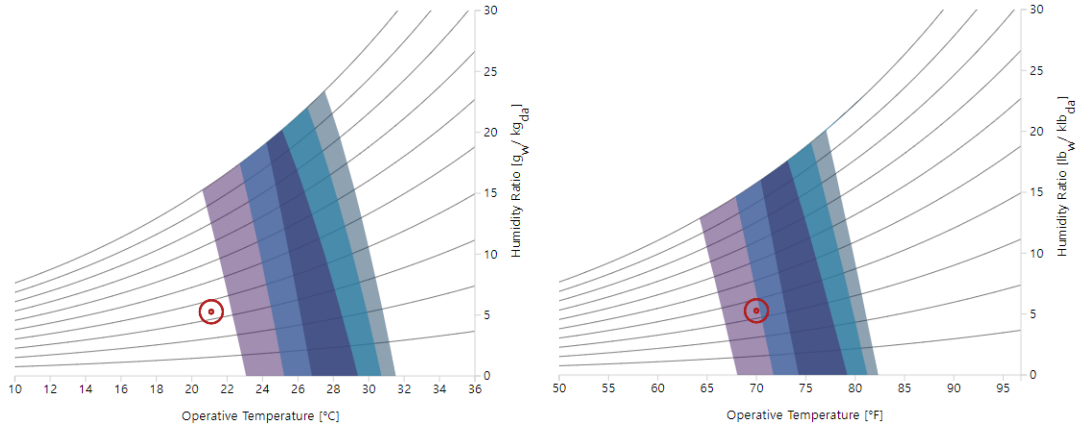


Figure 4: Psychrometric Chart before Closing Windows (left, air-speed: 0.8m/s) and after Closing Windows (right, air-speed: 0.1m/s)

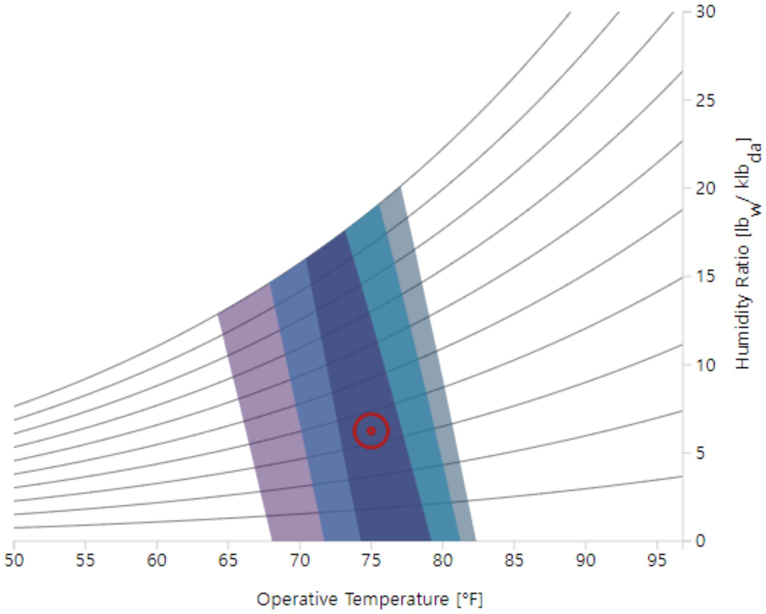


Figure 5: Psychrometric Chart before turning on equipment (left, air-speed: 0.1m/s, air temperature: 70°F) and after turning on (right, air-speed: 0.1m/s, air temperature: 75°F)

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, Long-sleeve coveralls, t-shirt: 0.72 clo, the blue area in Figure 6), a 59-year-old mother dancing (metabolic rate: 3.4,

Long-sleeve coveralls, t-shirt: 0.72 clo, the grey area in Figure 6), and a 32-year-old daughter cleaning the house (metabolic rate: 2.7, Long-sleeve coveralls, t-shirt: 0.72 clo, the purple area in Figure 6). 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.

