Vitality HUB Perceived Thermal Comfort | Project Plan

Thermal Comfort-as-a-Service (CaaS) IoT system

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Contents

Version control

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Introduction

Within the scope of smart sensing and awareness system development for the Vitality HUB this document presents an updated project plan aligned with EU‑funded LOLLIPOP‑IoT goals on energy reduction and comfort optimization. It adopts a user‑centered, V‑model‑based systems development approach, detailing refined user stories, requirements, and high‑level architecture for a reproducible Comfort‑as‑a‑Service solution focused on perceived thermal comfort for both the lab and client sites.

Background

The initial concept was an AIoT LED sensing Black Board [1]. Then it was restructured into a system of modular wireless components with sensors, LED output and analog input. The reason was an internal organisational change in the project, quitting 3Beam and new operational policy. To avoid IP conflicts, a new project plan was made [2]. These components had to magnetically connect to existing whiteboards in offices and provide the necessary IoT Infrastructure and ecosystem. After a discussion with the system architect at Vitality HUB, several remarks were received:

- Project plan missed user stories,
- Without user stories requirements were unclear,
- Ongoing research with perceived thermal comfort gained higher priority and hardware was obtained for it to sense the indoor environmental quality. This is a funded project (with EU funding) https://www.lolipop-iot.eu/, focusing on energy reduction and comfort optimization.

Based on this feedback a new literature study in perceived thermal comfort was conducted, a study of available hardware, user stories and initial V-model stages were outlined.

Objectives

1. Develop and validate an occupant-centric Comfort-as-a-Service platform in the Living Lab that senses and predicts perceived thermal comfort, engages workers and visitors through simple feedback channels, and is reproducible on client sites to enhance workplace vitality while reducing energy use.

2. Provide a research-grade, centrally managed infrastructure that enables researchers and infrastructure owners to experiment with models and control strategies, collect high-quality multimodal data (including from low-power or energy-harvested wireless sensors), and rigorously evaluate their impact on comfort and energy performance for future smart-building deployments.

Problem statement & proposed solution concept

The current situation in the Vitality HUB and comparable workplaces is characterized by a persistent tension between maintaining comfortable indoor conditions for diverse occupants and reducing energy use, aggravated by fragmented sensor deployments, limited occupant feedback channels, and a lack of actionable insight into how people actually experience the environment.

Despite existing building automation and monitoring, comfort is often tuned to generic standards rather than real occupant needs, making it difficult for workers and visitors to influence conditions, and for researchers and facility managers to evaluate comfort–energy trade-offs in a systematic, data-driven way.

To address these pain points, the proposed solution is a reproducible Comfort-as-a-Service platform that fuses dense Indoor Environmental Quality (IEQ) and location sensing with occupant self-reports to estimate and predict perceived thermal comfort, provides simple feedback and visualization interfaces for occupants, and exposes configurable control and experimentation tools for researchers and infrastructure owners.

Deployed first in the Vitality HUB Living Lab and designed to integrate emerging long-life power platforms from the LoLiPoP-IoT project, this service-oriented system wraps sensing, prediction, feedback, and comfort-aware control into a transferable blueprint that can be replicated on client sites to enhance workplace vitality while supporting energy optimization and low-maintenance, retrofit-friendly instrumentation.

Literature Review: Background & State of the Art on Perceived Thermal Comfort

Perceived thermal comfort research has evolved from population-average models such as Predictive Mean Vote (PMV) and Adaptive Comfort. They link comfort to heat balance and outdoor climate but only correctly predict individual sensations in a fraction of real-world cases. Aiming toward occupant- and building-specific models that leverage self-reported feedback, contextual human factors (e.g. clothing, activity, mood), and rich sensor data to significantly improve predictive accuracy and support more responsive, energy-aware control of Heating, Ventilation, and Air Conditioning (HVAC) and related systems in everyday buildings.

Recent studies and reviews demonstrate that combining mobile or wearable self-reporting, machine-learning-based personal comfort models, and emerging Comfort-as-a-Service concepts—where occupants provide simple feedback and receive tailored comfort while operators gain data-driven tools—offers a practical, validated pathway to higher satisfaction, better handling of individual diversity, and meaningful energy savings in smart workplaces and living labs.

