REPORT

2025/2026

CSLAB

Smart Lighting and Heating System

G01

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Requirements

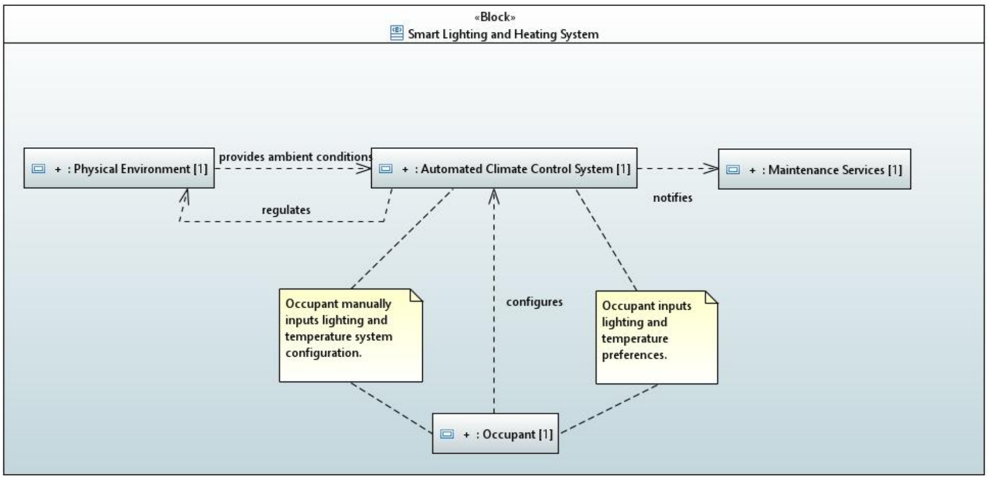
The following requirements describe the expected behavior of the Automated Climate Control System (ACCS) when stimulated by external inputs or environmental changes. Each requirement is expressed in a clear, testable, and implementation-agnostic manner, following the black-box perspective. The table below enumerates all functional requirements currently identified for the system.

Table 1: Requirements Specification.

ID	TITLE	DESCRIPTION
R-1	Automatic Natural Light Optimization	While the system is in Automatic Mode, the ACCS shall adjust the smart blinds to the fully open position to maximize natural sunlight entry.
R-2	Artificial Light Compensation	When the blinds are fully open and natural light level is measured below the user-defined threshold, the ACCS shall activate the artificial smart lights to achieve user-defined light preferences.
R-3	Automatic Temperature Regulation	While the system is in Automatic Mode, the ACCS shall regulate the smart heater output to maintain the office temperature within the user-defined temperature preferences.
R-4	User Preference Configuration	When the Occupant inputs configuration changes via the User Interface, the ACCS shall store the new preferences for lighting and temperature.
R-5	Manual Override Control	When a manual command is received for a specific device (Blinds/Lights/Heater), the ACCS shall suspend automatic control for that device and adjust it to the user-requested value.
R-6	Performance Deviation Alert	If the measured environmental parameters (light/temperature) deviate from the current system configuration target values for 1 minute, the ACCS shall display a warning message on the User Interface.

System Context

The Smart Lighting and Heating System operates within a broader environment involving physical conditions, human interaction, and external support services. The System Context defines the system boundaries and identifies all external entities that interact with the ACCS. This clarifies what lies inside the system and what remains outside.



Use Cases

This section describes the functional interactions between external actors and the Smart Lighting and Heating System. It identifies the interactions between users, external services, and the ACCS, capturing how each actor initiates or participates in system functions. The following table presents the use cases identified as well as their description.

Table 2: Description of Use Cases.

ID	TITLE	DESCRIPTION
UC-1	Configure System Preferences	The Occupant inputs or updates lighting and temperature preferences. The ACCS stores these preferences for use in automatic regulation.
UC-2	Override System Configuration	The Occupant manually controls a specific device (e.g. blinds, lights, heater). The ACCS suspends automatic control for that device and applies the requested setting.
UC-3	View Alert Messages	The Occupant views warning or informational messages generated by the ACCS, typically related to performance deviations or detected malfunctions.
UC-4	Regulate Light Level	The ACCS automatically adjusts smart blinds and/or artificial lighting to achieve the desired light level based on sensor readings and configured preferences.
UC-5	Regulate Temperature Level	The ACCS controls the smart heater to maintain indoor temperature within the user-defined range.
UC-6	Store Occupant Preferences	The ACCS saves updated lighting and temperature configurations submitted by the Occupant.

ID	TITLE	DESCRIPTION
UC-7	Monitor System Configuration Deviations	The ACCS continuously compares environmental conditions with the target values. If deviations persist beyond a defined duration, the system prepares an alert.
UC-8	Send Alert Messages	When abnormal conditions or potential malfunctions are detected, the ACCS issues alert messages to the Occupant and, when necessary, to Maintenance Services.
UC-9	Receive Malfunctioning Alert Messages	Maintenance Services receives fault notifications from the ACCS, enabling appropriate maintenance actions.

Diagram 9 presents the use cases associated with their respective actors.

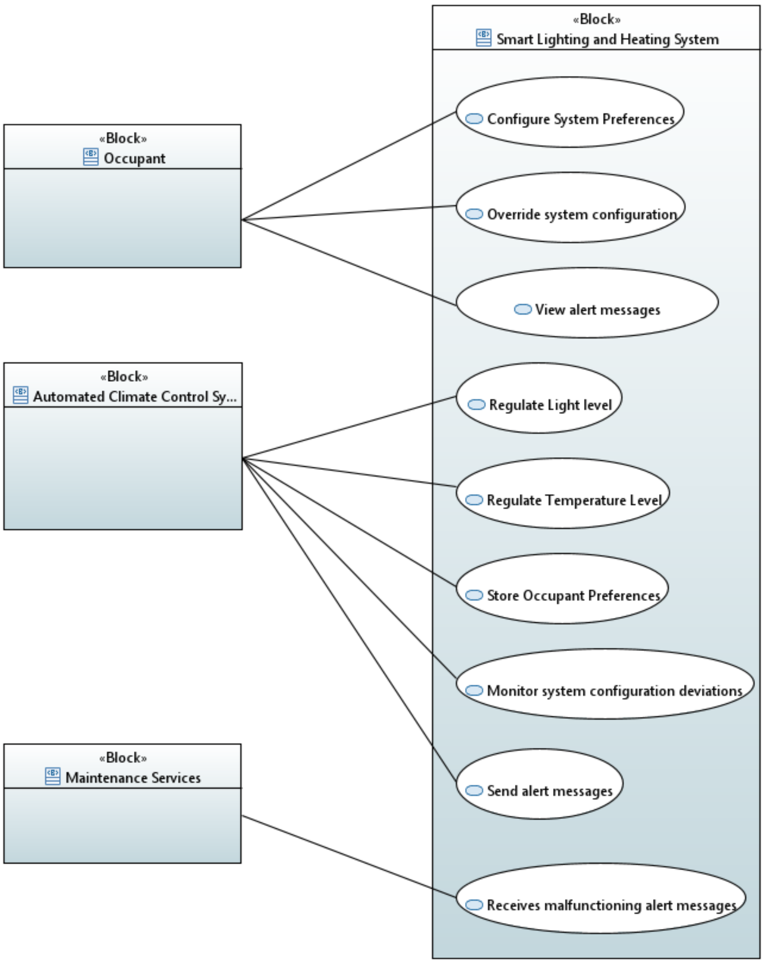


Diagram 1: Use Case Diagram.

Activity Diagrams

Considering the use cases presented in the previous section, the following activity diagrams were developed for the main use cases of the system.