Sample Answer from Ontology: Close the window and turned on the fan and dehumidifier

Terms used from Ontology: room, Indoor Environmental Quality, indoor, outdoor, air temperature, relative humidity, air speed, air quality, occupant profile, age, sex, height, weight, clothing insulation, metabolic rate, air-conditioner, fan, dehumidifier, power consumption

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, the loaded data, and the PMV equation (see Appendix A, Appendix B, Appendix C, and Appendix D and Appendix B), (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: Three occupants in a living room, who are doing different activities. Only one person feels comfortable, and they want to find an optimal solution to enhance IEQ using minimal energy

Description/Description + Ontology Usage: Based on users' input data, the system would load BIM/weather/sensor data, and the PMV equation, the current PMV value, and lower and upper bound of the comfort zone can be calculated for the three occupants. The ontology would be leveraged to find out how to improve IEQ by changing indoor environmental parameters. For example, PMV value is too low, and it can be improved by increasing air temperature or relative humidity, or decreasing air speed. Then, reasoning could be applied to identify which room components can be viable to change the parameters. In this example, an electric heater can be one of the viable solutions because it only increases air temperature. Based on the information on power consumption for the components, the system could suggest the room component that consumes the least energy.

Reasoning: Window sensors show that the windows are opened; but, they should be closed due to low outdoor air quality. 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 Figure 6) are only in the son's comfort zone (the blue area in Figure 6). 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 Figure 6. 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.

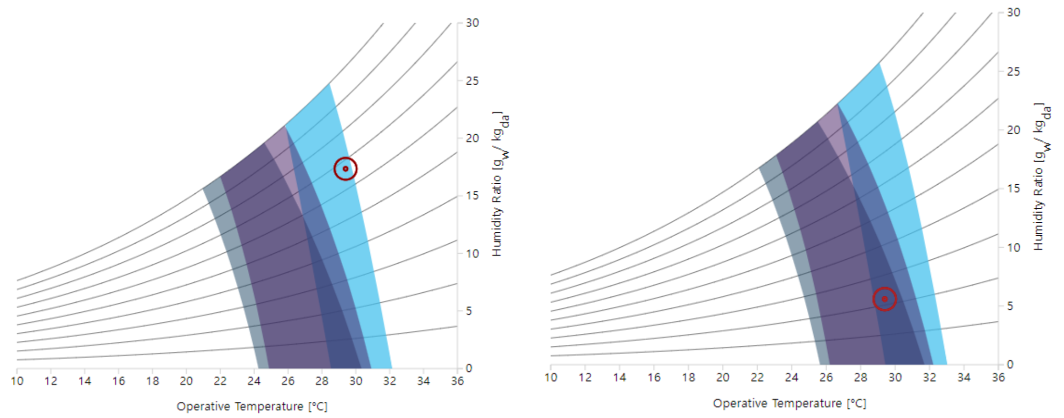


Figure 6: Psychrometric Chart before turning on equipment (left, air-speed: 0.8m/s, relative humidity: 67%) and after turning on (right, air-speed: 1.5m/s, relative humidity: 22%)

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 Figure 7), 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 Figure 7), 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 Figure 7). 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. An air conditioner (power consumption: 1350W) and floor fan (power consumption: 48W) are available.

   Sample Answer from Ontology: Opened windows and turn on a floor fan

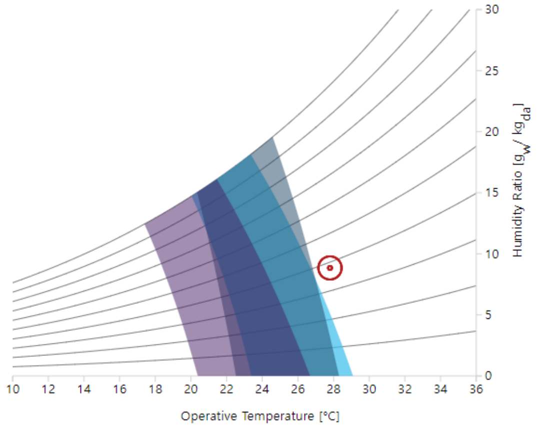
   Terms used from Ontology: room, Indoor Environmental Quality, indoor, outdoor, air temperature, relative humidity, air speed, air quality, occupant profile, age, sex, height, weight, clothing insulation, metabolic rate, air-conditioner, fan, power consumption

