

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

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Table of Contents

| | |
|---|----|
| List of Tables..... | 6 |
| List of Figures..... | 6 |
| Used abbreviations..... | 7 |
| Executive Summary | 8 |
| 1.Introduction | 9 |
| 1.1 The oPEN Lab approach to PENS..... | 9 |
| 1.2 Aim of deliverable | 10 |
| 1.3 Structure of the deliverable | 11 |
| 2.Methodology..... | 13 |
| 2.1 Desk research and literature review..... | 13 |
| 2.2 oPEN Lab project deliverables and data collection..... | 13 |
| 2.3 Technical tests..... | 14 |
| 2.4 Qualitative research | 15 |
| 3.Occupant-technology interactions in PENS..... | 16 |
| 3.1 Technology inside the home | 16 |
| 3.2 Technology outside the home | 20 |
| 3.3 Studying technology acceptance..... | 21 |
| 3.4 Studying occupant-technology interaction..... | 27 |
| 3.5 oPEN Lab approach to studying technology acceptance and user-technology interactions in PENS..... | 28 |
| 4.Technology and user in the oPEN Lab PENS | 32 |
| 4.1 Genk PEN local context..... | 32 |
| 4.1.1 Qualitative feedback gathering in the Genk LL..... | 33 |
| 4.1.2 Technology-occupant interactions in the Genk PEN | 44 |
| 4.1.2.1 Internal systems testing: analytics and monitoring in the Genk PEN | 44 |
| 4.2 Pamplona PEN local context..... | 44 |
| 4.2.1 Qualitative feedback gathering in the Pamplona PEN | 45 |
| 4.2.2 Technology-occupant interactions in the Pamplona PEN | 47 |
| 4.2.2.1 Internal systems testing: analytics and monitoring in the Pamplona PEN..... | 47 |
| 4.3 Tartu PEN local context | 49 |
| 4.3.1 Qualitative feedback gathering in the Tartu PEN..... | 49 |
| 4.3.2 Technology-occupant interactions in the Tartu PEN..... | 50 |
| 4.3.2.1 Internal systems testing: analytics and monitoring in the Tartu PEN | 51 |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

5.Lessons learnt on occupant-technology interaction in the PENs of oPEN Lab: technology optimisation and user responses52
Future updates53
References.....54
Annex 1: Data collection template for technologies/setpoints/indicators56
Annex 2: Data collection template for technical tests planned/conducted57
oPEN Lab Partners59

DRAFT

List of Tables

| | |
|---|----|
| Table 1. oPEN Lab project deliverables and materials relevant for D5.4 | 14 |
| Table 2. Barriers to implementing home automation systems. Source: authors, based on exemplary projects learnings. | 19 |
| Table 3. oPEN Lab approach to study technology-occupant interaction. Source: authors | 30 |
| Table 4. oPEN Lab multi-layered mixed-method approach. Source: authors | 31 |
| Table 5. The district and building level technologies deployed in oPEN Lab PENs..... | 32 |
| Table 6. Qualitative feedback gathering method 1 in Genk..... | 35 |
| Table 7. Qualitative feedback gathering method 2 in Genk..... | 37 |
| Table 8. Qualitative feedback gathering method 3 in Genk..... | 40 |
| Table 9. Qualitative feedback gathering method 4 in Genk..... | 42 |
| Table 10. Qualitative feedback gathering method 5 in Genk..... | 44 |
| Table 11. User-technology interactions in the Genk PEN | 44 |
| Table 12. Qualitative feedback gathering method 1 in Pamplona | 46 |
| Table 13. User-technology interactions in the Pamplona PEN..... | 47 |
| Table 14. Internal systems testing method 1 in Pamplona..... | 48 |
| Table 15. Qualitative feedback gathering method 1 in Tartu..... | 50 |
| Table 16. User-technology interactions in the Tartu PEN | 51 |

List of Figures

| | |
|---|----|
| Figure 1. Characteristics of Living Labs..... | 9 |
| Figure 2. Structure of the deliverable..... | 12 |
| Figure 3. Examples of occupant energy consumption at home. | 17 |
| Figure 4. A smart home system control panel installed in a private apartment – an example of an energy feedback method..... | 18 |
| Figure 5. Models of UTAUT and UTAUT2. | 23 |
| Figure 6. Approach to studying occupant-technology interaction..... | 29 |

Used abbreviations

| Abbreviation | Meaning |
|--------------|--|
| NZEB | Near Zero Energy Building |
| PEN | Positive Energy Neighbourhood |
| PV | Photovoltaics |
| EV | Electric Vehicle |
| BIPV | Building-Integrated Photovoltaics |
| DH | District Heating |
| PPPP | Public-private-people partnership |
| HVAC | Heating, Ventilation, and Air Conditioning |
| TAM | Technology Acceptance Model |
| UTAUT | The Unified Theory of Acceptance and Use of Technology |
| SEM | Structural Equation Modelling |
| RH | Relative Humidity |

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Executive Summary

Report D5.4, *Lessons learnt on occupant–technology interaction in nearly zero energy buildings and districts*, is an output of the oPEN Lab project, which develops Positive Energy Neighbourhoods (PENs) through real-life Living Labs in Tartu (EE), Pamplona (ES), and Genk (BE).

This deliverable investigates the **interaction between occupants and technologies**, considering both technical and social dimensions. Its key goals are to evaluate how technologies affect **resident well-being and comfort**, assess **user acceptance and behaviour**, and identify ways to **optimise technology performance and engagement**. The study also explores the role of third-party actors (e.g. local authorities, housing associations, energy companies) in facilitating adoption.