- ***Regulate Temperature Level***

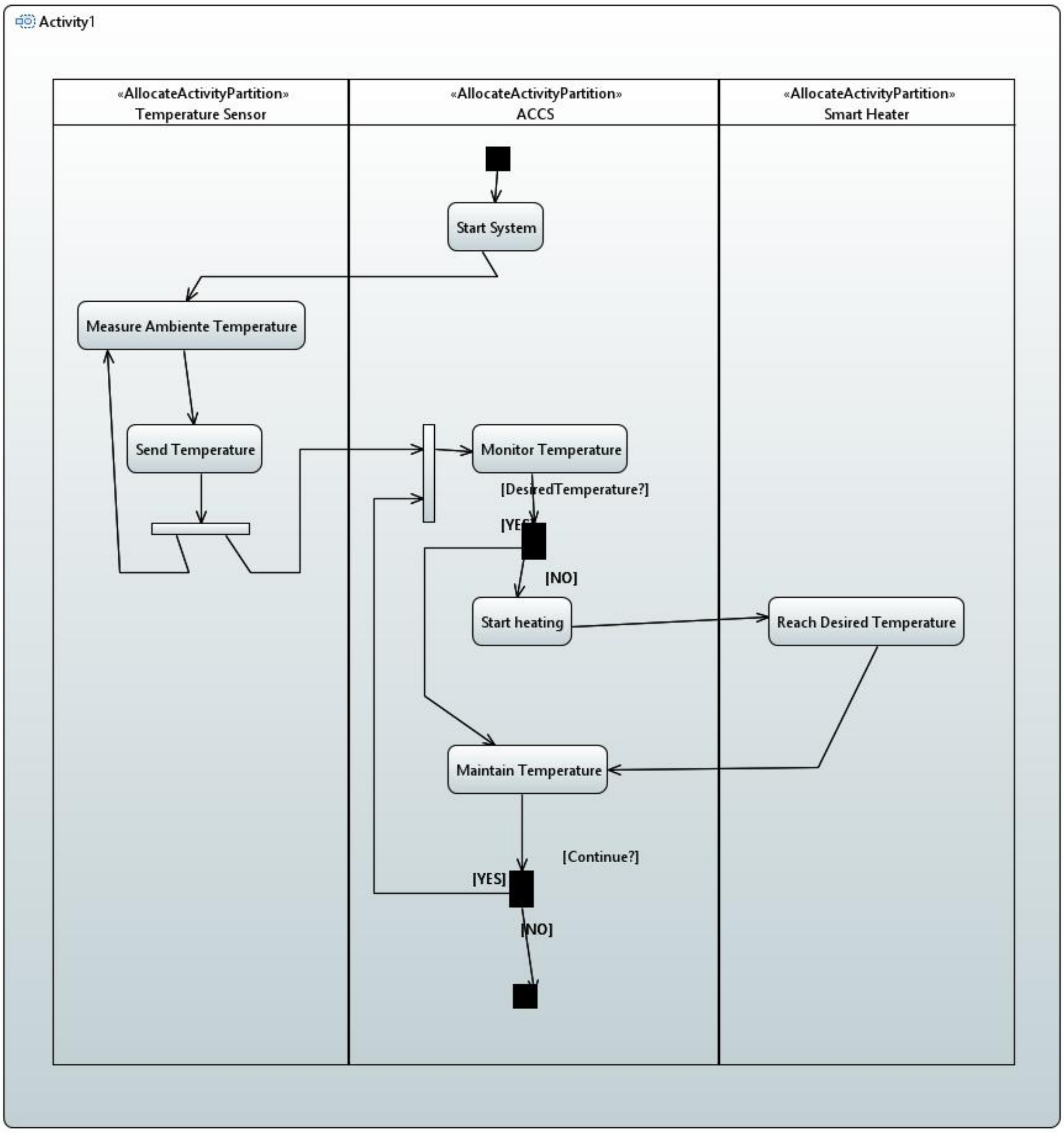


Diagram 2: "Regulate Temperature Level" Activity Diagram.

- ***Regulate Light Level***

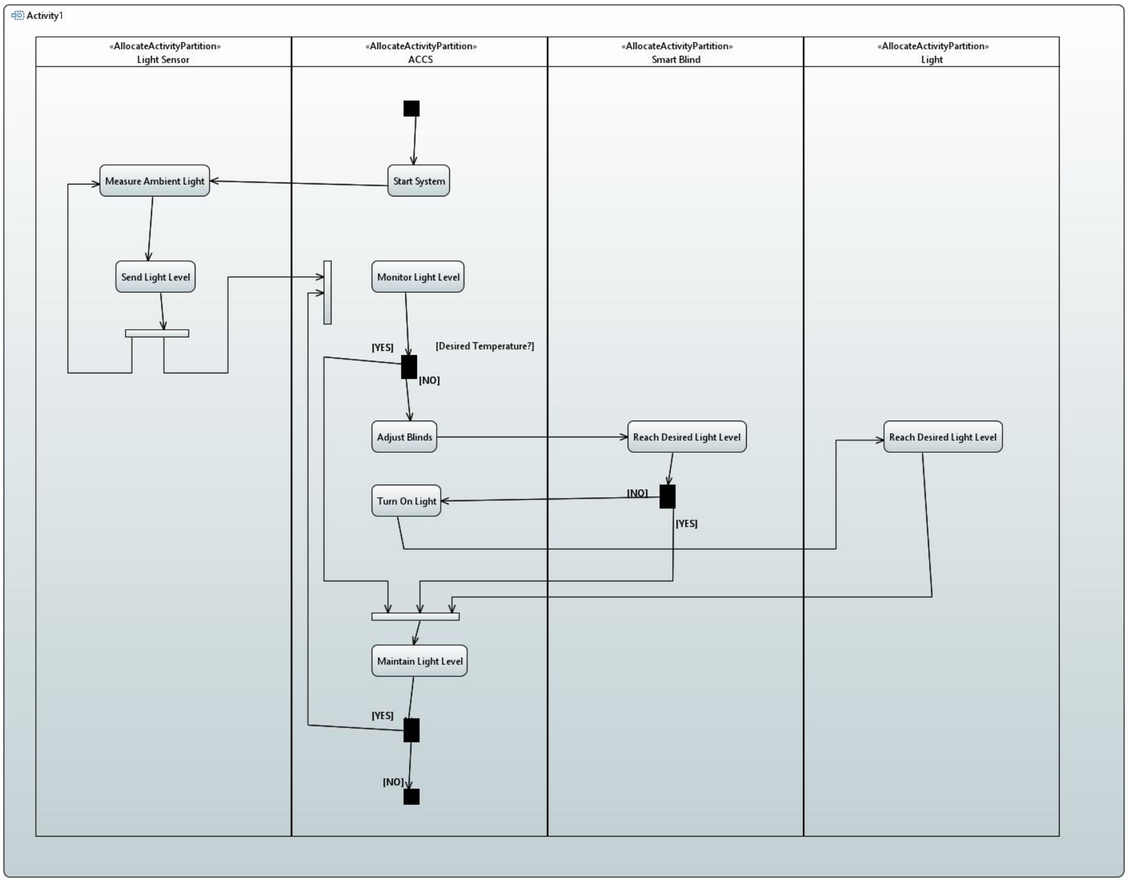


Diagram 3: "Regulate Light Level" Activity Diagram.

White Box

Conceptual Subsystems

The ACCS is composed of three internal subsystems: the Office Control Unit, Heating Control, and Light Control. This section defines the system's internal structure and identifies the key functional blocks.