Complete review: literature_review_perceived_thermal_comfort.pdf

Stakeholders & user groups

The project involves multiple stakeholder groups with distinct but complementary interests in workplace vitality, perceived thermal comfort, and smart building operation.

- **Workers and visitors (building occupants)** – People using the Vitality HUB and client workplaces on a daily basis. Their primary interests are a comfortable, healthy indoor environment, minimal disruption, simple ways to express comfort preferences, transparency about how their feedback is used, and assurance of privacy and data protection.

- **Researchers** – Academic and industrial researchers using the Living Lab as an experimental environment. They seek high-quality multimodal datasets (sensors, location, self-reports), flexible experimentation with different comfort models and control strategies, reproducible protocols, and tools to analyze and publish results.

- **Infrastructure owners and facility managers** – Parties responsible for the Living Lab and client buildings (e.g. real estate, IT/OT, facility services). Their interests include reliable operation, energy reduction, integration with existing BMS/IoT infrastructures, low-maintenance sensing (including long-life / energy-harvested devices), and dashboards that link comfort, complaints, and energy KPIs to support operational decisions and investment cases.

- **LOLLIPOP-IoT consortium partners** – Technology and research partners developing long-life power platforms for wireless IoT edge devices. Their interests are to validate energy-harvesting and micro-power management solutions in a realistic smart-building use case, gather requirements and field data from the Vitality HUB and client pilots, and demonstrate transferable solutions for retrofittable, low-power comfort sensing in energy-efficient buildings.

Project scope & boundaries

In this phase, the project focuses on designing, implementing, and piloting an occupant-centric Comfort-as-a-Service system for perceived thermal comfort in the Vitality HUB Living Lab, with a clear path to replication at client sites. The emphasis is on end-to-end functionality—from user stories and requirements through predictive algorithms, integration and verification—rather than on production-grade scaling or realizing new hardware energy-harvesting platforms.

In scope

- Conduct analysis of the context and stakeholders, compile initial user stories, and iteratively validate them against literature and Living Lab needs.
- Perform a literature review on perceived thermal comfort, existing models and control approaches, and relevant datasets and tools.
- Derive functional and non-functional requirements from user stories and state of the art (for occupants, researchers, facility owners, and LoLiPoP-IoT partners).
- Design a high-level system architecture (interaction, sensing, analytics/control, research/operations) consistent with the V-model.
- Provide detailed technical specifications for the system, including how available hardware, sensors, and infrastructure are to be used.
- Provide standardized diagrams for HW/SW/Infra levels.
- Realize the system using the available hardware: develop software and firmware, integrate devices, set up communication and data infrastructure, and deploy in the Living Lab.
- Utilize previously developed smart sensor kit (AIoT Black Board). Integrate new sensors, make an easily reproducible and upgradable kit.
- Design the predictive algorithm/solution for perceived thermal comfort (starting with an LLM-based approach and, if needed, complementing or replacing it with ML/RL or fine-tuned models as suggested by best practices).
- Implement and operationalize the predictive algorithm within the system, including data pipelines, model execution, and basic monitoring.
- Ensure that the model can be adaptive and use different amounts of input sources. E.g. minimal number of sensors. Or more input from advanced systems and the building.
- Integrate all components, perform system-level testing, and verify that requirements are met.
- Design a software application for user feedback and interaction.
- Realize the software for user feedback as a web-application accessible from a smartphone.
- Design central dashboard, presumably with Home Assistant.
- Realize the central dashboard.

Potentially in scope (subject to time/resources)

- User testing with workers/visitors and researchers in the Living Lab (e.g., usability of feedback channels, perceived usefulness of predictions and visualizations).
- Iterative tuning and customization of the predictive algorithm(s) based on test results and validation studies.
- System verification and validation against defined KPIs (comfort indicators, engagement, basic energy metrics, data quality).
- Contribution to the LoLiPoP-IoT research mission at the use-case level: defining requirements for long-life/energy-harvested sensors, hosting and instrumenting pilot nodes, and analyzing their performance in the comfort use case (without building the EH hardware itself).
- Design and realize hardware/tablet for user feedback

Out of scope (for this phase)

- Full realization and industrialization of energy-harvesting or micro-power hardware platforms (these are developed at consortium level; this project acts as a use case and integrator, not the primary hardware designer).
- Delivery of a production-grade, fully productized solution ready for large-scale commercial deployment across many external buildings (beyond a well-engineered Living Lab deployment and limited demonstrator-style client pilots).