This report adopts a **mixed-method, multi-layered approach** combining:

1. **Desk research and literature review** on technology acceptance and occupant behaviour, drawing on widely recognised technology acceptance models as well as the social practice theory.
2. **Project data** from other oPEN Lab deliverables and work packages, including reports on building and district technology demonstrations.
3. **Technical tests**, encompassing monitoring, analytics, and optimisation activities that measure or analyse how residents interact with installed systems.
4. **Qualitative research**, qualitative inquiries, surveys, interviews, workshops, and participatory activities designed to capture users' experiences, perceptions, and comfort levels.

Preliminary insights from the literature highlight that occupant behaviour, technical/digital literacy, and trust are critical to the success of nearly zero energy systems. While smart home and energy feedback technologies improve comfort, efficiency, and awareness; barriers include high costs, technical complexity, privacy concerns, and waning user engagement over time. Residents' digital competence and socio-economic background influence interaction patterns, underscoring the need for intuitive interfaces, clear communication, and continued guidance. The research recommends user-centric design, transparent information on benefits, and participatory feedback loops to sustain long-term user engagement with smart home technologies.

Methodologically, self-reported data of oPEN Lab emerging PEN end users will be combined with technical monitoring to track user behaviour with technology, behavioural change, and seek means of optimisation in PEN contexts.

The final version that is due in autumn 2026 will integrate post-renovation data from all three oPEN Lab cities – Genk, Pamplona and Tartu - and distil comprehensive lessons on user behaviour, technology optimisation, and behavioural adaptation within the PENs of oPEN Lab.

1. Introduction

1.1 The oPEN Lab approach to PENs

The aim of the oPEN Lab project is to revitalise urban areas across Europe to lead the transition to Positive Energy Neighbourhoods (PENs). The activities of the project take place in three cities in different parts of Europe: Tartu (EE), Pamplona (ES), and Genk (BE).

These cities have chosen specific neighbourhoods for demonstration activities. They are advancing these selected neighbourhoods through a Living Lab approach, which integrates technological experimentation, social innovation, and stakeholder co-creation within real urban contexts and enables testing promising new technologies, processes and social innovations in an integrated approach. The aim is to facilitate the (future) advancement of an energy-efficient and energy-flexible urban area – a PEN – through renovation and local renewable energy production while also taking into account the context of each Living Lab.

At the core of each Living Lab lies a **multi-stakeholder approach** to creating PENs in which stakeholders from key sectors (government, industry, academia, residents/people) come together to form a public-private-people partnership (PPPP), see Figure 1.

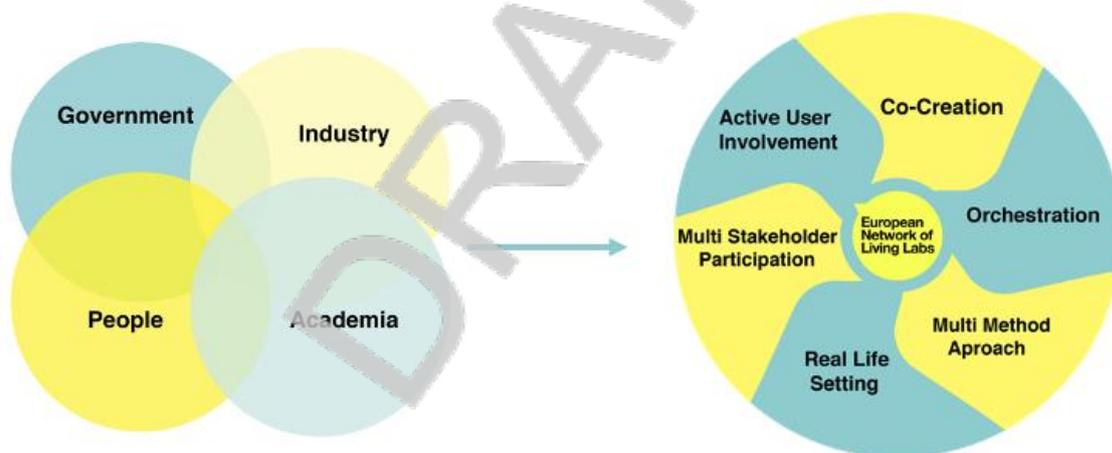


Figure 1. Characteristics of Living Labs. Source: oPEN Lab report *Implementation Plans for the oPEN Living Labs* by ENOLL, pp 2

In the oPEN Lab project, this is referred to as the **Quadruple Helix approach**. This type of partnership in a Living Lab ensures that new technologies can be tested iteratively and in real-life settings with the support of key stakeholders. The residents of the Living Labs participate in the process co-creatively, and act as both beneficiaries and testers of the new technologies.

Within each Living Lab, a PEN is advanced [1]: “*Within the oPEN Lab project, a positive energy neighbourhood (PEN) is an approach which aims to decarbonise a neighbourhood, while the Living Lab is a network of stakeholders which enables co-creation with the local community for testing of technological, process and social innovations in a real-life environment.*” (pp. 2)

As such, for the purposes of this project, a PEN is defined as:

“A group of buildings and public spaces with connected infrastructure, within a geographical area. A PEN aims for energy-efficient and energy-flexible groups of connected buildings and urban areas which produce net zero greenhouse gas emissions from energy use on an annual basis and actively manage an annual local or regional surplus production of renewable energy.” (pp. 15).