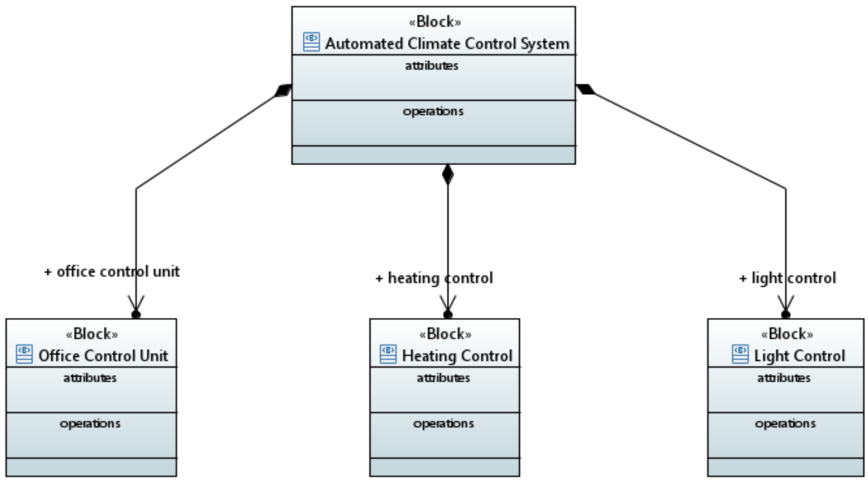


Diagram 4: Conceptual Subsystems.

Conceptual Interfaces

The Smart Lighting and Heating System interacts with its environment through a set of defined input and output ports. This section specifies these interaction points, detailing the flow of sensor data and user commands into the system, and the corresponding control updates sent to actuators like heaters and blinds.

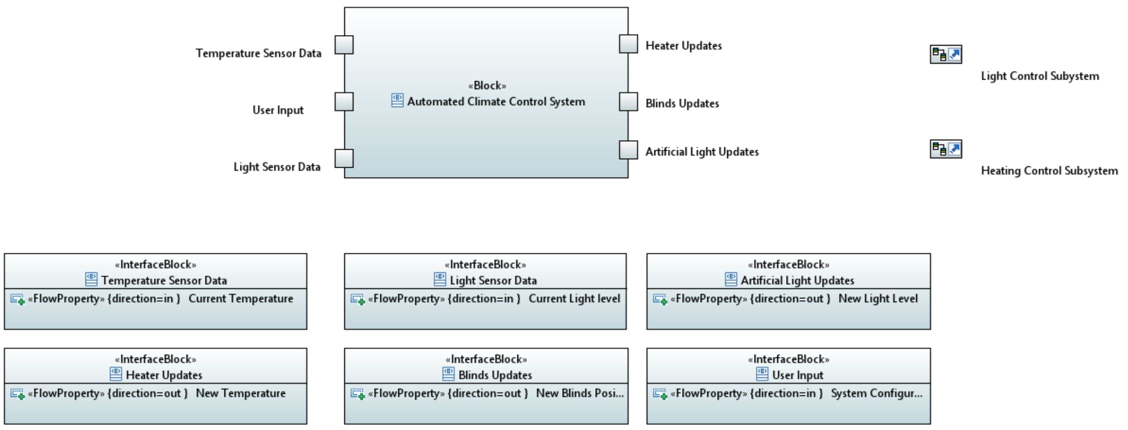


Diagram 5: Conceptual Interfaces.

Traceability

This section describes the links between the system components and the requirements introduced earlier. Due to space limitations, only a shortened version of the traceability table is provided.

	A	B	C	D	E	F	G
	User Input	Heating Control Info...	Light Control Infor...	Temperature Se...	Heater Upd...	Information Output	Information Input
Deviation Alert	☐	☐	☐	☐	☐	☑	☐
Manual Override Control	☐	☐	☐	☐	☐	☐	☑
User Preference Configuration	☐	☐	☐	☐	☑	☐	☑
Automatic Temperature Regulation	☐	☑	☐	☑	☐	☐	☐
Artificial Light Compensation	☐	☐	☑	☐	☐	☐	☐
Automatic Natural Light Optimiz...	☐	☐	☑	☐	☐	☐	☐

Diagram 6: Traceability between system components and requirements.

Hazard Analysis

The Hazard Analysis identifies potential failure modes that could disrupt the system's operation. This section outlines specific risks associated with actuator and sensor malfunctions and defines the necessary mitigation strategies to maintain system reliability and user comfort.

Table 3: Hazard Analysis.

HAZARD	MITIGATION
One of the smart heater actuators is malfunctioning	Identify the failure, provide user with temporary fix (regulate by hand), and initiate long-term fix (send message to maintenance services)
The smart blind actuator is stuck in the "closed" position during the day.	Detect discrepancy between command and state. Notify the Occupant to manually adjust the blind and send message to maintenance services.

The smart light actuator fails to switch OFF (stuck ON).	Detect continuous energy usage or light input when not requested. Notify user to manually switch off the switch and send message to maintenance services.
The smart light actuator fails to switch ON (bulb/circuit failure).	Detect lack of change in light intensity after command. Notify user and suggest using natural light and send message to maintenance services.
The temperature sensor is malfunctioning	Implement Dual-Sensor Redundancy and Range Validation. Each sensor is first checked against a realistic range. If both are valid, they are compared; if the difference exceeds a threshold, the system disables automation and notifies the occupant and sends message to maintenance services.
The light sensor is malfunctioning	Implement Dual-Sensor Redundancy and Range Validation. Each sensor is first checked against a realistic range. If both are valid, they are compared; if the difference exceeds a threshold, the system disables automation and notifies the occupant and sends message to maintenance services.

List of Technologies

The system uses a communication architecture using UDP and MQTT to balance performance and manageability.

- **UDP (User Datagram Protocol) with Custom QoS:** UDP is used for local communication between the Worker Devices and the Control Unit. To mitigate the inherent unreliability of standard UDP, we are implementing a custom Quality of Service (QoS) layer. This layer utilizes a Syn-Ack style protocol to verify the delivery of critical sensor readings and actuator commands, ensuring data integrity without the overhead of full TCP.
- **MQTT (Message Queuing Telemetry Transport):** The Office Control Units (OCUs) communicate with the central Configuration Center using MQTT. This protocol is selected for its robust handling of remote connections and efficient message distribution.

