ClimaSense

Smarter confort, safer driving

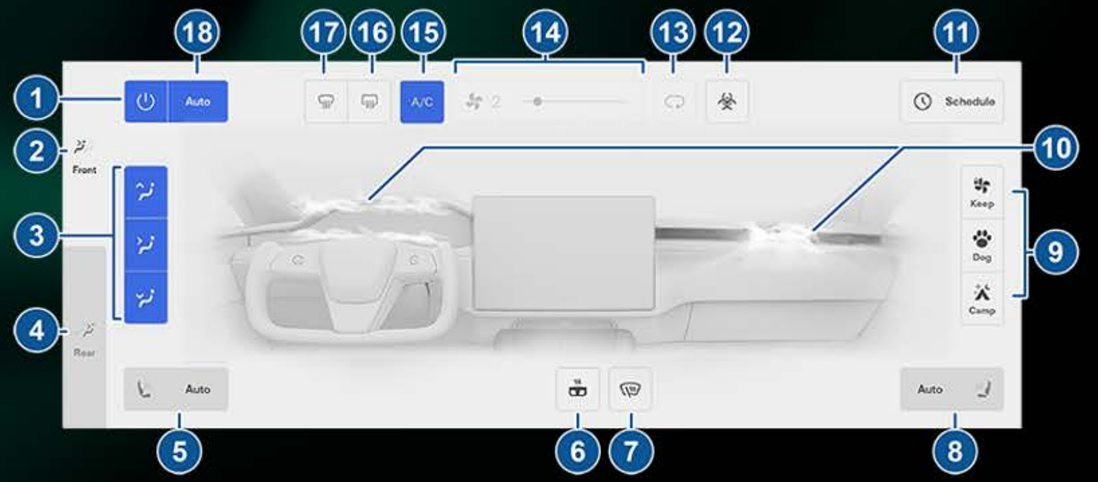
Current challenges

- Adjusting the air temperature and flow distracts the driver
- Incorrect air settings can stress driver and passengers, or induce drowsiness in the driver
- Climatization in cars is currently not adaptive, every preference has to be set either manually or by voice or apps

State of the art

in autonomous air conditioning systems

Tesla



- Automatically adjust air, seat and steering wheel temperature based (only) on cabin temperature
- Keep air conditioned if set to “Dog” mode or “Keep Climate On” mode

Everything must be set manually, either by touching the infotainment or by smartphone

We want to make every feature displayed here completely automatic, yet manually settable

Ferrari

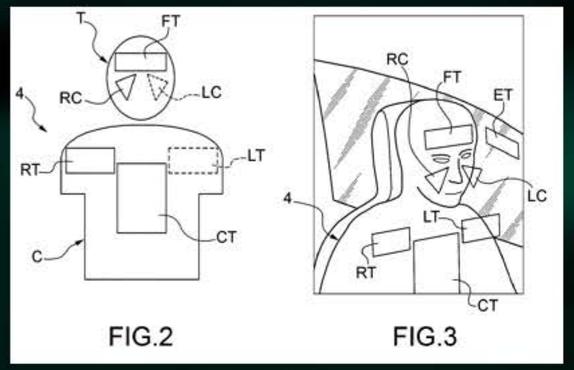


FIG.2 FIG.3

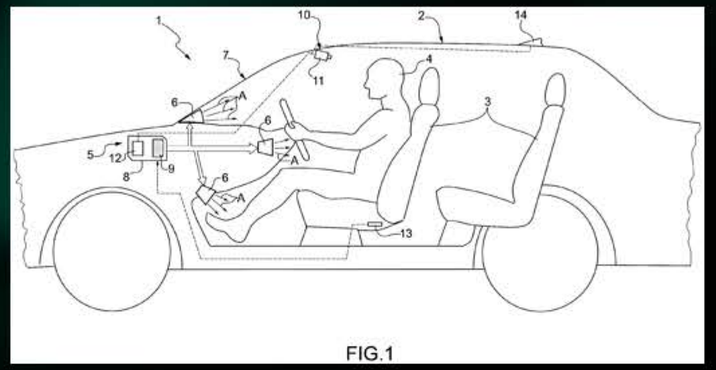


FIG.1

- Detects body temperature with thermal cameras to adjust ventilation and air temperature
- Detects windshield temperature to defrost automatically

Does not take into account passengers and driver emotions, does not adapt to infants or animals and does not detect drowsiness

Temperature regulation must be automatic and based on body temperature, emotion and type of passenger