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, the loaded data, and the PMV equation (see Appendix A, Appendix B, Appendix C, and Appendix D and Appendix B), (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: Three occupants in a gym, who are doing different activities, feel discomfort and want to find an optimal solution to enhance IEQ using minimal energy

Description/Description + Ontology Usage: Based on users' input data, the system loads BIM/weather/sensor data, and the PMV equation, the current PMV value, and lower and upper bound of the comfort zone can be calculated for the three occupants. The ontology would be leveraged to find out how to improve IEQ by changing indoor environmental parameters. For example, if the PMV value is too low, it can be improved by increasing air temperature or relative humidity, or decreasing air speed. Then, reasoning could be applied to identify which room components can be used to change the parameters. For example, an electric heater can be one of the viable solutions because it only increases air temperature. Based on the information on power consumption for the components, the system could suggest the room component that consumes the least energy.

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 Figure 7 and Figure 8, the purple areas represent Sarah's comfort zones, and the current air temperature and relative humidity (the red dot in Figure 7) are out of Sarah's comfort zones (the purple area in Figure 7). 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.



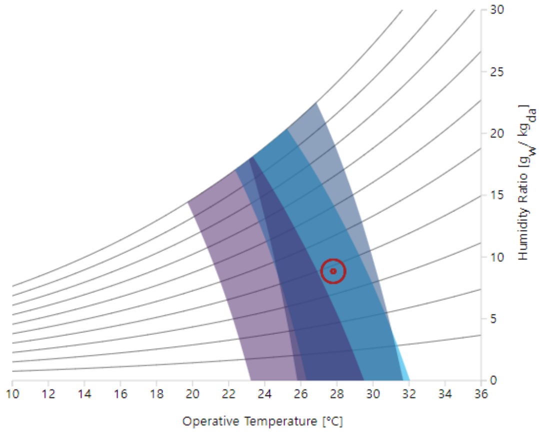


Figure 7: Psychrometric Chart before Opening Windows (left, air-speed: 0.1m/s) and after Opening Windows (right, air-speed: 0.9m/s)

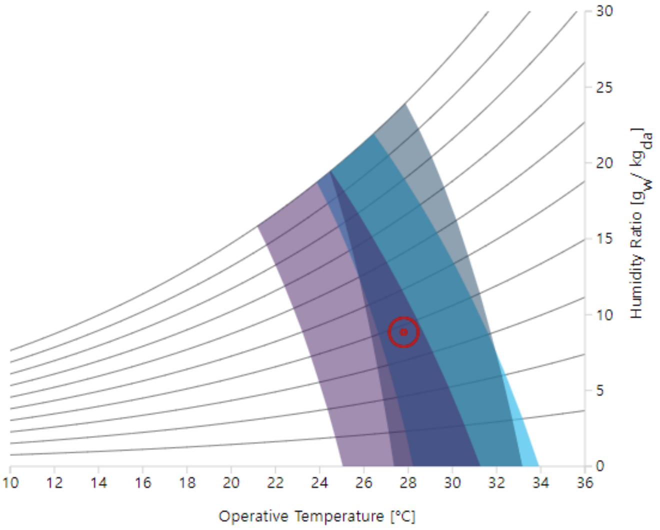


Figure 8: Psychrometric Chart after Opening Windows and Air-Speed is 2m/s

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 buildings*	*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/#/*	*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/*	*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 occupants' 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 commercial office building spanning 9 months and covering room-level occupancy for three different spaces*	*Liu et al.*	https://zenodo.org/record/996587	*open*
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*
CBE Thermal Comfort Tool for ASHRAE-55 - GitHub	*Github Repository*		*A web interface for comfort model calculations and visualizations according to ASHRAE Standard-55, EN Standard 16798 and ISO Standard 7730.*	*Tartarini et al.*	*https://github.com/CenterForTheBuiltEnvironment/comfort_tool*	*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	*OWL, RDF/XML, CSV*	*Ontology for describing topological*	*W3C*	[*https://w3c-lbd-cg.github.io/bot/*](https://w3c-lbd-cg.github.io/bot/)	*n/a*	*open*

(BOT)		*concepts of a building*				
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 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		*ontology to represent*	*W3C*	https://www.w3.org/2005/Incubator/geo/XGR-geo-ont-2	*n/a*	*open*

Ontologie s		*geospatial concepts and properties*		0071023/		

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Appendix A. Equation of the Predicted Mean Vote (PMV) [7]

The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale (see Table 1), based on the heat balance of the human body. Thermal balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment.