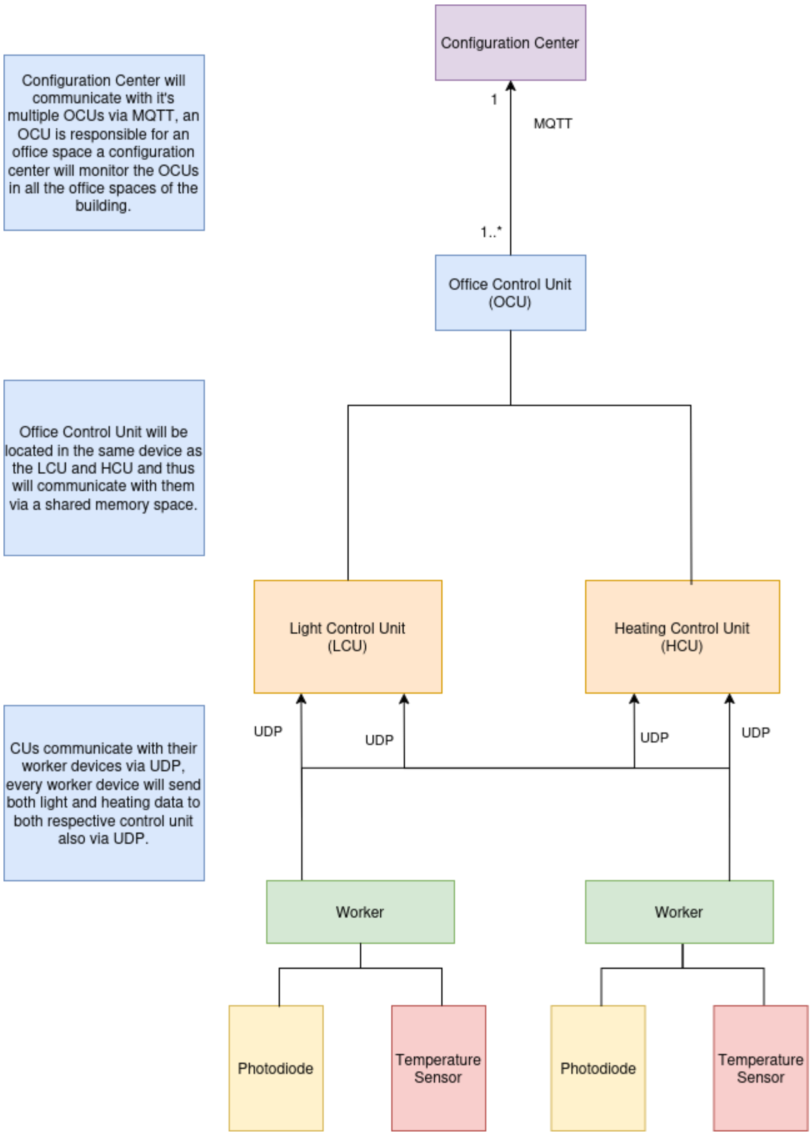


Diagram 7: Component Communication.

List of Physical Sensor(s)/Actuators

Considering composition of Automated Climate Control System presented in Diagram 21, the following hardware components have been selected to implement the system:

- 2 Micro-controllers
- 2 Temperature sensors
- 2 Photodiodes (Light sensors)
- 4 LED lights
- 2 Servo motors

List of Real-Time Tasks

Based on the use cases defined in section 15, the following are classified as real-time tasks due to their specific timing constraints:

- **Override system configuration:** this task is defined as a real-time task as any office conditions updates or overrides must take effect in less than 60 seconds.
- **Regulate Light level:** this task is defined as a real-time task because the system is considered to have failed if the office light level does not change within 5 seconds of an update command, or if the sensor readings fail to reach the appropriate control unit within 2 seconds of being captured by the Worker Device.
- **Regulate Temperature level:** this task is defined as a real-time task because the system is considered to have failed if the office temperature does not change within 30 seconds after an update command, or if the temperature readings from the sensors fail to reach the appropriate control unit within 2 seconds of being captured by the worker.

Submission 2

Requirement Specification

This submission incorporates several updates relative to the previous version. Key changes include revisions to the system use cases and system context. Consequently, the black box activity diagram has been updated to focus specifically on the "Control ACCS operation" use case. Furthermore, the hazard analysis has been updated to include probability and impact. Finally, this version introduces new elements, including measures of effectiveness, functional decomposition, composition of the physical environment and the conceptual interfaces of the subsystems.

Black Box

Requirements

The following requirements describe the expected behavior of the Automated Climate Control System (ACCS) when stimulated by external inputs or environmental changes. Each requirement is expressed in a clear, testable, and implementation-agnostic manner, following the black-box perspective. The table below enumerates all functional requirements currently identified for the system.

Table 4: Requirements Specification.

ID	TITLE	DESCRIPTION
R-1	Automatic Natural Light Optimization	While the system is in Automatic Mode, the ACCS shall adjust the smart blinds to the fully open position to maximize natural sunlight entry.
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R-3	Automatic Temperature Regulation	While the system is in Automatic Mode, the ACCS shall regulate the smart heater output to maintain the office temperature within the user-defined temperature preferences.
R-4	User Preference Configuration	When the Occupant inputs configuration changes via the User Interface, the ACCS shall store the new preferences for lighting and temperature.
R-5	Manual Override Control	When a manual command is received for a specific device (Blinds/Lights/Heater), the ACCS shall suspend automatic control for that device and adjust it to the user-requested value.

ID	TITLE	DESCRIPTION
R-6	Performance Deviation Alert	If the measured environmental parameters (light/temperature) deviate from the current system configuration target values for 1 minute, the ACCS shall display a warning message on the User Interface.

System Context

The Smart Lighting and Heating System operates within a broader environment involving physical conditions, human interaction, and external support services. The System Context defines the system boundaries and identifies all external entities that interact with the ACCS. This clarifies what lies inside the system and what remains outside.

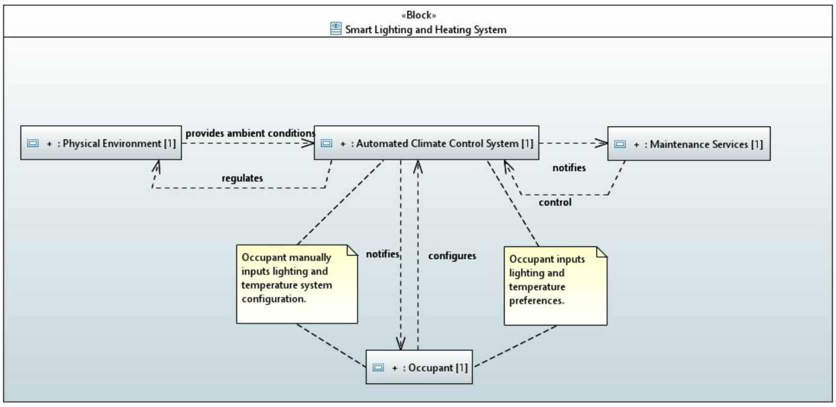

Diagram 8: System Context.

Use Cases

This section describes the functional interactions between external actors and the Smart Lighting and Heating System. It identifies the interactions between users, external services, and the ACCS, capturing how each actor initiates or participates in system functions. The following table presents the use cases identified as well as their description.

Table 5: Description of Use Cases.

ID	TITLE	DESCRIPTION
UC-1	Configure System Preferences	The Occupant inputs or updates lighting and temperature preferences. The ACCS stores these preferences for use in automatic regulation.
UC-2	Override System Configuration	The Occupant manually controls a specific device (e.g. blinds, lights, heater). The ACCS suspends automatic control for that device and applies the requested setting.
UC-3	View Alert Messages	The Occupant views warning or informational messages generated by the ACCS, typically related to performance deviations or detected malfunctions.

ID	TITLE	DESCRIPTION
UC-4	Control ACCS Operation	Maintenance Services initiate the ACCS operation. Once active, the ACCS autonomously regulates indoor temperature and light levels based on stored occupant preferences, continuously monitors system behavior, and notifies Maintenance Services when malfunctions are detected. In case of a malfunction, the ACCS disables automated control to ensure safe operation.

Diagram 9 presents the use cases associated with their respective actors.

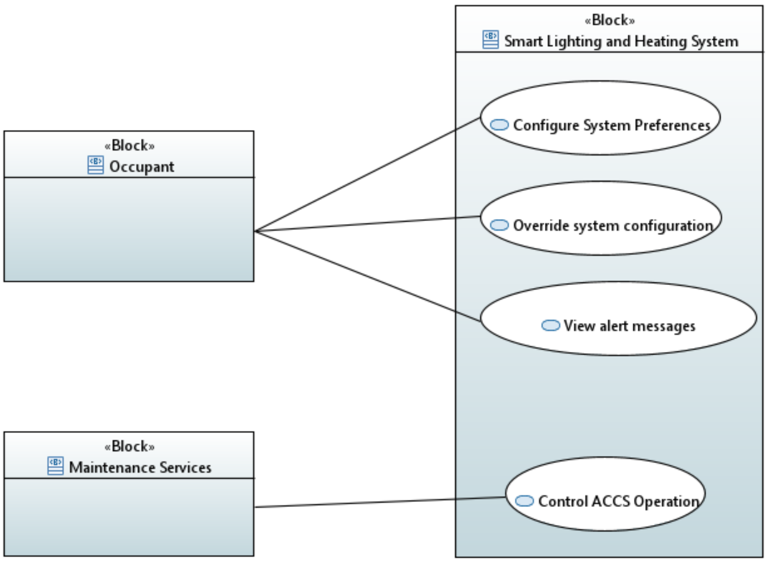

Diagram 9: Use Case Diagram.

