Expert System for Smart Home

Yichen Cai, Yikai Chen

1 Introduction

The specific knowledge domain focus on intelligent control decision-making for indoor home environments, encompassing temperature, humidity, lighting, security, and ventilation systems. This domain requires making rational decisions on home device operation strategies based on environmental state changes (such as temperature, humidity, time periods, and occupancy status) and user preferences. It must balance living comfort with energy efficiency, minimizing energy waste while meeting comfort requirements.

The decision-making process for indoor environmental control is typically rule-based and heavily reliant on experiential knowledge—such as which temperature and humidity ranges are generally considered comfortable, or what control strategies should be adopted during specific seasons and time periods. This knowledge exhibits distinct characteristics of expert systems, making it well-suited for expression and reasoning through rules.

Additionally, after making control decisions, the system explains the rationale to users, clarifying why it took specific actions. This is particularly necessary for safety-related decisions, helping users understand and evaluate whether to adopt system recommendations. Authoritative information on indoor comfort, air quality, and energy-saving controls is widely available in public technical literature and standards, providing robust support for building system knowledge.

Given that most users lack the expertise to balance comfort and energy efficiency in daily life, expert systems in this domain can provide valuable guidance and automated decision-making solutions. They demonstrate strong scalability and applicability across diverse residential environments.

2 TODO1: Domain

The expert system's knowledge base is derived from authoritative sources on home comfort, safety, and energy efficiency. The following subsections detail the core rules implemented in the system.

2.1 Temperature Control

Temperature management balances comfort with energy efficiency based on occupancy and activity status.

2.1.1 Heating Guidelines

For winter heating, the system follows energy-efficient temperature settings recommended by Natural Resources Canada [4]:

- Set thermostat to 17°C when sleeping or away from home

- Set thermostat to 20°C when awake and at home

These settings provide adequate comfort while minimizing energy consumption during periods of reduced activity or absence.

2.1.2 Cooling Guidelines

For summer cooling, the system implements recommendations from Natural Resources Canada's guide on room air conditioners [3]:

- Select 25.5°C as the highest comfortable thermostat setting when the space is occupied

- If the space will be unoccupied for more than four hours, raise the thermostat to approximately 28°C

- If the space will be unoccupied for more than 24 hours, turn off the air conditioning system

This approach prevents excessive cooling costs while maintaining comfort during occupancy.

2.2 Humidity Control

Proper humidity levels are essential for health and home maintenance. According to Health Canada's Healthy Home Guide [2], humidity levels should be maintained between 30% and 50% using a humidifier or dehumidifier as necessary.

- **Low humidity (below 30%):** May aggravate skin allergies and cause respiratory infections. The system recommends using a humidifier.

- **High humidity (above 50%):** Can lead to mould growth. The system recommends using a dehumidifier.

2.3 Carbon Monoxide Safety

Carbon monoxide (CO) detection is a critical safety feature. Health Canada warns that exposure to CO can lead to health problems ranging from tiredness and headaches to chest pain and even death, depending on the concentration in the air [2].

When the carbon monoxide alarm triggers, the system issues an immediate emergency alert recommending evacuation and contacting emergency services.

2.4 Indoor Air Quality (IAQI)

The system monitors indoor air quality using the Atmotube Indoor Air Quality Index (IAQI), which ranges from 0 to 100, with higher values indicating cleaner air [1]. The scale is divided into five categories:

- **Good (81–100):** Optimal air quality. The system aims to maintain this level in occupied spaces.

- **Moderate (61–80):** Acceptable but improvement recommended.

- **Polluted (41–60):** Poor air quality requiring intervention.

- **Very Polluted (21–40):** Serious air quality issues requiring immediate action.

- **Severely Polluted (0–20):** Critical air quality requiring urgent intervention.

The system recommends improving ventilation when IAQI falls below 61.

2.5 Outdoor Air Quality (AQHI)

The Air Quality Health Index (AQHI) measures outdoor air quality on a scale from 1 to 10. Health Canada recommends keeping windows closed when outdoor air quality is poor, such as during wildfires or extreme heat [2]. The system helps prevent poor outdoor air from entering the house by recommending that windows, doors, and skylights remain tightly sealed when AQHI exceeds 6.

3 TODO2: Project Goal

The goal of this project is to design a rule-based intelligent home expert system that makes rational decisions regarding the operation of home appliances based on indoor environmental conditions and user preferences. This ensures residential comfort and safety while enhancing energy efficiency.

3.1 Environmental Perception and Status Evaluation

The system determines whether the current indoor environment is comfortable, safe, and energy-efficient based on environmental facts (e.g., temperature, humidity, time of day, occupancy status).

3.2 Intelligent Decision-Making and Control Recommendations

The system will generate explicit control decisions or recommendations for heating, air conditioning, ventilation, lighting, and related devices based on a rule base. These may include actions such as turning devices on/off or adjusting operating modes.