ClimaSense idea

ClimaSense goals

Zero Distractions
Fully automatic climate control

Peaceful and Safe Travel
Active mitigation of driver stress and drowsiness

High Quality of Travel
Turn every journey into an enjoyable experience

Efficiency and Personalization
Optimal temperature and humidity for each individual passenger

Wellness for All
Personalized comfort even for those who cannot ask for it (infants, people with disabilities)

Market analysis

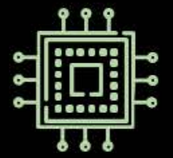
Brand	Maintain fixed temperature	Personalized climate settings	Vocal input adjusting	Sunlight aware	Interaction free adjusting	Emotion aware	Baby and pet care function
	✅	✅	✅	❌	❌	❌	✅
	✅	✅	✅	❌	❌	❌	❌
	✅	✅	✅	✅	❌	❌	❌
	✅	✅	✅	✅	❌	❌	❌
	✅	✅	✅	✅	✅	✅	✅

System specifications

Functional requirements

Passenger Detection and Analysis:

- The system must identify the presence and location of passengers inside the vehicle.
- The system must use facial expression recognition (FER) cameras to detect emotions (e.g., happiness, stress, discomfort), gaze direction, and satisfaction levels related to climate control.
- The system must be able to detect signs of stress or drowsiness in the driver through analysis of facial expressions and behavior.



Environmental and Body Monitoring:

- The system must use thermal cameras to detect the body temperature of passengers (e.g., forehead, chest, hands).
- The system must continuously monitor the temperature inside and outside the vehicle using appropriate sensors.
- The system must continuously monitor humidity levels inside and outside the vehicle via appropriate sensors.

Functional requirements

Adaptive Climate Control:

- The system must automatically adjust the temperature and power of airflow from the air vents, using servo motors, based on data collected from sensors and passenger analysis.
- The system must be able to redirect the airflow from the vents in an individualized manner for each passenger.
- The system must actively intervene to mitigate driver stress or drowsiness, such as through targeted fresh air jets or temperature changes.
- The system must optimize temperature and humidity distribution for each passenger, including those unable to express preferences (e.g., infants).

User Interface and Manual Override:

- Despite automation, the system must allow manual setting of climate control preferences via the vehicle interface (e.g., infotainment) or dedicated apps, if provided.

Non-functional requirements

Performance:

- Latency: The system must respond to changes in passenger and environmental conditions within a defined maximum time (e.g., 0.3 seconds) to ensure timely comfort.
- Accuracy: Sensors (thermal, humidity, RES cameras) must provide data with a high degree of accuracy. The emotion and stress recognition algorithm must have a minimum accuracy of 80%.

Reliability:

- If a sensor or component fails, the system must enter a safe mode or allow easy manual override.

Usability:

- The interaction for any manual override must be intuitive and require minimal effort on the part of the driver so as not to cause distraction.

Non-functional requirements

Safety (Safety & Security):

- The system must not compromise driving safety in any way.
- Data collected on passengers (images, temperatures) must be handled in compliance with privacy and GDPR regulations, with appropriate IT security measures.

Maintainability:

- The system must be designed to facilitate diagnostics, software upgrades, and eventual replacement of hardware components.

Robustness:

- The system must be able to function properly in a variety of environmental conditions (e.g., extreme temperatures, varying light levels for cameras).

Efficiency:

- The system must aim for optimized energy use so as not to place an undue burden on the vehicle battery.

Integration:

- The system must be able to integrate with the vehicle's existing electronic and software architecture.

What is needed?

Hardware

Cameras (FER)

From expression to action: how ClimaSense interprets users' needs

Servo motors

Intelligent Air Flow: automatic directioning for everyone's well-being

Thermal imaging cameras

Comfort on the skin: thermal mapping for precision air conditioning

Temperature and humidity sensors

The ideal environment, inside and out: advanced sensors for total control

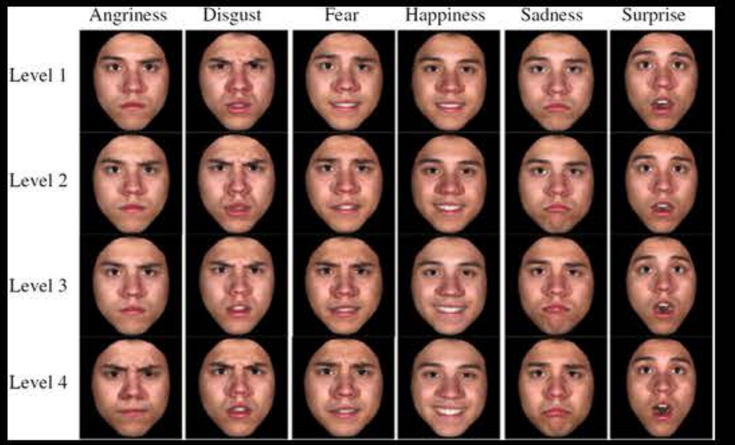
Cameras (FER)

How are they used?