Some key principles of PEN are:

- a focus on decarbonisation and energy efficiency at the neighbourhood scale;
- active management of renewable energy production and consumption;
- stakeholder collaboration, ensuring social and economic sustainability.

1.2 Aim of deliverable

The aim of this deliverable is to **study the interaction between technology and the user**, taking into account also the role of third-party stakeholders, through internal technical tests but also qualitative research.

The technical tests are designed to test and investigate the technical set-up in zero-energy buildings (NZEBS) and districts created in oPEN Lab: map redundancies, seek means of optimisation, and study data sharing methods. A ‘test’ can be any activity that measures, monitors, or analyses occupant interaction with building or district systems. **The qualitative research will evaluate the perceived improvement in well-being and comfort for the residents and map their responses to the automation systems installed.**

The deliverable is placed in the larger context of oPEN Lab project WP5 (Building and districts energy systems in PEN environment), which describes the demonstrated technologies and studies their operations on both the building and neighbourhood level.

In short, the deliverable aims to answer three core questions:

1. How well have users (residents) accepted the new technologies, i.e. what are the user responses?
2. What are the key factors influencing the user acceptance of new technologies in a PEN setting?
3. Which optimisation strategies regarding home automation can be applied?

As the resident (the user) is at the centre of the demonstration actions, the main goal of this analysis is to evaluate the changes in the well-being and comfort of the PEN residents, and to better understand how the various interventions of each emerging PEN, including the new technologies and processes implemented, have impacted the residents’ daily lives. The residents’ interactions with emerging PENs will also be explored in order to understand the residents’ acceptance of new technologies and to further seek out means of optimisation of these new technologies.

This is the first draft of this deliverable that will be further elaborated during 2026.

1.3 Structure of the deliverable

This deliverable consists of five chapters: (1) introduction, (2) methodology, (3) occupant-technology interactions in PENs, (4) technology and user in the oPEN Lab PENs and (5) the lessons learnt. The structure aims to create a **logical progression from a theoretical foundation to the local context of each oPEN Lab PEN**.

The first chapter, **introduction**, gives an overview of the aim of the deliverable and describes the distinction between a Living Lab and a PEN as it has been defined and applied in the oPEN Lab project. The second chapter, **methodology**, introduces the four key sources of input for this deliverable: desk research and literature review, project deliverables and data collection, technical tests, and qualitative research.

The third chapter on **occupant-technology interactions in PENs** explores PEN technologies inside and outside the home and the user's (or the resident's) acceptance and use of these technologies through extensive desk research and literature review. In the last subchapter it introduces this deliverable's approach to studying technology acceptance and user-technology interactions in PENs – the qualitative and quantitative approaches and how they combine into a mixed-method triangulation approach.

The fourth chapter on the oPEN Lab PENs features a subchapter for each PEN and presents **the data collection efforts to date**: the qualitative, quantitative, and technical tests approaches. In this first draft version of the deliverable, the collected data is presented as is and the majority of the technical tests still remain to be devised and executed (see the chapter *Future updates* for a more detailed outline of further plans).

Once the data collection is completed and all inputs analysed, a **lessons learnt** chapter will be formulated that will explore technology acceptance and means of optimisation based on the users' responses and internal testing.

Figure 2 describes the structure of the deliverable: the combination of theory and practice to formulate the lessons learnt on technology acceptance, optimisation, behavioural change, and comfort and satisfaction.