Activity Diagram

Considering the use cases presented in the previous section, the following activity diagrams were developed for the main use cases of the system.

- ***Control ACCS operation***

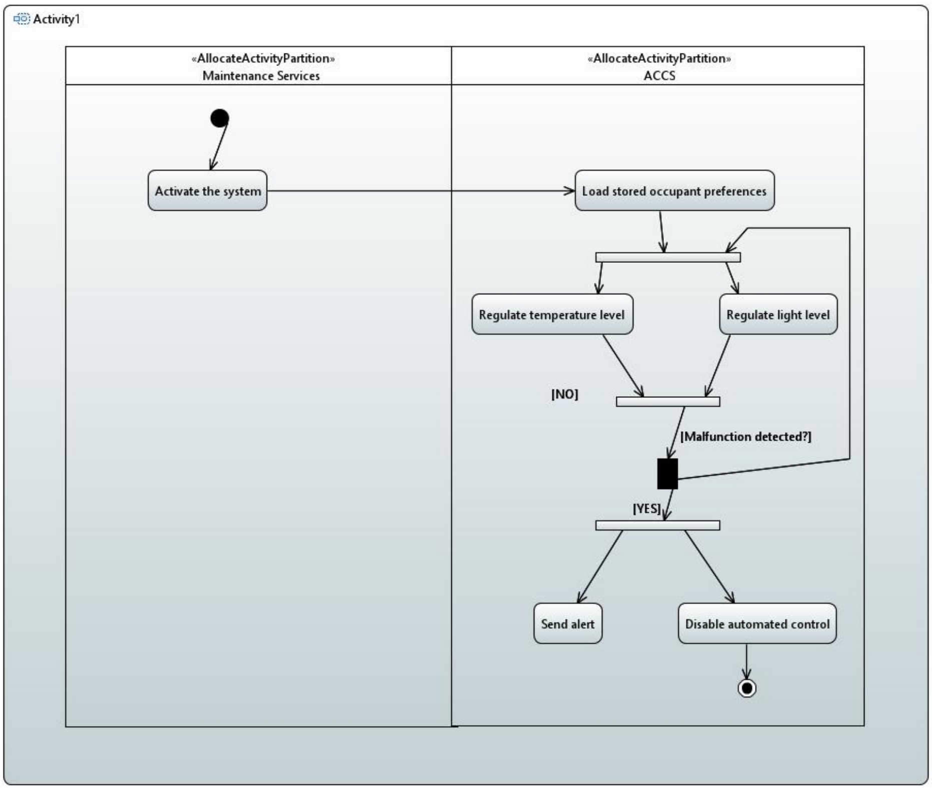

Diagram 10: "Control ACCS operation" activity diagram.

Measure of Effectiveness

To evaluate the system's performance, distinct measures of effectiveness (MOEs) have been defined, as illustrated in the diagram below.

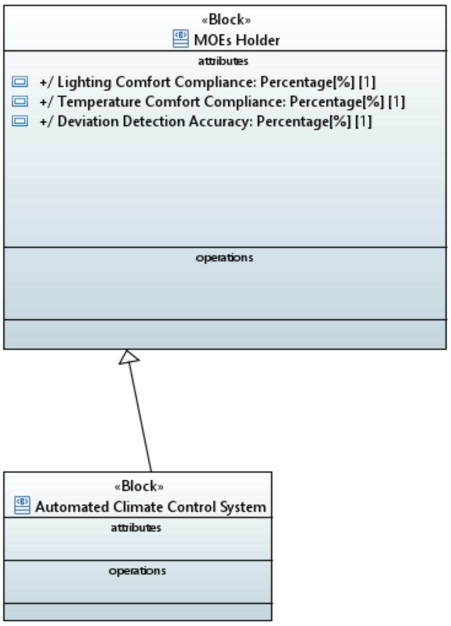

Diagram 11: Measure of Effectiveness diagram.

White Box

Functional Decomposition

Based on Diagram 10, the following functional decomposition of activities was performed:

- ***Regulate Temperature Level***

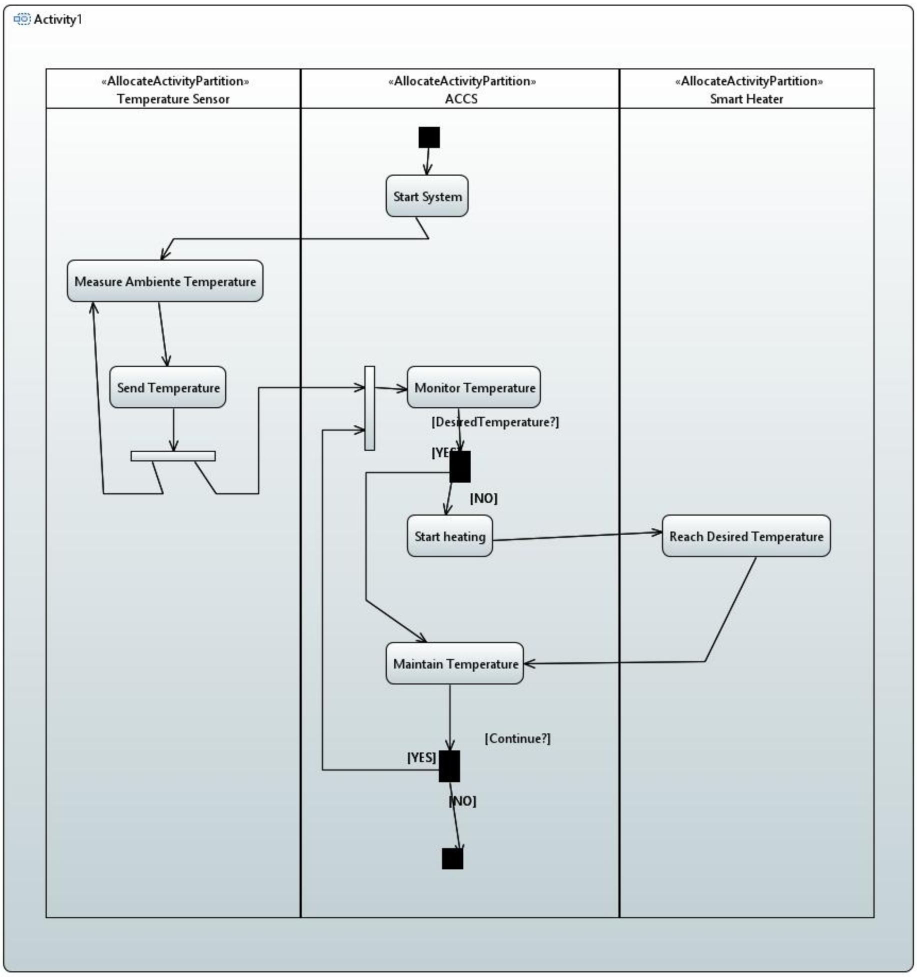

Diagram 12: "Regulate Temperature Level" Activity Diagram.