- Facial Expressions Recognition
- Emotions, gaze, stress and satisfaction with air conditioning detection

What are the features extracted?

- Facial Expression features
- Stress value



Thermal imaging cameras

How are they used?

- Body temperature detection
- Climatisation effectiveness check and calibration

What are the features extracted?

- Forehead temperature
- Chest temperature
- Hands temperature

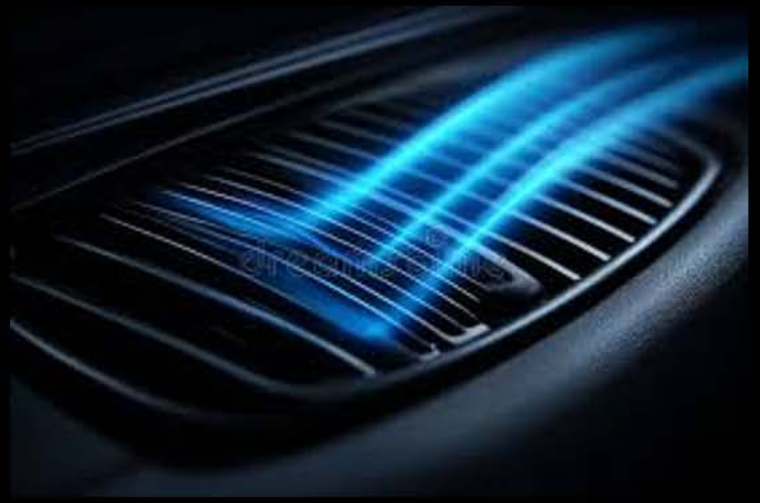
Servo motors

How are they used?

- On air vents:
  - Air flow redirection
  - Air flow power management

What are the features extracted?

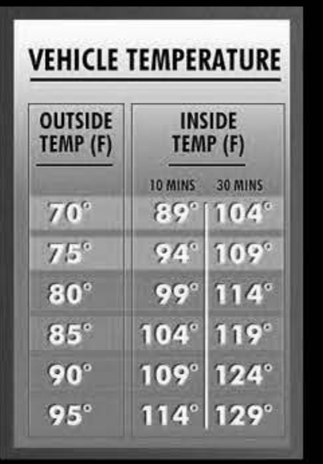
- Air flow angle



Temperature and humidity sensors

How are they used?

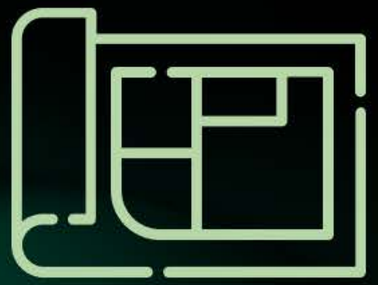
- Internal and External temperature detection
- Internal and External humidity detection
- Climatisation effectiveness check and calibration