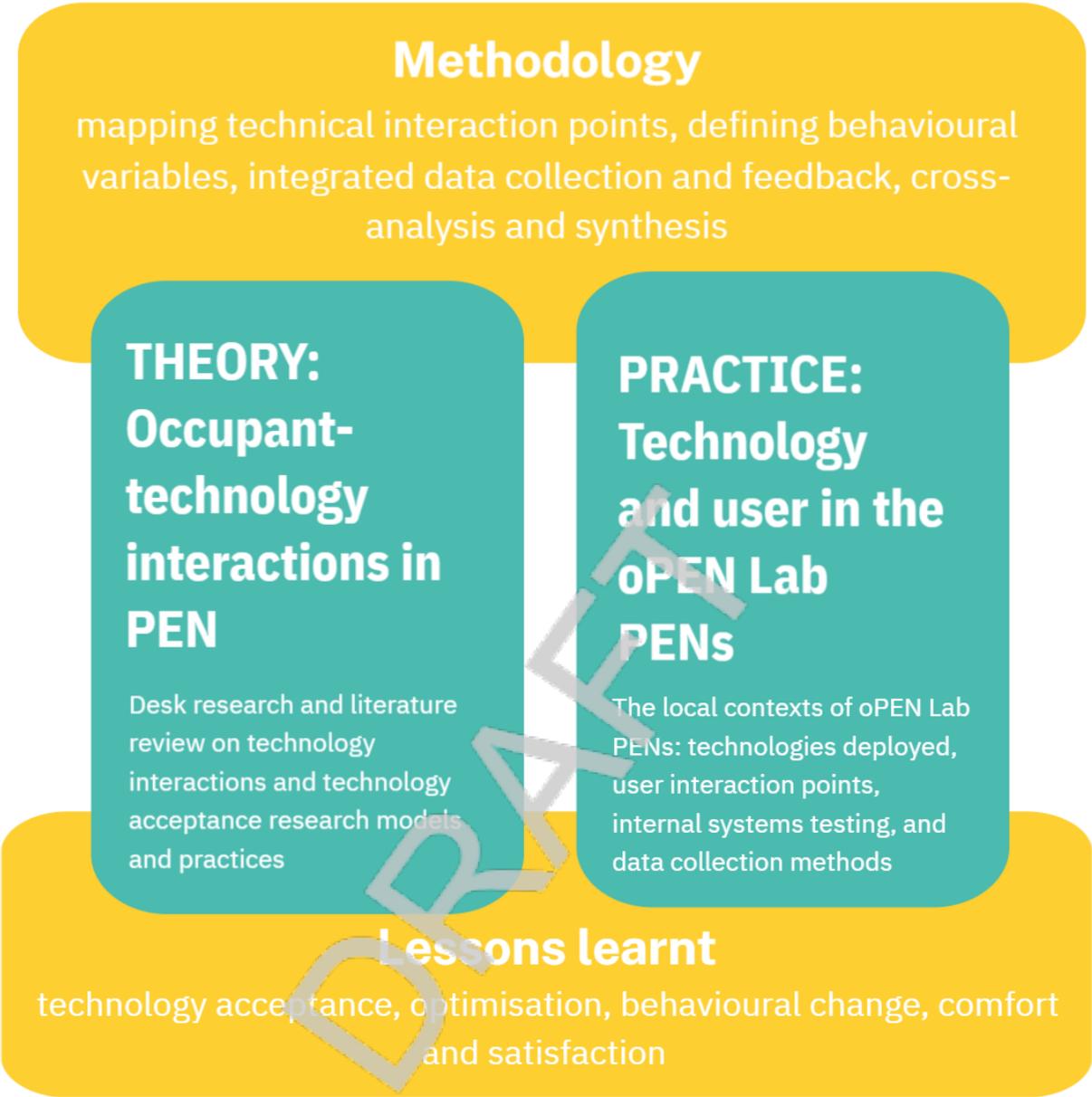


Figure 2. Structure of the deliverable. Source: authors

2. Methodology

Studying technology acceptance requires the combination of various resources: a strong theoretical foundation for the formulation of a research approach, a solid understanding of the technologies deployed in each oPEN Lab Living Lab and a data collection approach that helps to gauge the technology-occupant interactions in the Living Labs.

In short, this deliverable uses **four key sources of input**:

1. Desk research and literature review
2. oPEN Lab project deliverables and data collection
3. Technical tests conducted in oPEN Lab PENs by the project's technology partners
4. Qualitative research targeting the residents of the PENs

2.1 Desk research and literature review

The first input is desk research and literature review. This literature review includes journal articles, publications and other research on technology acceptance, occupant behaviour, building energy management, home automation, etc. Furthermore, includes a comprehensive overview of the key deliverables from the Smart Cities and Communities lighthouse projects¹ to understand how previous projects have studied technology interaction in NZEB settings.

2.2 oPEN Lab project deliverables and data collection

Secondly, from the oPEN Lab project, the deliverable relies on inputs from different sources, these are detailed in Table 1 :

| Resource | Description |
|--|--|
| Task 2.5 and Deliverable 2.4 Conceiving organisational PEN models | This task will provide background information into understanding PEN operations both on a theoretical and practical level with insight into the PENs of the oPEN Lab project as well. |
| Task 5.1 Implementation and demonstration of innovative energy systems on building level | This task will implement and demonstrate the innovative technologies in the Living Labs on a building level. It will describe and explain which energy systems and technologies are implemented in the buildings of each Living Lab. This task will also provide an overview of relevant sensor data collected at building level. |
| Task 5.2 Implementation and demonstration of innovative energy systems at district level | This task will implement and demonstrate the innovative technologies in the Living Labs at district level. It will describe and explain which neighbourhood level energy infrastructure and technologies are implemented in the districts of each Living Lab. This task will also provide an overview of relevant sensor data collected at district level. |
| Task 5.3 Development and evaluation of multi-vector energy flow control, | The objective of this task is to evaluate the effectiveness of multi-vector (electric, thermal, |

¹ Note: The authors were only able to review those projects which had their materials, deliverables and publications publicly accessible.

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

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| aggregation mechanisms, virtual power plants and dispatching for effective PEN operation | electrochemical) integration at system level for PEN operation. Its focus on optimisation will also inform this deliverable. |
| Task 6.3 User experience and feedback | The aim of this task is to learn about the perception of the users on the functionality of the systems of the PEN, which also includes conducting several surveys or interviews: 1) among oPEN Lab PEN residents, which will help gauge their satisfaction and home comfort; 2) third-party operators to understand their role in PEN and how they can better facilitate technology acceptance among the users; 3) local authorities. |
| D7.1 Outline of the oPEN Lab Policy Roadmap | D7.1 provides a thorough understanding of the local context of each PEN, mapping both drivers and barriers for the PENs' emergence in each oPEN Lab city. |
| Living Lab surveys | All qualitative feedback methods such as interviews, surveys, focus groups, etc. conducted by Living Lab implementers will be studied. |
| Reiterative validation rounds during dedicated meetings with Living Lab implementers and WP5 joint meetings | A workshop(s) will be organised with all three Living Lab implementers to validate the other data inputs, answer any pending questions, and fill in any gaps in data or understanding. |
| Data collection* | All Living Lab leaders and technical partners will provide an overview of the technical tests planned and technologies already implemented or to be installed using a specialised template. |

Table 1. oPEN Lab project deliverables and materials relevant for D5.4

* Two dedicated templates were prepared to facilitate this data collection (see Annexes 1, 2):

1. A table to map all setpoints/indicators of each city's PEN that the users can interact with, additionally exploring their various features such as type of interface or means of data logging.
2. A table to list the technical tests done or needed in the framework of Task 5.4 (Occupant and multi-stakeholder interaction in PEN operation) that also maps the test's methodology, occupant interaction points, etc.