- ***Regulate Light Level***

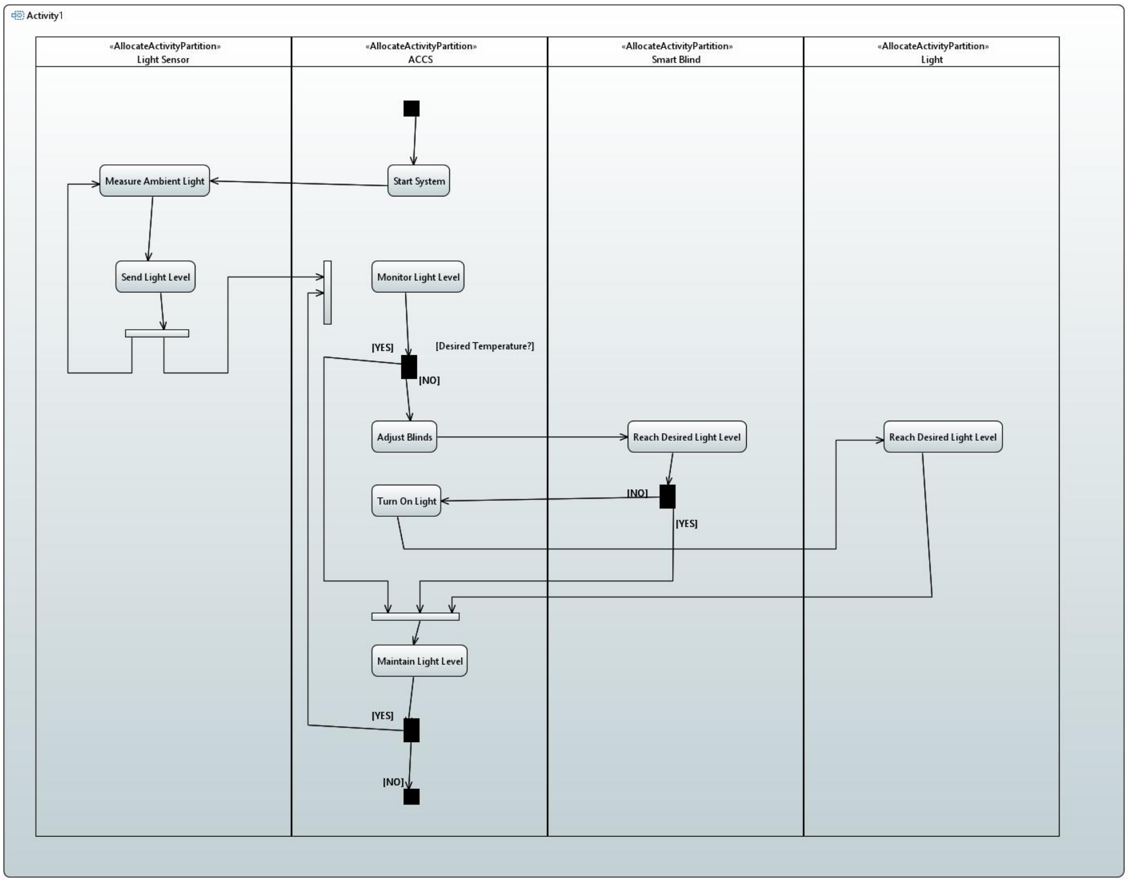

Diagram 13: "Regulate Light Level" Activity Diagram.

In these activity diagrams, the partitions correspond directly to specific structural blocks, such as the "Temperature Sensor." This sensor is an integral component of the Physical Environment defined in the system context. As illustrated in the diagram below, the Physical Environment aggregates the following constituent parts: a Temperature Sensor, Light Sensor, Smart Heater, Smart Blind, and Light.

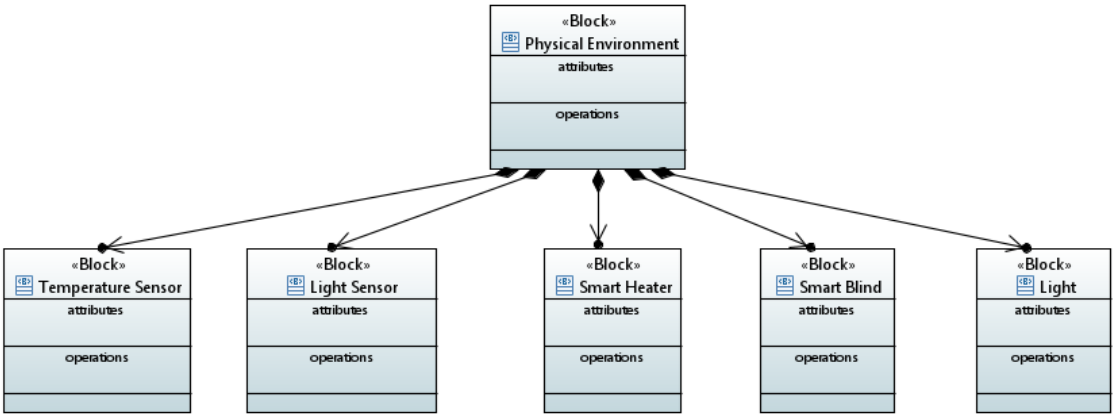

Diagram 14: Physical Environment composition.

Conceptual Subsystems

The ACCS is composed of three internal subsystems: the Office Control Unit, Heating Control, and Light Control. This section defines the system's internal structure and identifies the key functional blocks.

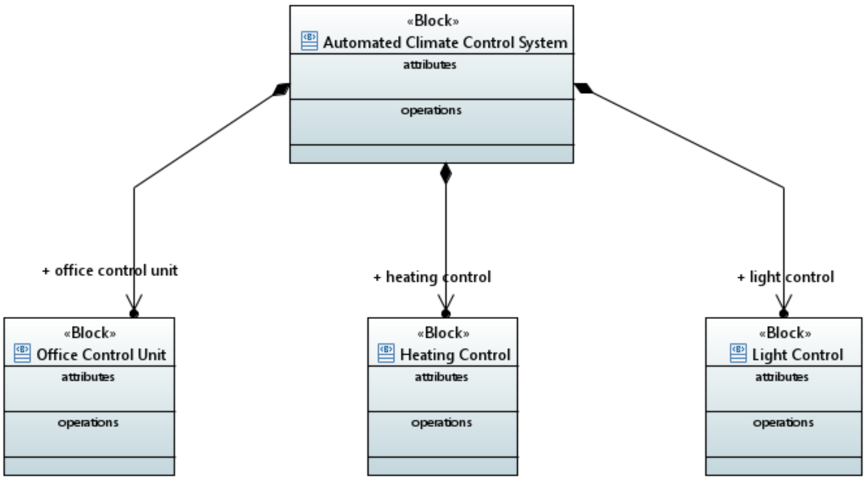

Diagram 15: Conceptual Subsystems.

Conceptual Interfaces

The Smart Lighting and Heating System interacts with its environment through a set of defined input and output ports. This section specifies these interaction points, detailing the flow of sensor data and user commands into the system, and the corresponding control updates sent to actuators like heaters and blinds.

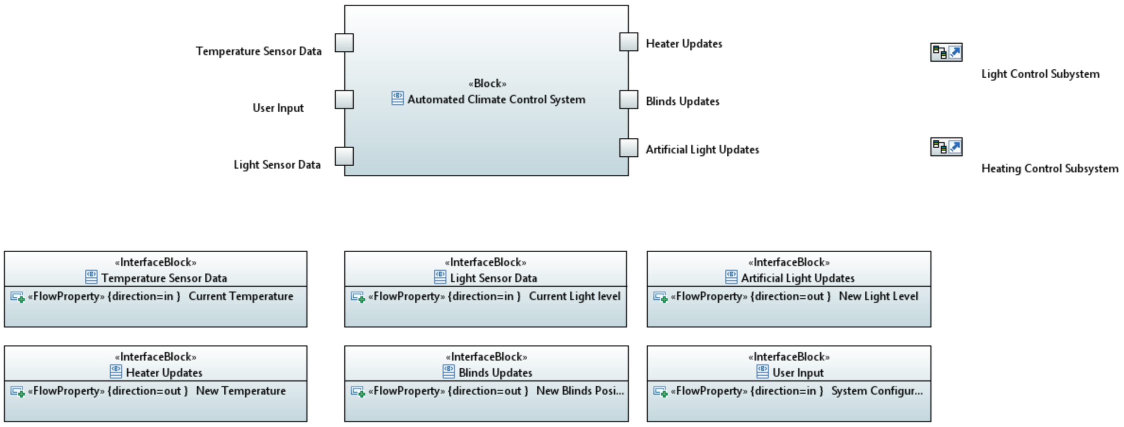

Diagram 16: Conceptual Interfaces.