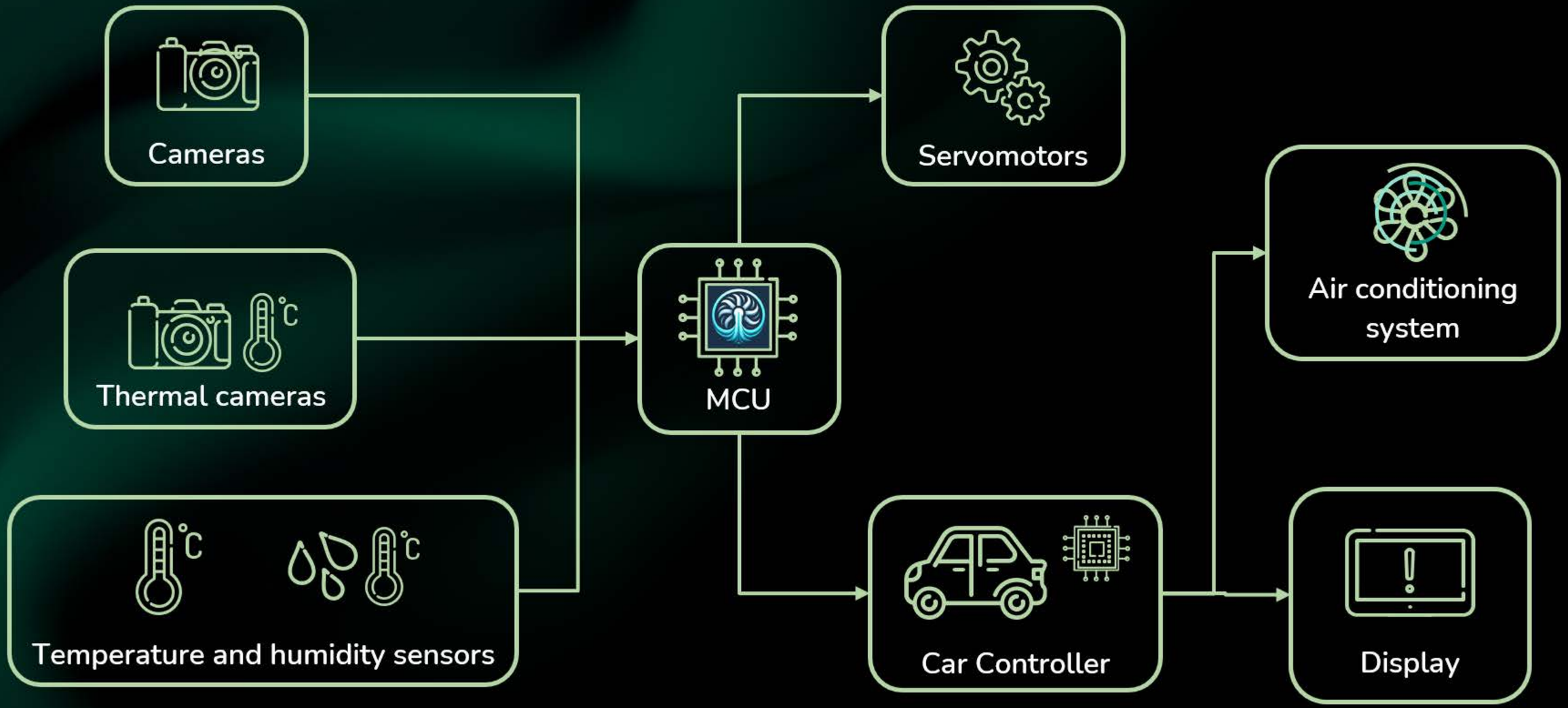
What are the features extracted?

- Internal temperature
- External temperature
- Internal humidity
- External humidity

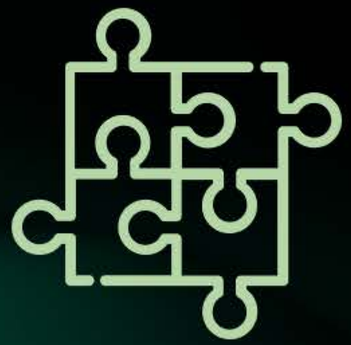
System architecture



System architecture



Work Packages



Work package #1 (1/3)

WP 1	WP Title: State-of-the-Art Analysis, Requirements Definition, and Feasibility Study WP Type: R.I.	Activity Start: Month 1	Activity End: Month 2
Man/Month: 1.35			

Objectives:
- Thoroughly understand current automatic and semi-automatic climate control technologies in vehicles.
- Identify the most suitable sensor technologies (cameras, thermal cameras, temperature/humidity sensors) and their current applications.
- Define in detail the functional and non-functional requirements of the proposed system.
- Evaluate the preliminary technical feasibility of the idea.

Activities:
- In-depth analysis of the state-of-the-art in automotive climate control systems and sensor fusion technologies; research on applications of cameras and thermal cameras for monitoring the vehicle's internal environment and occupants (Month 1).
- Study of temperature and humidity sensor types and their integration into complex systems (Month 1).
- Definition of system use cases and drafting of the user and system requirements document (Month 2).
- Preliminary feasibility analysis of the key identified technologies (Month 2).