3.3 Decision Explanation

The system will provide clear explanations for its decisions, detailing the conditions and rationale that triggered the decision. This helps users understand system behavior and determine whether to adopt the recommendation.

4 TODO3: User

The target users for this project are usual household residents—individuals who use smart home devices in daily life but lack specialized knowledge in indoor environmental control, energy management, or automation systems.

These users typically desire a home environment that remains comfortable, secure, and energy-efficient, yet lack experience in assessing how various environmental factors collectively impact indoor conditions. For instance, they may struggle to accurately determine how to appropriately adjust temperature, humidity, lighting, or ventilation systems based on different seasons, time periods, or occupancy status.

Additionally, these users prefer not to manually adjust device settings frequently. Instead, they expect the system to automatically provide reasonable control recommendations based on current environmental conditions and personal preferences, or to make automated decisions when necessary. Simultaneously, users value the explainability of system decisions, particularly regarding safety or energy consumption, and wish to understand why the system takes specific actions.

Therefore, a rule-based smart home expert system capable of providing clear explanations can effectively meet this user's needs for comfort, safety, and energy efficiency.

5 TODO4: Factbase + Rulebase

5.1 Fact Base

The working memory of the expert system is defined in `facts.clp`.

The file contains ten `deffacts` blocks, one for each day in the ten-day evaluation period. Each block asserts the following facts for its respective date:

- **One `env` fact** combining all sensor readings for the day: indoor temperature (°C), relative humidity (%), Indoor Air Quality Index (IAQI, 0–100), CO alarm status, fire alarm status, occupancy status (`awake`, `sleep`, or `gone`), season (`winter` or `summer`), outdoor high and low temperatures, and the outdoor Air Quality Health Index (AQHI, 1–11).

- **One `themostat` fact** initialised to mode `off` with a default target of 22°C.

- **Four `device` facts** — humidifier, dehumidifier, window, and air purifier — each initialised to `off`.

All facts carry the same `date` field so that each rule can match sensor data and controllable devices belonging to the same day, preventing cross-day fact interference in the CLIPS rete network.

5.2 Rule Base

The expert system is implemented in CLIPS as a set of production rules in `rules.clp`. Each rule follows the standard IF/THEN structure: the IF part (left-hand side) lists the conditions that must hold simultaneously; the THEN part (right-hand side) specifies the actions taken when all conditions are satisfied. Rules are evaluated in priority order (salience): safety alarms first (100), temperature control (60), humidity (40), window and outdoor air quality (35), and indoor air quality assessment (30). Emergency rules assert a sentinel fact (`emergency date`) that all lower-priority rules test for, ensuring no further actions are taken on a day where an emergency was detected.

5.2.1 Safety Alarms (salience 100)

R1 – Carbon Monoxide Emergency   **IF** the CO alarm is *on* for a given date
THEN assert an `emergency` sentinel for that date (blocking all lower-priority rules for that day) and issue the alert: *"Carbon monoxide detected. Evacuate immediately and call 911. All other actions are blocked until the emergency is resolved."*

R2 – Fire Emergency   **IF** the fire alarm is *on* for a given date
THEN assert an `emergency` sentinel for that date (blocking all lower-priority rules for that day) and issue the alert: *"Fire/smoke detected. Evacuate immediately and call 911. All other actions are blocked until the emergency is resolved."*

5.2.2 Temperature Control (salience 60)

The thermostat is modelled as a single device with three modes: `heat`, `cool`, and `off`. Heating rules apply only in winter; cooling rules apply only in summer. All temperature rules are skipped on any day flagged with an emergency sentinel.

R3 – Heating When Awake   **IF** the season is *winter*
AND the occupant status is *awake*
AND the indoor temperature is below 20˚C
AND the thermostat is off
THEN set the thermostat to *HEAT* at 20˚C and recommend: *"Indoor temperature is below the 20˚C comfort target for an occupied home (Natural Resources Canada)."*

R4 – Heating When Sleeping   **IF** the season is *winter*
AND the occupant status is *sleep*
AND the indoor temperature is below 17˚C
AND the thermostat is off
THEN set the thermostat to *HEAT* at 17˚C and recommend: *"Indoor temperature is below the 17˚C sleep target (Natural Resources Canada)."*

R5 – Heating When Away   **IF** the season is *winter*
AND the occupant status is *gone*
AND the indoor temperature is below 17˚C
AND the thermostat is off
THEN set the thermostat to *HEAT* at 17˚C and recommend: *"Indoor temperature is below the 17˚C away-from-home target (Natural Resources Canada)."*

R6 – Cooling When Awake   **IF** the season is *summer*
AND the occupant status is *awake*
AND the indoor temperature exceeds 25˚C
AND the thermostat is off
THEN set the thermostat to *COOL* at 25˚C and recommend: *"Indoor temperature exceeds the 25.5˚C occupied comfort limit (Natural Resources Canada)."*