Furthermore, the conceptual interfaces for each subsystem have been specified.

- **Heating Control**

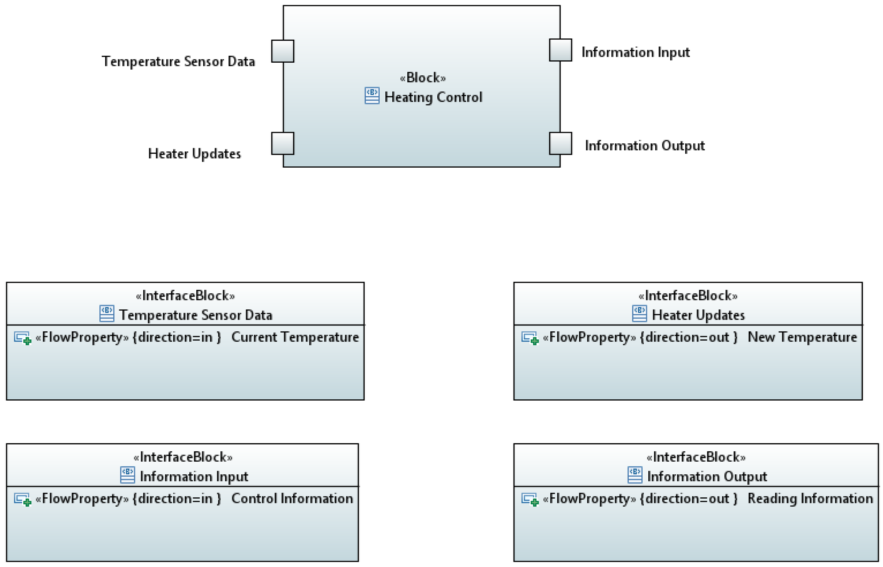

Diagram 17: Conceptual Interfaces of "Heating Control" subsystem.

- **Light Control**

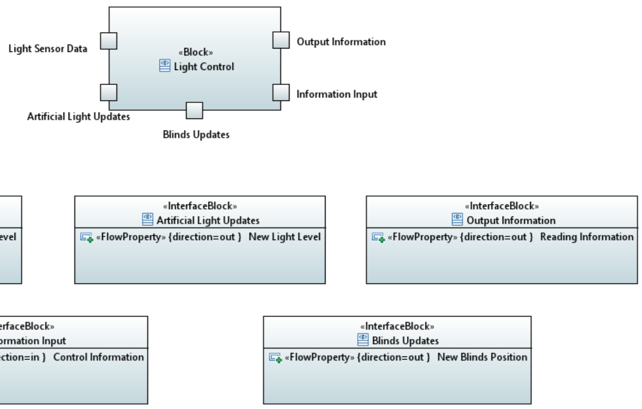

Diagram 18: Conceptual Interfaces of "Light Control" subsystem.

- **Office Control Unit**

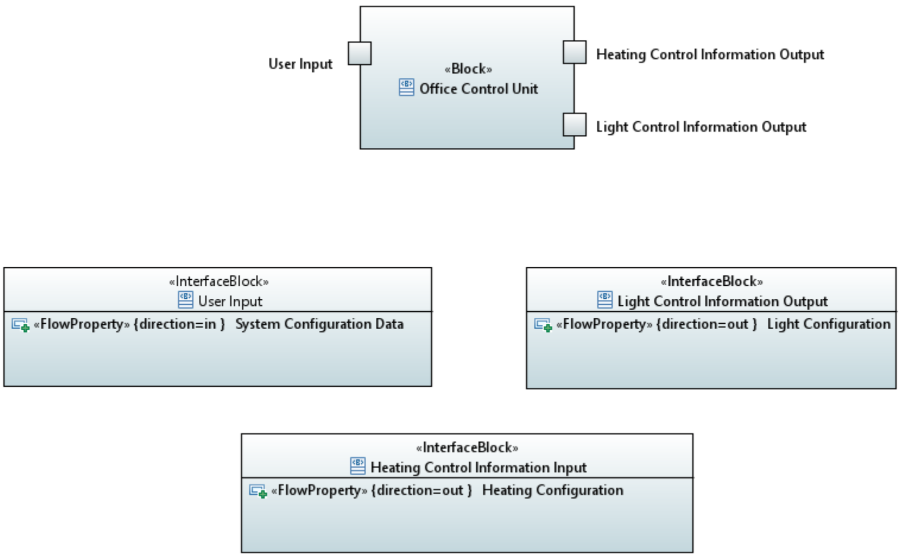

Diagram 19: Conceptual Interfaces of "Office Control Unit" subsystem.

Traceability

This section describes the links between the system components and the requirements introduced earlier. Due to space limitations, only a shortened version of the traceability table is provided.

	A	B	C	D	E	F	G
	User Input	Heating Control Info...	Light Control Infor...	Temperature Se...	Heater Upd...	Information Output	Information Input
Deviation Alert	☐	☐	☐	☐	☐	☑	☐
Manual Override Control	☐	☐	☐	☐	☐	☐	☑
User Preference Configuration	☐	☐	☐	☐	☑	☐	☑
Automatic Temperature Regulation	☐	☑	☐	☑	☐	☐	☐
Artificial Light Compensation	☐	☐	☑	☐	☐	☐	☐
Automatic Natural Light Optimiz...	☐	☐	☑	☐	☐	☐	☐

Diagram 20: Traceability between system components and requirements.

Hazard Analysis

The Hazard Analysis identifies potential failure modes that could disrupt the system's operation. This section outlines specific risks associated with actuator and sensor malfunctions and defines the necessary mitigation strategies to maintain system reliability and user comfort. Additionally, it also defines the probability and impact on a scale of 0-5.

Table 6: Hazard Analysis.

HAZARD	MITIGATION	PROBABILITY	IMPACT
One of the smart heater actuators is malfunctioning	Identify the failure, provide user with temporary fix (regulate by hand), and initiate long-term fix (send message to maintenance services)	2	4
The smart blind actuator is stuck in the "closed" position during the day.	Detect discrepancy between command and state. Notify the Occupant to manually adjust the blind and send message to maintenance services.	2	3
The smart light actuator fails to switch OFF (stuck ON).	Detect continuous energy usage or light input when not requested. Notify user to manually switch off the switch and send message to maintenance services.	3	2
The smart light actuator fails to switch ON (bulb/circuit failure).	Detect lack of change in light intensity after command. Notify user and suggest using natural light and send message to maintenance services.	3	2
The temperature sensor is malfunctioning	Implement Dual-Sensor Redundancy and Range Validation. Each sensor is first checked against a realistic range. If both are valid, they are compared; if the difference exceeds a threshold, the system disables automation and notifies the occupant and sends message to maintenance services.	2	5
The light sensor is malfunctioning	Implement Dual-Sensor Redundancy and Range Validation. Each sensor is first checked against a realistic range. If both are valid, they are compared; if the difference exceeds a threshold, the system disables automation and	2	3

	notifies the occupant and sends message to maintenance services.		

Communication Software Infrastructure

The following diagram illustrates the base technologies, sources, and destinations, along with their interactions. A key update from the previous submission is the introduction of redundancy at the higher layer. Specifically, a direct connection has been established between the Workers and the Configuration Center. This ensures that even if the control unit fails, the occupant continues to receive data regarding temperature and lighting conditions.