Implementation & deployment approach

Implementation follows a phased V-model-aligned approach, starting with analysis and design, then moving to prototyping, integration, and Living Lab deployment, with a clear hand-over point to the next semester for extended user research.

1. **Analysis & literature study**
    - Consolidate user stories, stakeholder needs, and LoLiPoP-IoT context.
    - Perform the literature study on perceived thermal comfort models, data collection methods, and Comfort-as-a-Service patterns.
    - Refine functional/non-functional requirements and initial KPIs.

2. **Architecture & technical design**
    - Finalize the high-level system architecture (interaction, sensing & context, data integration, analytics & prediction, control/operations).
    - Define interfaces between software, infrastructure, and hardware work packages (e.g. APIs, data schemas, integration with Home Assistant and building systems).
    - Produce detailed technical specifications for the sensing network, data platform, and predictive algorithm pipeline.

3. **Prototype implementation**
    - Implement the first version of the occupant feedback web/mobile app.
    - Integrate the key hardware components (Senseca logger, Zigbee sensors, Aqara hub, Home Assistant, building and weather APIs) into a unified data pipeline. Utilize the existing smart sensor kit.
    - Implement baseline comfort calculations (PMV, adaptive) and an initial predictive algorithm (LLM-driven pipeline plus simple ML models where needed).

4. **System build & lab deployment (target: by February)**
    - Harden the prototype into a stable lab deployment: containerize or otherwise package services, configure monitoring/logging, and document deployment steps.
    - Deploy the full stack in the Vitality HUB: sensors installed and mapped to zones, backend running, app available to selected internal users.
    - Conduct internal pilot testing (technical validation, small group of early users) and fix integration issues.

5. **Handover for extended user research (next semester)**
    - At the start of the next semester (February), provide the ready system to VHUB researchers as a platform for structured user studies, UX refinement, and model validation.
    - Use their findings to guide iterative improvements, customization of predictive algorithms, and preparation for potential external client pilots in a later phase.

Risk analysis & mitigation

1. Technical risks

R1 – Sensor / integration failures

- Risk: Zigbee devices, logger, or building APIs are unstable or harder to integrate than expected.
- Mitigation:
    - Start with a minimal “happy path” (1–2 sensors + logger + Home Assistant) and harden that before scaling.
    - Use proven integrations (HA, MQTT) and log all failures for quick debugging.
    - Keep a small set of backup devices (extra temp/humidity sensor, second gateway).

R2 – Data quality and gaps

- Risk: Missing timestamps, inconsistent units, mis-labelled zones, or long offline periods make data unusable for modelling.
- Mitigation:
    - Define a simple data schema early (units, naming, zone IDs).
    - Implement basic validation (sanity ranges, heartbeat checks per sensor).
    - For analysis, plan for cleaning scripts and document known gaps.

R3 – Predictive model underperforms

- Risk: LLM/ML models do not beat simple baselines or are too noisy for useful feedback.
- Mitigation:
    - Start with baselines (PMV, adaptive, simple regression) as a benchmark.
    - Implement Model Context Protocol, add system prompt into LLM to guide it through existing models and best practices.
    - Frame this phase as “building the pipeline” and “exploring feasibility”, not as guaranteeing high accuracy.
    - Keep the architecture model-agnostic so another model can be swapped in later.
    - Use existing Python libraries and frameworks for Thermal Comfort. Implement best practices around these frameworks.

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2. User adoption & data risks

R4 – Low occupant engagement

- Risk: Few people use the feedback app, so you don’t get enough subjective data.
- Mitigation:
    - Keep feedback to 1–2 taps; avoid long surveys.
    - Pilot with a small, motivated group (e.g., lab staff, students) and schedule short “campaigns” rather than permanent prompting.

    - Offer simple feedback in return (e.g., “comfort map” or trend view) so interaction feels meaningful.