R7 – Cooling When Away   **IF** the season is *summer*
AND the occupant status is *gone*
AND the indoor temperature exceeds 28˚C
AND the thermostat is off
THEN set the thermostat to *COOL* at 28˚C and recommend: *"Indoor temperature exceeds the 28˚C unoccupied energy-saving limit (Natural Resources Canada)."*

R8 – Thermostat Off When Away and Temperature Acceptable   **IF** the season is *summer*

AND the occupant status is *gone*
AND the indoor temperature is at or below 28°C
AND the thermostat is off
THEN report: *"Thermostat OFF: home is unoccupied and indoor temperature is within the 28°C energy-saving limit."*

5.2.3 Humidity Control (salience 40)

R9 – Activate Humidifier **IF** the indoor humidity is below 30%
AND the humidifier is off
THEN turn the humidifier *on* and recommend: *"Low humidity may aggravate skin allergies and respiratory infections (Health Canada)."*

R10 – Activate Dehumidifier **IF** the indoor humidity exceeds 50%
AND the dehumidifier is off
THEN turn the dehumidifier *on* and recommend: *"High humidity promotes mould growth (Health Canada)."*

R11 – Humidity Comfortable **IF** the indoor humidity is between 30% and 50% (inclusive)
THEN report: *"Humidity is in the comfortable range (30–50%). No action needed."*

5.2.4 Window and Outdoor Air Quality Control (salience 35)

R12 – Close Windows: Poor Outdoor Air **IF** the outdoor AQHI exceeds 6
AND the window is closed
THEN report: *"Window CLOSED: outdoor AQHI exceeds 6. Keep windows sealed to block outdoor pollutants (Health Canada)."*

R13 – Acceptable Outdoor Air **IF** the outdoor AQHI is 6 or below
AND the window is closed
THEN report: *"Outdoor AQHI is acceptable. No action needed."*

5.2.5 Indoor Air Quality Assessment (salience 30)

The following six rules fire independently for each day's sensor reading, providing a per-day air quality report. The IAQI scale ranges from 0 to 100, where higher values indicate cleaner air. Rules for Polluted and below also turn on the air purifier if it is not already running. When both indoor and outdoor air quality are poor simultaneously, an additional rule reinforces the air purifier action and advises keeping windows closed.

R14 – IAQI Good (81–100) **IF** the indoor IAQI is 81 or above
THEN report: *"Indoor air quality: Good. No action needed."*

R15 – IAQI Moderate (61–80)   **IF** the indoor IAQI is between 61 and 80
THEN report: *"Indoor air quality: Moderate. The indoor air quality is acceptable, no action needed."*

R16 – IAQI Polluted (41–60)   **IF** the indoor IAQI is between 41 and 60
AND the air purifier is off
THEN turn the air purifier *on* and report: *"Indoor air quality: Polluted. The system has turned on the air purifier."*

R17 – IAQI Very Polluted (21–40)   **IF** the indoor IAQI is between 21 and 40
AND the air purifier is off
THEN turn the air purifier *on* and report: *"Indoor air quality: Very Polluted. The system has turned on the air purifier."*

R18 – IAQI Severely Polluted (0–20)   **IF** the indoor IAQI is below 21
AND the air purifier is off
THEN turn the air purifier *on* and report: *"Indoor air quality: Severely Polluted. The system has turned on the air purifier. Urgent intervention required."*

R19 – Both Indoor and Outdoor Air Quality Poor   **IF** the indoor IAQI is below 61 (Polluted or worse)
AND the outdoor AQHI exceeds 6
AND the air purifier is off
AND no air purifier action has been issued yet for this run
THEN turn the air purifier *on* and report: *"Indoor IAQI is poor and outdoor AQHI exceeds 6. Keep windows closed to avoid worsening indoor air quality."*

References

[1] Atmotube.   Indoor air quality index (iaqi): What is it and how to use it. `https://atmotube.com/blog/indoor-air-quality-index-iaqi`, 2024. Accessed: 2026-01-31.

[2] Health Canada.   Healthy home guide.   `https://www.canada.ca/en/health-canada/services/healthy-home/guide.html`, 2024.   Accessed: 2026-01-31.

[3] Natural Resources Canada.   Guide to room air conditioners.   `https://natural-resources.canada.ca/stories/spotlight-energy-efficiency/guide-room-air-conditioners`, 2024. Accessed: 2026-01-31.

[4] Natural Resources Canada.   Winter is coming: Top tips to heat your home for less.   `https://natural-resources.`

canada.ca/stories/spotlight-energy-efficiency/
winter-coming-top-tips-heat-your-home-less, 2024. Accessed:
2026-01-31.