Work package #1 (2/3)

Main Deliverables:
- D1.1: State-of-the-Art Analysis and Sensor Technologies Report (Month 1)
- D1.2: User and System Requirements Document (Month 2)
- D1.3: Preliminary Technical Feasibility Study Report (Month 2)

Roles hours per Task:
- Activity 1.1 (State-of-the-art):
  - Scientific Expert in the Automotive Field: Approx. 50 hours (0.3 Man/Month) @ €30/hour = €1,500
  - Biomedical Engineer: Approx. 25 hours (0.15 Man/Month) @ €30/hour = €750
- Activity 1.2 (Sensor Study):
  - Embedded Engineer: Approx. 25 hours (0.15 Man/Month) @ €35/hour = €875
- Activity 1.3 (Requirements and Use Cases):
  - Scientific Expert in the Automotive Field: Approx. 25 hours (0.15 Man/Month) @ €30/hour = €750
  - Scientific Researcher in Statistical Sciences: Approx. 50 hours (0.3 Man/Month) @ €25/hour = €1,250
  - Biomedical Engineer: Approx. 25 hours (0.15 Man/Month) @ €30/hour = €750
- Activity 1.4 (Technological Feasibility):
  - Embedded Engineer: Approx. 25 hours (0.15 Man/Month) @ €35/hour = €875

Work package #1 (3/3)

Total Expert Costs for WP1:
- Scientific Expert in the Automotive Field: 75 hours = €2,250
- Biomedical Engineer: 50 hours = €1,500
- Embedded Engineer: 50 hours = €1,750
- Scientific Researcher in Statistical Sciences: 50 hours = €1,250

Total WP Cost: €6,750

Work package #2 (1/2)

WP 2	WP Title: System Architecture Design and Key Component Selection WP Type: R.I./S.D.	Activity Start: Month 3	Activity End: Month 4
Man/Month: 1.35			
Objectives: - Define the overall hardware and software architecture of the system. - Select specific models of cameras, thermal cameras, temperature/humidity sensors, and the processing unit. - Define the interfaces between system components. - Derive product specifications based on user requirements.			
Activities: - Hardware architecture development: sensor placement, interconnections, choice of processing platform (Month 3). - Software architecture development: modules for data acquisition, image/thermal data processing, decision-making algorithms, climate control actuator control (Months 3-4). - Comparison and selection of specific hardware components based on performance, cost, integrability (Month 4). - Definition of communication protocols between sensors and the processing unit and drafting of detailed technical specifications (Month 4).			

Work package #2 (2/2)

Main Deliverables:
- D2.1: Hardware and Software Architecture Definition Document (Month 4)
- D2.2: List of Selected Components and Relative Technical Specifications (Month 4)
- D2.3: Product Technical Specifications Document (Month 4)

Roles hours per Task:
- Activity 2.1 (Hardware Architecture):
  - Embedded Engineer: Approx. 50 hours (0.3 Man/Month) @ €35/hour = €1,750
  - Scientific Expert in the Automotive Field: Approx. 25 hours (0.15 Man/Month) @ €30/hour = €750
- Activity 2.2 (Software Architecture):
  - Embedded Engineer: Approx. 50 hours (0.3 Man/Month) @ €35/hour = €1,750
  - AI Engineer: Approx. 50 hours (0.3 Man/Month) @ €40/hour = €2,000
- Activity 2.3 (Component Selection):
  - Embedded Engineer: Approx. 25 hours (0.15 Man/Month) @ €35/hour = €875
  - Scientific Expert in the Automotive Field: Approx. 25 hours (0.15 Man/Month) @ €30/hour = €750
- Activity 2.4 (Protocols and Specifications):
  - Embedded Engineer: Approx. 25 hours (0.15 Man/Month) @ €35/hour = €875

Total Expert Costs for WP2:
- Embedded Engineer: 150 hours = €5,250
- Scientific Expert in the Automotive Field: 50 hours = €1,500
- AI Engineer: 50 hours = €2,000

Total WP Cost: €8,750

Work package #3 (1/3)

WP 3	WP Title: Control Algorithm and System Software Development WP Type: E.D.	Activity Start: Month 5	Activity End: Month 8
Man/Month: 2.05			

Objectives:
- Develop algorithms for interpreting sensory data (person detection, thermal comfort estimation, emotion/stress detection).
- Implement the automated control logic for temperature and airflow regulation.
- Develop software for acquiring, processing, and fusing data from different sensors.
- Potential development of machine learning algorithms for system adaptation to user preferences (if planned).

Activities:
- Development of algorithms for image analysis (cameras) and thermal data (thermal cameras) for extracting relevant features (Months 5-6).
- Development of sensor data fusion algorithms and implementation of the decision-making logic for automatic climate control regulation (Months 6-7).
- Development of drivers for sensors and firmware for the processing unit, integration of software modules (Months 7-8).
- Testing and debugging of individual software modules and the data processing chain (Month 8).