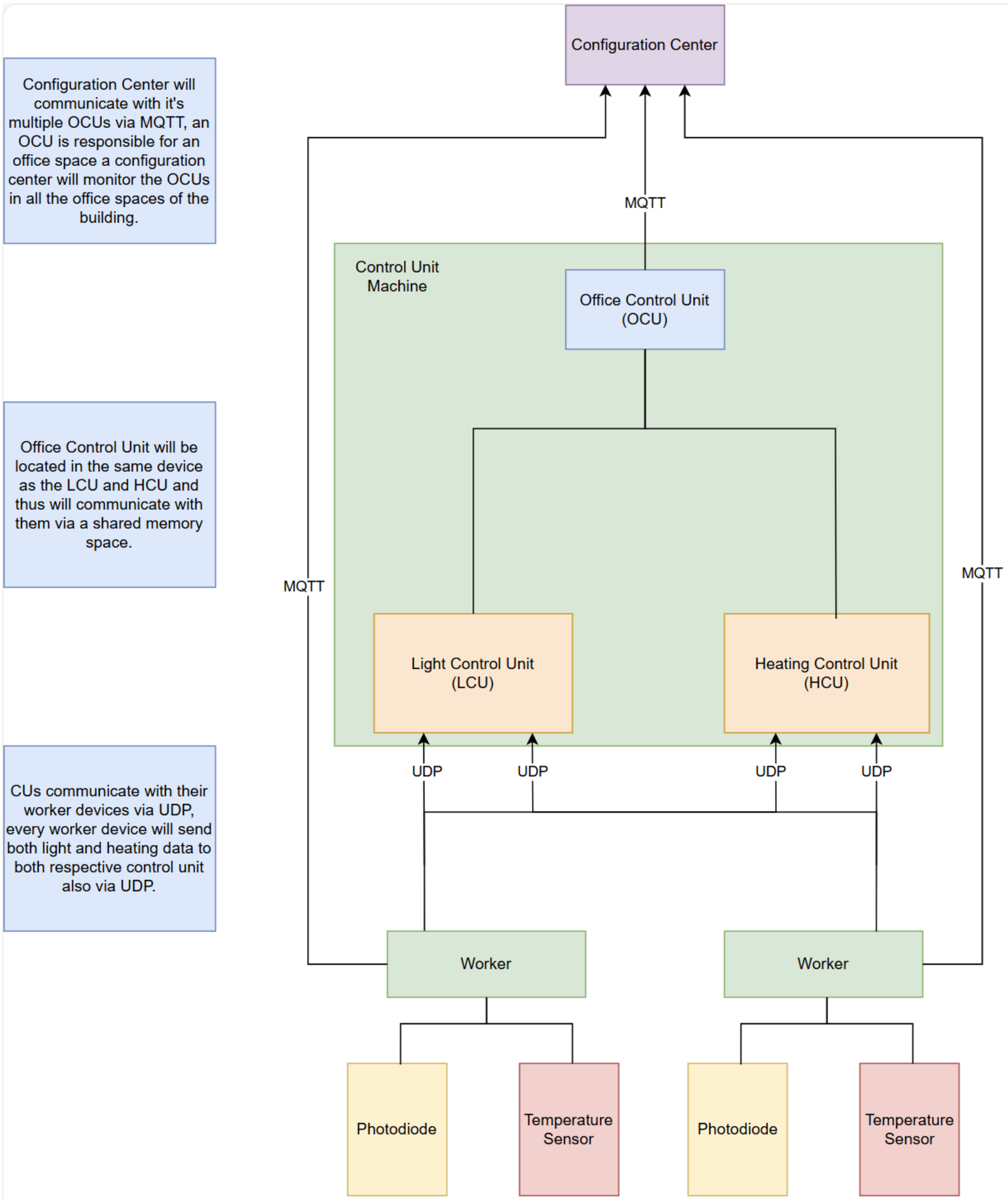

Diagram 21: Component Communication.

Physical Sensor(s)/Actuators

Considering composition of Automated Climate Control System presented in Diagram 21, the following hardware components have been selected to implement the system:

- **2 micro-controllers:** these are needed to act as the physical interface between the digital system and the real world, obtaining data from the sensors and driving the actuators. Two are needed for redundancy, guaranteeing that if one worker node fails or loses connection, the other is available to keep the system running.
- **2 temperature sensors:** these are required to provide ambient temperature data. Two are needed (one for each microcontroller) to ensure that if one sensor provides faulty readings or breaks, the system can rely on the second sensor to maintain a comfortable temperature.
- **2 photodiodes (light sensors):** these are needed to measure the current light level. Two are needed (one for each microcontroller) to ensure that if one sensor provides faulty readings or breaks, the system can rely on the second sensor to maintain comfortable lighting.
- **4 LED lights:** these are needed to simulate the artificial office lighting and to simulate the heating system activation (two per microcontroller: one for light, one for heat). Four are needed to guarantee redundancy, ensuring that if the lighting or heating simulator on one device fails, the other is available to perform the function.
- **2 servo motors:** these are needed to simulate the smart blinds mechanism (controlling natural light or insulation). Two are needed for redundancy guaranteeing that if one blind mechanism gets stuck or fails, the other is available to adjust the window coverage.

Assembly Functionality

In accordance with the hazard analysis, sensor integrity is verified by comparing readings against a defined threshold to detect potential malfunctions. This specific logic, calculating the differential and validating it against the limit, is implemented in Assembly.

The resulting function accepts three double-precision parameters (value1, value2, and limit) and returns an integer status: 1 indicates the threshold has been exceeded, while 0 confirms the difference is within the acceptable range.

```
.section .text
.global check_limit

# int check_limit(double value1, double value2, double limit)
check_limit:

    # Step 1: compute difference = value1 - value2
    movapd %xmm0, %xmm3          # xmm3 = value1
    subsd  %xmm1, %xmm3          # xmm3 = xmm3 - xmm1

    # Step 2: check if difference < 0
    xorpd %xmm4, %xmm4           # xmm4 = 0.0
    comisd %xmm4, %xmm3          # compare xmm3 with 0
    jb make_positive              # if xmm3 < 0, jump

continue:

    # Step 3: compare |difference| with limit
    comisd %xmm2, %xmm3          # compare xmm3 with limit
    ja limit_exceeded             # if xmm3 > limit

    # Step 4: return 0 (not exceeded)
    movl $0, %eax
    ret

make_positive:
    # Step 2b: diff = 0 - diff  (manual absolute value)
    subsd %xmm3, %xmm4           # xmm4 = 0 - xmm3
    movapd %xmm4, %xmm3
    jmp continue

limit_exceeded:
    # Step 5: return 1 (limit exceeded)
    movl $1, %eax
    ret
```

Real-Time Tasks

The real-time task set has been refined to be more granular and atomic. Building upon the previous submission, these tasks are now further decomposed to provide greater detail.

Additionally, specific scheduling parameters were established for all tasks to comply with the previously identified timing constraints.

Table 7: Real-time tasks scheduling parameters.

TASK	C (ms)[1]	T (ms)	D (ms)
Read and transmit data from heat sensor.	500	2500	2000
Read and transmit data from light sensor.	500	2500	2000
Change intensity of artificial lights	300	-	5000
Change position of smart blinds	300	-	5000
Change temperature of smart heater	300	-	30000

The last three tasks in the set do not have an associated period (T). These are classified as aperiodic because they are event-driven, actuation occurs solely in response to changes in occupant preferences or manual system overrides.

[1] The listed execution times are currently preliminary estimates. A formal analysis will be conducted to determine the definitive Worst-Case Execution Time (WCET) for each task.