Table 1: Seven-point thermal sensation scale

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

$$PMW = [0.303 \cdot exp(-0.036 \cdot M) + 0.028] \cdot$$
$$\left\{(M - W) - 3.05 \cdot 10^{-3} \cdot [5733 - 6.99 \cdot (M - W) - P_a] - 0.42 \cdot [(M - W) - 58.15]\right\}$$
$$\left\{- 1.7 \cdot 10^{-5} \cdot M \cdot (5867 - P_a) - 0.0014 \cdot M \cdot (34 - t_a)\right\}$$
$$\left\{- 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\underline{t_r} + 273)^4] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\right\} \quad (1)$$

$$t_{cl} = 35.7 - 0.028 \cdot (M - W)$$
$$- I_{cl} \cdot \left\{3.96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\underline{t_r} + 273)^4\right] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\right\} \quad (2)$$

$$h_c = \left\{2.38 \cdot \left|t_{cl} - t_a\right|^{0.25} for\ 2.38 \cdot \left|t_{cl} - t_a\right|^{0.25} > 12.1 \cdot \sqrt{v_{ar}}\right\}$$
$$or \left\{12.1 \cdot \sqrt{v_{ar}}\ for\ 2.38 \cdot \left|t_{cl} - t_a\right|^{0.25} < 12.1 \cdot \sqrt{v_{ar}}\right\} \quad (3)$$

$$f_{cl} = \left\{1.00 + 1.290 \cdot I_{cl}\ for\ I_{cl} \leq 0.078 m^2 \cdot K/W\right\}$$
$$or \left\{1.05 + 0.645 \cdot I_{cl}\ for\ I_{cl} > 0.078 m^2 \cdot K/W\right\} \quad (4)$$

where

M is the metabolic rate, in watts per square meter (W/m2);

W is the effective mechanical power, in watts per square meter (W/m2);

I_{cl} is the clothing insulation, in square metres kelvin per watt (m2 · K/W);

f_{cl} is the clothing surface area factor;

t_a is the air temperature, in degrees Celsius (°C);

$\underline{t_r}$ is the mean radiant temperature, in degrees Celsius (°C);

v_{ar} is the relative air velocity, in meters per second (m/s);

P_a is the water vapor partial pressure, in pascals (Pa);

h_c is the convective heat transfer coefficient, in watts per square meter kelvin [W/(m2 · K)];

f_{cl} is the clothing surface temperature, in degrees Celsius (°C).

Appendix B. Metabolism Estimation based on Age, Sex, Weight, and Height [8]

$$Basal\ Metabolic\ Rate\ (BMR)\ = (\frac{10m}{1Kg} + \frac{6.25h}{1cm} - \frac{0.5a}{1year} + s)\frac{Kcal}{day} \quad (5)$$

where

m is the mass of the body (in kilograms);

h is the height of the body in cm;

a is the age in years;

s is a factor relating to sex, $s = \{+\ 5\ for\ males\ or\ -\ 161\ for\ females\}$.

$$Estimated\ Energy\ Requirement\ (EER)\ =$$

$$\{864 - 9.72{\cdot}a(years) + PA{\cdot}(14.2{\cdot}m(kg) + 503{\cdot}h(meters))\ for\ males\}$$

$$or\ \{387 - 7.31{\cdot}a(years) + PA{\cdot}(10.9{\cdot}m(kg) + 660.7{\cdot}h(meters))\ for\ females\} \quad (6)$$

where

PA is the physical activity level

$for\ male,\ PA = \{1,\ 1.0 < PAL < 1.4\ (Sedentary);\ 1.12,\ 1.4 < PAL < 1.6\ (Low\ active)\}$