Work package #3 (2/3)

Main Deliverables:
- D3.1: Commented Source Code of Data Analysis Algorithms and Control Logic (Month 8)
- D3.2: Commented Source Code of Firmware and Sensor Drivers (Month 8)
- D3.3: Software Module Test Report (Month 8)

Roles hours per Task:
- Activity 3.1 (Image/Thermal Analysis Algorithms):
  - AI Engineer: Approx. 100 hours (0.6 Man/Month) @ €40/hour = €4,000
  - Embedded Engineer: Approx. 50 hours (0.3 Man/Month) @ €35/hour = €1,750
- Activity 3.2 (Data Fusion and Decision Logic):
  - AI Engineer: Approx. 50 hours (0.3 Man/Month) @ €40/hour = €2,000
  - Embedded Engineer: Approx. 50 hours (0.3 Man/Month) @ €35/hour = €1,750
  - Biomedical Engineer (Comfort consultation): Approx. 20 hours (0.1 Man/Month) @ €30/hour = €600
- Activity 3.3 (Drivers and Firmware):
  - Embedded Engineer: Approx. 80 hours (0.45 Man/Month) @ €35/hour = €2,800
- Activity 3.4 (Software Module Testing):
  - AI Engineer: Approx. 20 hours (0.12 Man/Month) @ €40/hour = €800
  - Embedded Engineer: Approx. 30 hours (0.18 Man/Month) @ €35/hour = €1,050
  - Medical Expert (Consultation on comfort criteria validation): Approx. 15 hours (0.1 Man/Month) @ €35/hour = €525

Work package #3 (3/3)

Total Expert Costs for WP3:
- AI Engineer: 170 hours = €6,800
- Embedded Engineer: 210 hours = €7,350
- Biomedical Engineer: 20 hours = €600
- Medical Expert: 15 hours = €525

Total WP Cost: €15,275

Work package #4 (1/3)

WP 4	WP Title: Prototype Integration, Testing, and Functional Validation WP Type: E.D.	Activity Start: Month 9	Activity End: Month 12
Man/Month: 1.8			

Objectives:
- Assemble a working prototype of the automated climate control system.
- Integrate hardware components and the developed software.
- Test the complete system functionalities in simulated and/or real operational scenarios (in a controlled environment).
- Validate the system against the requirements defined in WP1.
- Collect performance data and feedback on perceived comfort to identify areas for improvement.

Activities:
- Physical assembly of the prototype: integration of sensors, processing unit, and connection to a climate control system (or simulator) (Months 9-10).
- Installation and configuration of the system software on the prototype (Month 10).
- Execution of functional and performance tests in the laboratory (Months 11-12).
- User testing sessions (pending setup of a controlled environment) to gather feedback on effectiveness and perceived comfort; analysis of results and drafting of the final validation report (Month 12).
- Preparation of the final technical documentation for the prototype (Month 12).

Work package #4 (2/3)

Main Deliverables:
- D4.1: Integrated Working Prototype (Month 10)
- D4.2: Functional and Performance Test Report (Month 12)
- D4.3: User Test Report and Feedback Analysis (Month 12)
- D4.4: Final System Validation Report (Month 12)
- D4.5: Final Technical Documentation of the Prototype (Month 12)

Roles hours per Task:
- Activity 4.1 (Prototype Assembly):
  - Embedded Engineer: Approx. 80 hours (0.45 Man/Month) @ €35/hour = €2,800
  - Scientific Expert in the Automotive Field: Approx. 20 hours (0.12 Man/Month) @ €30/hour = €600
- Activity 4.2 (SW Installation and Configuration):
  - Embedded Engineer: Approx. 30 hours (0.18 Man/Month) @ €35/hour = €1,050
  - AI Engineer: Approx. 20 hours (0.12 Man/Month) @ €40/hour = €800
- Activity 4.3 (Functional and Performance Tests):
  - Embedded Engineer: Approx. 50 hours (0.3 Man/Month) @ €35/hour = €1,750
  - AI Engineer: Approx. 30 hours (0.18 Man/Month) @ €40/hour = €1,200
  - Scientific Researcher in Statistical Sciences: Approx. 20 hours (0.12 Man/Month) @ €25/hour = €500

Work package #4 (3/3)

Roles hours per Task:
- Activity 4.4 (User Tests, Validation Report):
  - Scientific Expert in the Automotive Field (Test coordination): Approx. 30 hours (0.18 Man/Month) @ €30/hour = €900
  - Biomedical Engineer (Comfort assessment): Approx. 20 hours (0.12 Man/Month) @ €30/hour = €600
- Activity 4.5 (Final Documentation):
  - Embedded Engineer (Technical support and documentation): Approx. 20 hours (0.12 Man/Month) @ €35/hour = €700
  - AI Engineer (Technical support and documentation): Approx. 20 hours (0.12 Man/Month) @ €40/hour = €800