2.3 Technical tests

Thirdly, the deliverable will utilise **various internal systems tests** to:

- a. optimise the user's role in control based on various aspects (user centric automation strategies, home assistant app, etc.)
- b. set up models and feedback data analysis to users to optimise consumption

It is important to note **that the term "test" covers a wide range of interactions from technical tests to monitoring activities and data aggregation, i.e. any activity that measures, monitors or analyses occupant interaction with the building or district system** that offers information on the user's behaviour with the technologies.

These tests, both implemented and planned, were captured during the data collection phase of the deliverable (see chapter 2.2).

2.4 Qualitative research

Lastly, qualitative research in the form of **user surveys or interviews** will be conducted to:

- a. Understand the effectiveness and user-friendliness of home automation/smart building interfaces
- b. Study the willingness of users to share specific data at building level/district level
- c. Investigate willingness of occupants to accept temperature variations to activate thermal mass
- d. Users' responses to the indoor climate changes in their home environment (e.g. changes in temperature variations, their responses to cooling technologies)
- e. Analyse the user-technology interactions

The ultimate goal of the user surveys or interviews is to understand the residents' home comfort levels and how the new technologies in their homes impact it. By combining both self-reported and qualitative data with technical tests and user interaction analysis, this report will be able to analyse the lessons learnt on occupant-technology interactions of oPEN Lab PENS.

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3. Occupant-technology interactions in PENs

This chapter will explore **occupant-technology interactions based on literature review and desk research**. It will focus on technologies inside and outside the home, i.e. on an apartment/building and district level, and the user's interactions with them. The chapter concludes with an overview of technology acceptance research and how it has been approached in past projects.

3.1 Technology inside the home

At the heart of every technology demonstration is its end-user. In the case of a positive energy Living Lab, or NZEB or district, this user is the resident – the person living there, who is interacting with the technologies and who is impacted by them. In terms of PENs where local energy production and energy-efficiency is the main goal, residents take on an even bigger role by being *“integral elements of a building ecosystem, and their behaviour can have a substantial impact on energy consumption in buildings”* [2]. As such, it is important to understand the resident's role in building energy management and the mutual relationship the occupant has with its dwelling.

The term **occupant behaviour** denotes the contribution of the user towards the energy use of a building; i.e. how does occupancy affect the final energy use of a building. According to studies, occupancy accounts for high variations of energy use in both commercial and domestic settings, creating a significant gap between the expected/planned and the actual/realistic energy use of a building [3]. This indicates that occupants have a large impact on the energy consumption of buildings that cannot be accurately predicted in the design phase.

In case of a domestic setting, the resident interacts with most parts of a dwelling by consuming heat, electricity, and water, making their contribution to the energy consumption of a building very important to understand (Figure 3).