$or\ \{1.27,\ 1.6 < PAL < 1.9\ (Active);\ 1.54,\ 1.9 < PAL < 2.5\ (Very\ active)\};$

$for\ female,\ PA = \{1,\ 1.0 < PAL < 1.4\ (Sedentary);\ 1.14,\ 1.4 < PAL < 1.6\ (Low\ active)\}$

$or\ \{1.27,\ 1.6 < PAL < 1.9\ (Active);\ 1.45,\ 1.9 < PAL < 2.5\ (Very\ active)\}$

$$PAL\ = ((I - 1)\ [(1.15/0.9) \times DD\ (minutes)]/1440))/\ (BEE/[0.0175 \times 1440 \times w\ (kg)]) \quad (7)$$

where

I is the activity intensity;

D is the activity duration

$BEE = \{2933.8 \cdot a(years) + 456.4 \cdot h(meters) + 10.12 \cdot w(kg)\ for\ male\}$

$or\ \{2472.67 \cdot a(years) + 401.5 \cdot h(meters) + 8.6 \cdot w(kg)\ for\ female\}$

$$MET = \frac{EER}{BMR} \quad (8)$$

Appendix C. Metabolic Rates for Typical Tasks [10]

Activity	Metabolic Rate		
	Met Units	W/m^2	$Btu/h \cdot ft^2$
Resting			
Sleeping	0.7	40	13
Reclining	0.8	45	15
Seated, quiet	1.0	60	18
Standing, relaxed	1.2	70	22
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	37
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	48
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	70
Office Activities			
Reading, seated	1.0	55	18
Writing	1.0	60	18
Typing	1.1	65	20
Filing, seated	1.2	70	22
Filing, standing	1.4	80	26
Walking about	1.7	100	31
Lifting/packing	2.1	120	39

Driving/Flying			
Automobile	1.0 to 2.0	60 to 115	18 to 37
Aircraft, routine	1.2	70	22
Aircraft, instrument landing	1.8	105	33
Aircraft, combat	2.4	140	44
Heavy vehicle	3.2	185	59
Miscellaneous Occupational Activities			
Cooking	1.6 to 2.0	95 to 115	29 to 37
House cleaning	2.0 to 3.4	115 to 200	37 to 63
Seated, heavy limb movement	2.2	130	41
Machine work			
sawing (table saw)	1.8	105	33
light (electrical industry)	2.0 to 2.4	115 to 140	37 to 44
heavy	4.0	235	74
Handling 50 kg (100 lb) bags	4.0	235	74
Pick and shovel work	4.0 to 4.8	235 to 280	74 to 88
Miscellaneous Leisure Activities			
Dancing, social	2.4 to 4.4	140 to 225	44 to 81
Calisthenics/exercise	3.0 to 4.0	175 to 235	55 to 74
Tennis, single	3.6 to 4.0	210 to 270	66 to 74
Basketball	5.0 to 7.6	290 to 440	90 to 140
Wrestling, competitive	7.0 to 8.7	410 to 505	130 to 160

Appendix D. Clothing Insulation l_{cl} Values for Typical Ensembles [10]

Clothing Description	Garments Included	l_{cl}, clo

Resting	(1) Trousers, short-sleeve shirt	0.57
	(2) Trousers, long-sleeve shirt	0.61
	(3) #2 plus suit jacket	0.96
	(4) #2 plus suit jacket, vest, t-shirt	1.14
	(5) #2 plus long-sleeve sweater, t-shirt	1.01
	(6) #5 plus suit jacket, long underwear bottoms	1.30
Skirts/dresses	(7) Knee-length skirt, short-sleeve shirt (sandals)	0.54
	(8) Knee-length skirt, long-sleeve shirt, full slip	0.67
	(9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater	1.10
	(10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket	1.04
	(11) Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
Shorts	(12) Walking shorts, short-sleeve shirt	0.36
Overalls/coveralls	(13) Long-sleeve coveralls, t-shirt	0.72
	(14) Overalls, long-sleeve shirt, t-shirt	0.89
	(15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	1.37
Athletic	(16) Sweat pants, long-sleeve sweatshirt	0.74
Sleepwear	(17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96