Total Expert Costs for WP4:
- Embedded Engineer: 180 hours = €6,300
- Scientific Expert in the Automotive Field: 50 hours = €1,500
- AI Engineer: 70 hours = €2,800
- Scientific Researcher in Statistical Sciences: 20 hours = €500
- Biomedical Engineer: 20 hours = €600

Total WP Cost: €11,700

Work packages summary

WP1: €6,750 (1.35 Man/Month)
WP2: €8,750 (1.35 Man/Month)
WP3: €15,275 (2.05 Man/Month)
WP4: €11,700 (1.8 Man/Month)

ESTIMATED TOTAL PROJECT COST: €42,475
ESTIMATED TOTAL MAN/MONTHS: 6.55 Man/Month

Gantt Chart

WP	Activity	1	2	3	4	5	6	7	8	9	10	11	12
State-of-the-Art Analysis, Requirements Definition, and Feasibility Study	In-depth analysis of the state-of-the-art in automotive climate control systems and sensor fusion technologies; research on applications of cameras and thermal cameras for monitoring the vehicle's internal environment and occupants												
	Study of temperature and humidity sensor types and their integration into complex systems												
	Definition of system use cases and drafting of the user and system requirements document												
	Preliminary feasibility analysis of the key identified technologies												
System Architecture Design and Key Component Selection	Hardware architecture development: sensor placement, interconnections, choice of processing platform												
	Software architecture development: modules for data acquisition, image/thermal data processing, decision-making algorithms, climate control actuator control												
	Comparison and selection of specific hardware components based on performance, cost, integrability												
	Definition of communication protocols between sensors and the processing unit and drafting of detailed technical specifications												
Control Algorithm and System Software Development	Development of algorithms for image analysis and thermalata for extracting relevant features												
	Development of sensor data fusion algorithms and implementation of the decision-making logic for automatic climate control regulation (Months 6-7).												
	Development of drivers for sensors and firmware for the processing unit, integration of software modules												
	Testing and debugging of individual software modules and the data processing chain												
Prototype Integration, Testing, and Functional Validation	Physical assembly of the prototype: integration of sensors, processing unit, and connection to a climate control system												
	Installation and configuration of the system software on the prototype												
	Execution of functional and performance tests in the laboratory												
	User testing sessions to gather feedback on effectiveness and perceived comfort; analysis of results and drafting of the final validation report												
	Preparation of the final technical documentation for the prototype												

Roles and responsibilities

Roles and responsibilities

Role	Estimated salary	Responsibilities
Scientific Researcher in Statistical Sciences	€25/hour	Data analysis, statistical studies
Scientific Expert in the Automotive Field	€30/hour	Market analysis, automotive technologies, vehicle integration, project coordination
Medical Expert	€35/hour	Consultation on physiological aspects of comfort/thermal stress
Biomedical Engineer	€30/hour	Human-environment interactions, comfort metrics, interpretation of sensory data related to comfort
AI Engineer	€40/hour	AI/ML algorithm development, training, deployment
Embedded Engineer	€35/hour	HW/SW development for sensors, control unit, embedded system

Risks

Technical risks

Accuracy and Reliability Algorithms (Software & AI)

Potential Impact:

- Costs: Potential user dissatisfaction, costs for post-launch software upgrades.
- Time: Prolongation of the development phase.

Mitigation Strategy:

- Investment in robust testing and validation phases with large and diverse datasets.
- Iterative development with continuous feedback.
- Provide for an extensive beta-testing phase.

Integration with Existing Vehicle Systems

Potential Impact:

- Costs: Additional development costs for customizations, need for specific expertise.
- Time: Delays in adoption by manufacturers.

Mitigation Strategy:

- Design ClimaSense with standardized interfaces to facilitate integration.
- Collaborate early with potential OEM partners.

Dependency on third-party hardware components

Potential Impact:

- Costs: Increased production costs, need for redesign for alternative components (R&D Costs).
- Time: Delays in prototyping and production.