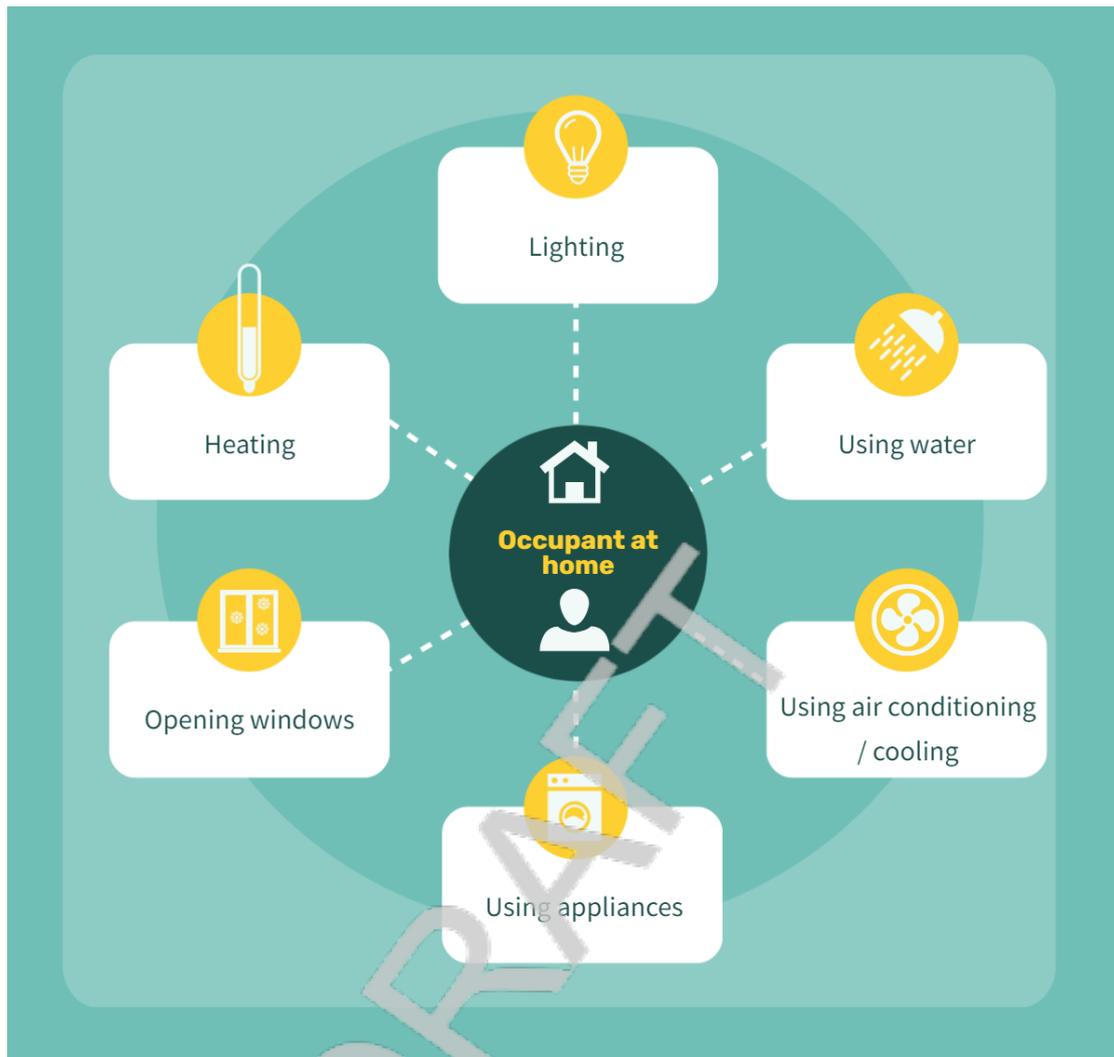


Figure 3. Examples of occupant energy consumption at home. Source: authors.

With the push towards greener technologies and optimising consumption, **the resident is expected to take on an increasingly bigger role in the energy management of their dwelling** both for the sake of financial savings and resource efficiency. This transition can be facilitated by educating the consumer and ensuring that energy consumption information, which they can use to modify their behaviour, is easily available and understandable.

Studies show that there are **major discrepancies between predicted and real building performance** which seem to stem from the inability to factor in the behaviour of the resident in the dwelling and how their behaviour impacts the final energy use [3]. This highlights the need for more occupancy-centric building control systems, i.e. those that respond to the occupants' actual needs. The benefit of these systems is two-fold: firstly, occupants will be able to finetune their dwellings to their real-time needs; and secondly, they help the occupant to understand their energy consumption patterns, which further helps finetune its use.

Home automation

Examples of such **home automation systems** have proliferated in recent years with the rise of the “smart home” that includes smart metering and other smart home control systems. While many such systems have become commonplace (e.g. adjustable thermostats on radiators),

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

many are still less commonly used (e.g. CO₂ tracking). For the home user, home automation carries a singular goal: to make their daily life more comfortable and easily manageable, and to ensure a healthy living environment.

One recent example of a smart home system installed in private apartments comes from the [SmartEnCity project](#) in which tablet computers were installed in private apartments that allow the residents to adjust the heating and ventilation in their apartments, monitor the CO₂ levels in different rooms, and display energy consumption data both in real-time and comparatively (e.g. comparing it with the previous month). Example can be seen on Figure 4 below. Thus, this system functions not only as a control panel for the apartment, but also as a feedback mechanism on energy consumption for the apartment owner. The tablet computers also have video intercom functionality.



Figure 4. A smart home system control panel installed in a private apartment – an example of an energy feedback method. Source: SmartEnCity project

Another example of a similar system for the home was developed in the [GrowSmarter project](#). In that pilot, 50 homes in Cologne were equipped with smart plug devices to enable the tenants to control heating and save electricity. As solar panels with a battery were also installed in the district, the smart home system allows the tenant to control their energy mix (PV or grid) with the smart home application as well. Energy feedback is also an integral part of the system, which helps to both educate the tenant on their consumption and aim for energy savings.

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

In the [Triangulum project](#), a home automation system was installed in a commercial setting: one wing of a large office building received a home automation solution that not only enables to control the indoor climate of different rooms and floors, but also includes self-learning capabilities (i.e. automatically optimising consumption during peak hours, predictive controls, and messages to the user to motivate behaviour change).

All of the abovementioned systems share commonalities: indoor climate control and energy feedback function. As the projects report, **installing home automation systems provides numerous benefits:**

- Reduced heating and electricity consumption, which leads not only to smaller bills but fewer GHG emissions
- Improved indoor climate, which ensures a healthier living environment
- Energy feedback, which helps educate the user and further optimise use and consumption
- Monitoring, which allows for real-time consumption decisions but also helps gather aggregate data and draw long-term conclusions
- Empowering the user through enabling direct control, which can trigger even more environmentally friendly behaviour

However, these projects have also expressed learnings from their experiences with home automation. As expected, there are also several **barriers to implementation** which may be divided into three large categories (as shown in Table 2):

| Barrier | Details |
|------------------------|---|
| High cost | Both the necessary hardware for a smart home system (such as tablet computers and smart sensors) and its installation can be costly. Additionally, making changes to existing systems, e.g. installing new controls that would work with the new smart home system can be very expensive. Thirdly, maintenance and upkeep of the system incur a recurring cost for the homeowner, which may be another barrier to implementation. |
| Technical difficulties | For example, one project reported that although new smart home devices were recently introduced to the marketplace, they did not have valid test protocols available, which is a great financial risk. Another project mentioned difficulty with conforming to existing systems, such as previously installed heating, ventilation, and air conditioning (HVAC) infrastructure that does not allow for finetuning consumption. |
| User behaviour | All projects felt that citizen/resident participation is key. However, many reported that while users may be interested in the data they receive initially, their interest wanes over time. Another project confirmed this with a survey that found that only a third of the respondents use their smart home system for energy consumption monitoring ² . |

Table 2. Barriers to implementing home automation systems. Source: authors, based on exemplary projects learnings.