R5 – Privacy concerns

- Risk: Users hesitate to participate because of location tracking and comfort data.
- Mitigation:
    - Use pseudonymous IDs and zone-level, not desk-level, reporting for this phase.
    - Provide a short, clear participation text: what is collected, why, and how it’s protected.
    - Make participation voluntary and easy to stop.

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3. Organizational / project risks

R6 – Scope creep

- Risk: Trying to implement full BMS control, advanced UX, and production-grade infrastructure within one semester.
- Mitigation:
    - Explicitly limit scope to: data pipeline + basic app + initial models + lab deployment.
    - Treat building API control and sophisticated UX as “future work” unless time remains at the end.
    - Use the V-model plan to keep focus on agreed deliverables.

R7 – Dependency on stakeholders (building IT, ethics, LoLiPoP partners)

- Risk: Delays in getting access to building APIs, network permissions, or formal approvals.
- Mitigation:
    - Design the system so the lab-only operation (local sensors + weather API) still delivers value.
    - Start API / access requests early, but plan a fallback scenario without deep BMS integration.

Governance, roles & responsibilities

This project is governed as a Vitality HUB Living Lab use case under the broader LoLiPoP‑IoT framework and EU government, with clear but lightweight roles suitable for a student‑led implementation.

- **Vitality HUB / local stakeholder**
  Acts as the use‑case owner and primary contact: defines and prioritizes goals, approves scope and milestones, provides access to the space, building data and stakeholders, and signs off on major decisions and deliverables.

- **Fontys ICT student team (2 Delta students)**
  Owns day‑to‑day execution: requirements analysis, literature study, architecture and technical design, implementation of sensing integration and data platform, development of the feedback/prediction software, lab deployment, and technical documentation. The team reports progress to the Vitality HUB contact, raises risks and scope issues, and prepares summary material that can be fed into LoLiPoP‑IoT reporting by the stakeholder.

- **LoLiPoP‑IoT**
  This work is carried out in the context of the EU‑funded LoLiPoP‑IoT project, which develops long‑life power platforms and energy‑harvesting/micro‑power management solutions for wireless IoT edge devices. Within this framework, Vitality HUB use case focuses on applying these technologies to reduce energy use and optimize perceived comfort in smart workplaces.

Operationally, day‑to‑day technical and design decisions are taken by the student team, while changes to scope, timeline, or alignment with LoLiPoP‑IoT objectives are agreed with the Vitality HUB stakeholder in periodic check‑ins.

Timeline, milestones & deliverables

[Late November]
Dates slack time for every task prioritize external dependencies
Phase 1: Analysis, literature & requirements (Week 1 - 2)

- Activities:
    - Refine project objectives.
    - Finalize user stories.
    - Consolidate key findings from perceived thermal comfort literature.
    - Collect enough research-based information to define the architecture (sensors, API, building, human)
    - The algorithm for AI-based sensing and prediction.
- Milestones:
    - M1: Scope (including in-scope/out-of-scope list).
    - M2: Draft user stories and initial list of functional/non-functional requirements.
    - M3: List of milestones.
- Deliverables:
    - D1: Project plan with a short “Background & State of the Art” section.
    - D2: Requirement document
    - D3: Milestone plan

Phase 2: Sensor hub (Week 3 - 4)

- Activities:
    - Designs and first prototype of data-pipeline with C4 levels 1 & 2.
    - Choose deployment target (local microcomputer vs. simple cloud setup).
    - Build first prototype, uploading data to the database.
- Milestones:
    - M4: Approved system concept & high-level architecture diagram.
    - M5: Defined database schema and integration plan (Home Assistant, Zigbee, logger, APIs).
- Deliverables:
    - D1: architecture section in the plan, integration checklist.
    - D2: data schema document
    - D3: C4 levels 1 & 2
    - D4: Realized Home Assistant set up, connected sensors (which available), DB

[December]
Phase 3: AI Advice (Week 5–6)

- Activities:
    - Best good and bad practices
    - LLM Competitor Analysis
    - LLM Available product analysis
    - Requirements for our language model