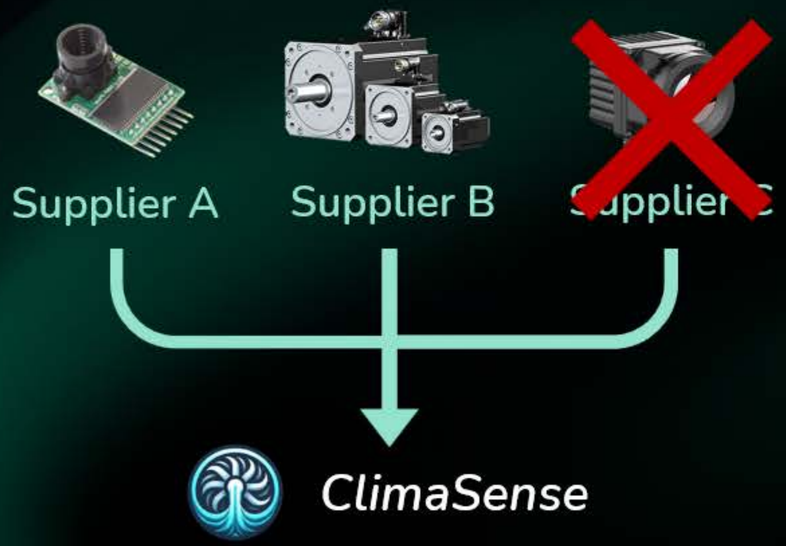
Mitigation Strategy:

- Identify multiple suppliers and technical alternatives for critical components.
- Enter into preliminary agreements or long-term orders (if feasible).
- Budget with contingency for price fluctuations.

Deep dive: Dependency on third-party hardware components

Most At-Risk Components:

- Thermal Cameras
- FER Cameras
- Microcontroller/SoC



Dependency given by: "Single Source" or "Limited Specialized Suppliers" (niche market)

Supplier Risk Type	Scenario	Est. Direct Cost (€)	Est. Delay (Months)	R&D Effort (M/M)
Supply Disruption	Thermal camera production stop (5 months)	175,000 (Lost Revenue)	5	-
Price Increase	+25% FER camera cost	60,000 (Annual)	-	-
Component Obsolescence	MCU redesign	72,500 (One-off)	7-10	Approx. 5
Supplier Quality	Defective humidity sensor batch	9,000+ (Annual from warranty)	-	-

Project and Management risks

Budget Overruns (Cost Overruns)

Potential Impact:

- Costs: Need for additional financing, reduced profitability.
- Time: Possible project disruptions if funds are not available.

Mitigation Strategy:

- Detailed cost planning and constant monitoring.
- Inclusion of a contingency reserve in the budget (e.g., 10-15%).
- Strict management of scope changes (scope creep).

Unforeseen technical complexities, supply delays, limited availability of skilled resources.

Potential Impact:

- Costs: Increased labor costs, loss of market windows.
- Time: Failure to meet agreed deadlines.

Mitigation Strategy:

- Realistic planning with clear milestones.
- Use of agile methodologies for flexibility.
- Critical path identification and proactive monitoring.

External and Market risks

Regulatory and Privacy Compliance (GDPR)

Potential Impact:

- Costs: Legal costs, significant fines for non-compliance, reputational damage.
- Time: Design adjustments to comply with regulations.

Mitigation Strategy:

- Specialized legal advice from the earliest stages of design (Privacy by Design).
- Clear processes for consent and data management.
- Data protection impact assessments (DPIA).

Rapid Technology Obsolescence

Potential Impact:

- Costs: Need for frequent upgrades or redesigns (R&D costs).
- Time: Reduction in product life cycle.

Mitigation Strategy:

- Modular architecture that facilitates component upgrades.
- Continuous monitoring of technology trends.
- Focus on software upgrades to improve functionality over time.

Market and User Unacceptance

Potential Impact:

- Costs: Low sales volumes, higher marketing costs to educate the market.

Mitigation Strategy:

- Clear communication of comfort, safety and welfare benefits.
- Ensure transparency on data management and GDPR compliance.
- Targeted marketing campaigns and effective demos.

References

- Tesla air conditioning system: https://www.tesla.com/ownersmanual/modelx/en_us/GUID-4F3599A1-20D9-4A49-B4A0-5261F957C096.html
- Mercedes-Benz air conditioning system: https://patents.google.com/patent/EP38321d325A1/de?oq=dEP3n865vdsd325A1
- Volkswagen air conditioning system: https://www.volkswagen-newsroom.com/en/press-releases/new-volkswagen-id7-with-smart-air-conditioning-15415
- Ferrari air conditioning system: https://patents.google.com/patent/EP3865325A1/de?oq=EP3865325A1

THANK YOU