² <https://tarkartu.ee/wp-content/uploads/2022/06/SmartEnCity-2022-kusitluse-kokkuvote.pdf>

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

Several barriers to the implementation of technologies inside the home have been identified during the advancement of PENs in the oPEN Lab project as well³. During renovations, residents complained about “loss of rest, privacy, and feelings of safety”, highlighting that the installation of in-home systems can disrupt end users’ daily life. Furthermore, residents showed scepticism toward new and untested technological innovations and voiced the fear of being used as “experimental test subjects”, especially regarding smart control systems and new insulation methods. Additionally, digital literacy and accessibility issues reduced residents’ ability to interact with home automation systems and understand the benefits of such technologies. Beyond technical performance, factors such as social acceptance, ease of use, and clear communication are key predictors of technology acceptance and adoption.

As evident, home automation is an intervention with great potential benefits but also several inherent barriers that need to be understood and addressed to ensure user acceptance. According to abovementioned use cases, some of these **keys to success** when setting up home automation include:

- It is important to keep the focus on the needs of the end-user, i.e. the resident, and to ensure all these systems are as intuitive and easy to use as possible.
- The benefits of home automation need to be clearly communicated, and their purpose understood by the end user.
- Potential financial savings have been shown to increase the motivation of users.
- Retaining user interest over time is important (i.e. with motivational messages or nudging techniques).

3.2 Technology outside the home

Outside the private sphere of a home, city dwellers come into contact with various other technologies as well. Modern cities have become to represent a complicated web of technologies that seamlessly integrate into daily life, from smart traffic systems to urban infrastructure monitoring, creating a dynamic and ever-evolving environment.

An area of technology the regular citizen may come into most frequent contact with is **electric mobility**. From electric buses to private electric vehicles (EVs), electric mobility is on the rise, spearheaded by the European Green Deal which aims to boost the uptake of zero-emission vehicles and create healthier and more sustainable urban mobility⁴. To support the growth of charging infrastructure, EU-27 will require between 3.4 million and 7.6 million public charging points by 2030 which means an investment of up to 280 billion euros [4]. Additionally, many governments across Europe have been subsidising the purchase of EVs, switching to EVs in the public sector, and mandating the installation of private charging ports for new property developments.

As the result of these incentives and preparations, most European cities have good EV charging infrastructure coverage with fast chargers becoming increasingly popular as well. However, there remain a few **barriers in the uptake of EVs and installing the necessary infrastructure**:

³ A. Kalms et al. “Report on demonstrated technologies at building and neighbourhood level in three demonstration areas”, oPEN Lab project, 2025 (forthcoming report).

⁴ *Sustainable and Smart Mobility Strategy*. The European Commission. https://transport.ec.europa.eu/transport-themes/mobility-strategy_en

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

- Cost: installing new chargers is costly and requires considerable preparation⁵.
- Grid capacity: maximum available capacity in the grid can be a bottleneck for new charging ports⁶.
- Lack of available business cases and regulations: highly innovative solutions such as direct charging with solar energy, combinations of vehicle-to-building (V2B) and vehicle-to-grid (V2G) services or using EV batteries as storage are still being piloted and tested, which means lack of available business cases or local regulations⁷.
- Inclusivity concerns: the high cost of public charging could be a deterrent for potential EV owners who do not have access to home charging but are dependent on public charging points [5].

As part of the oPEN Lab project, in addition to EV technologies, its PENs boast innovations such as **PV panels and batteries, including building integrated photovoltaics (BIPV), smart meters, and grid-connected buildings**, which render possible energy sharing and coordination across the neighbourhood. In Pamplona, this energy sharing and coordination is achieved via the **EMS-Cloud** that enables energy flow control at neighbourhood level between buildings and other energy assets, supporting flexibility and collective energy management. In Tartu Living Lab, for example, **a large thermal storage solution** was installed that integrates multiple sources of heat, collecting industrial residuals, surplus from air conditioning and renewables, and converting excess PV electricity to heat.

Together, these technologies form a **micro-grid approach**, linking dwellings, buildings, and neighbourhoods to optimise renewable energy generation, storage, and consumption within PENs⁸.

While many of these technologies lack specific interaction points with the user other than providing passive, oftentimes imperceptible benefits, their installation or uptake may still encounter resistance. As with EV chargers and the charging network, for **PV systems**, users often struggle to understand technical features, are sceptical of the installation reliability, and express concerns about aesthetics. For both technologies, external factors such as infrastructure availability, financial incentives, and societal acceptance interact with internal factors like technical knowledge, digital literacy, environmental values, and trust in utility providers to shape adoption and acceptance behaviour [6].

3.3 Studying technology acceptance

Most academic research on technology acceptance centres on what drives people to adopt and keep using a technology, typically by modelling behavioural intention and actual use. This subchapter will explore the most common theoretical frameworks applied by researchers in the field.