    - Design C4
    - Explore available Python frameworks and modules
- Milestones:
    - M6: “Thin slice” data pipeline working end-to-end (Sensor → DB → simple visualization).
    - M7: System prompt (rules)
    - M8: Model Context Protocol (MCP) Server
    - M9: Realized solution to get user feedback (Google Form or Web-based App)
    - M10: Implement PMV/adaptive comfort calculations using available data and Python modules
- Deliverables:
    - D1: running lab instance with core devices connected
    - D2: basic monitoring/logging,
    - D3: short integration notes,
    - D4: user feedback integrated into the pipeline
    - D5: AI component works, can analyse live input, give advice, predict, suggest changes

[December]
Phase 4: Connecting data pipeline and AI app (Week 7)
- Activities:
    - Design and implement the first prototype of the system dash board.
    - Connect the Data pipeline to the database
    - Troubleshoot integration issues
    - Display simple system information.
- Milestones:
    - M11: Feedback app MVP usable by a small internal group.
    - M12: Baseline comfort indices computed and visible in a simple dashboard
- Deliverables:
    - D1: app prototype.
    - D2: baseline comfort computation module
    - D3: updated documentation.

[January]
Phase 5: Internal pilot, wrap-up & hand-over (Week 9)
- Activities:
    - Short internal pilot with a small group of occupants.
    - Fix major issues.
    - Prepare documentation and hand-over materials for the next semester.
- Milestones:
    - M13: Internal pilot completed and main findings documented (what works, what needs improvement).
    - M14: Hand-over package ready for next-semester user research and potential client replication discussions.
- Deliverables:

- D1: Final project report (with architecture, implementation, and lessons learned).
- D2: Operations & deployment guide (so the lab can keep it running).

Future extensions & roadmap

Beyond the current project phase, the system can evolve along four main directions.

1. **Deeper smart‑building integration**
   - Extend integration from the current “advisory” and limited control actions to deeper interaction with the full building management system (BMS), including zone set‑point optimization, schedule adaptation, and demand‑response scenarios.
   - Connect additional building data sources (e.g. room booking, access control, detailed sub‑metering) to refine context and enable more advanced comfort–energy trade‑off strategies.

2. **Broader IEQ and Comfort‑as‑a‑Service scope**
   - Extend the platform from thermal comfort to a fuller IEQ perspective, incorporating acoustic comfort, lighting quality, and more detailed indoor air quality metrics, with corresponding feedback channels in the app.
   - Evolve the current prototype into a richer Comfort-as-a-Service offering, with configurable service “profiles” (e.g. focus on productivity, energy saving, or well-being) that can be tailored per building or tenant.

3. **LoLiPoP‑IoT integration and edge intelligence**
   - Gradually push selected analytics to the edge (e.g. simple comfort indicators or anomaly detection in sensor nodes or gateways) to reduce data traffic and power use, in line with LoLiPoP’s edge‑centric vision.

4. **Scaling, research, and replication**
   - Conduct larger‑scale user studies in subsequent semesters to refine interaction design, validate personal comfort models, and quantify comfort and engagement gains.
   - Prepare a generic deployment template (technical stack, configuration patterns, and minimal requirements) so the solution can be piloted in one or two external client buildings, testing adaptability to different BMS and organizational contexts.
   - Use accumulated data and experience to support academic publications, contributions to LoLiPoP‑IoT use‑case reporting, and possibly open, anonymized datasets to foster further research on perceived thermal comfort in real workplaces.

Conclusion

The project defines and implements an occupant-centric Comfort-as-a-Service prototype in the Vitality HUB Living Lab, using existing sensing hardware, building data, and a new feedback application to estimate and predict perceived thermal comfort. Within a limited timeframe, the work delivers a coherent architecture, an integrated data and sensing infrastructure, and a first predictive pipeline that together form a solid basis for subsequent user research, LoLiPoP-IoT technology validation, and future replication in client buildings.

Reference

1. Kraskov A., (2025), Project Proposal: WPVH Cluster Boards, [Online] Available:
   Canvas:
   https://fhict.instructure.com/courses/13084/assignments/270319?module_item_id=1369038
   Doc: Project Proposal: WPVH Cluster Boards
2. Kraskov A., (2025), Beets: Project Plan, [Online] Available:
   Canvas:
   https://fhict.instructure.com/courses/13084/assignments/270909?module_item_id=1371523
   PDF: Project Plan Beets
3. Kraskov A., (2025), Literature review on perceived thermal comfort, [Online] Available:
   PDF: literature_review_perceived_thermal_comfort.pdf