Technology acceptance models and limitations

Research on technology acceptance is guided by theoretical frameworks that focus on how and why users adopt new technologies. Two of the most influential models are the **Technology**

⁵ <https://www.bable-smartcities.eu/explore/use-cases/use-case/normal-charging-infrastructure-for-electric-vehicles.html>

⁶ <https://www.bable-smartcities.eu/explore/use-cases/use-case/smart-charging-for-electric-vehicles-in-eindhoven.html>

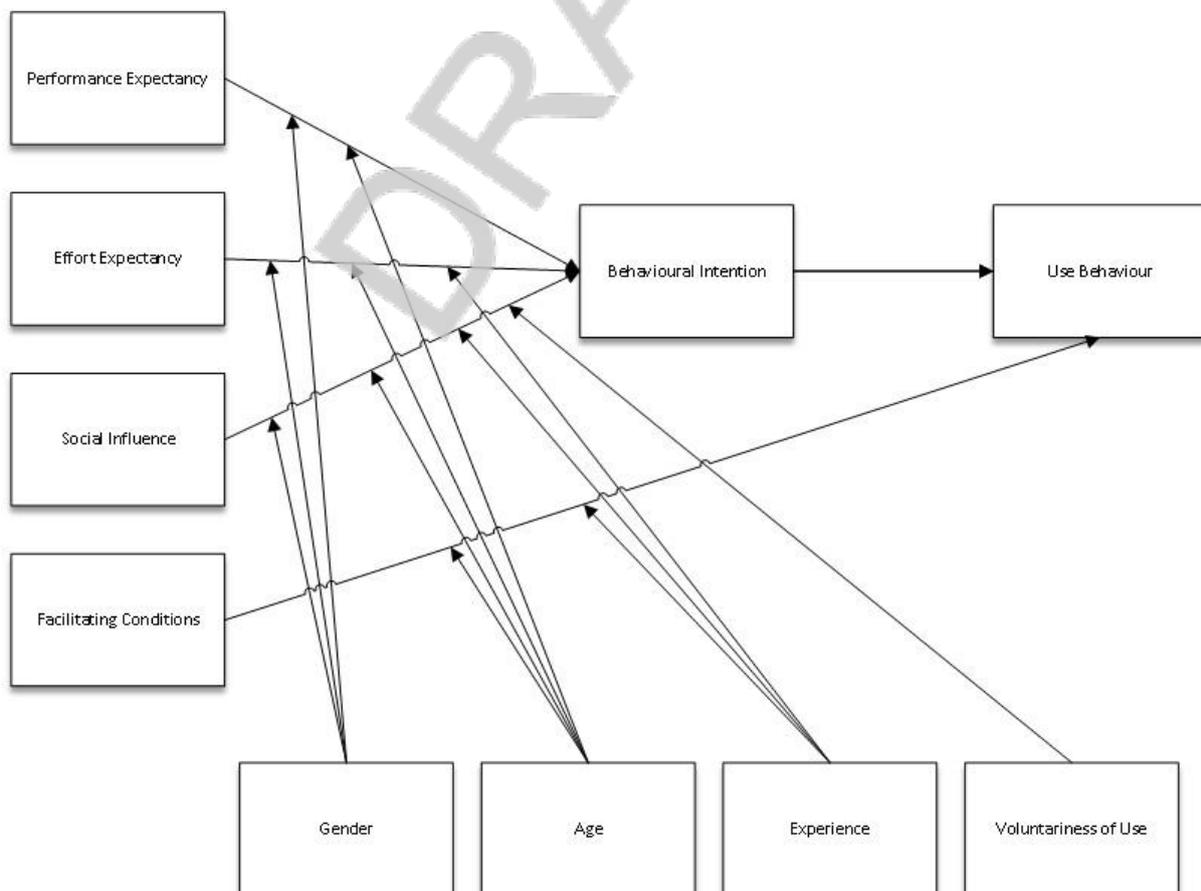
⁷ <https://www.bable-smartcities.eu/explore/use-cases/use-case/vehicle-to-x-v2x-charging-for-electric-vehicles.html>

⁸ E. Lambie et al. "Building integration in PEN", oPEN Lab project, 2025 (forthcoming report).

Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT).

TAM presupposes that technology adoption is influenced by perceived usefulness and perceived ease of use, which impact users' attitudes and behavioural intentions toward technology [7]. TAM has been adapted to environmental issues, which gave rise to the Sustainable Energy Technology Acceptance (SETA) model, which includes additional factors such as trust in technology providers, perceived risk, environmental awareness, and affective responses to green technologies [8]. Both TAM and SETA predict that support for and intention to use a new technology are influenced by perceptions of the technology itself [8]

UTAUT focuses on four determinants of adoption primarily in organisational settings: performance expectancy, effort expectancy, social influence, and facilitating conditions. [9] These effects are moderated by demographics, namely age, gender, experience, and voluntariness of use, to define the strength of each predictor. [7] An extension of the original model, **UTAUT2 was created to explain consumer technology acceptance**, adding constructs such as hedonic motivation, perceived value/cost, and habit while keeping vital moderating variables. [9] A comprehensive review by Tamilmani et al. [10] confirms that UTAUT2 achieves high predictive validity across cultural and technological settings but also highlights its individualistic and technology-centred focus. Researchers also adapted UTAUT2 to more accurately understand the adoption of green technologies, by integrating psychological factors such as curiosity, environmental awareness, along with perceived functional value and perceived satisfaction. [11] The first part of Figure 5 shows the interconnections in the UTAUT model: how the four determinants are moderated by the user's background. The second part on the figure depicts the UTAUT2 model which focuses on consumer technology acceptance and features additional constructs compared to the UTAUT.



D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

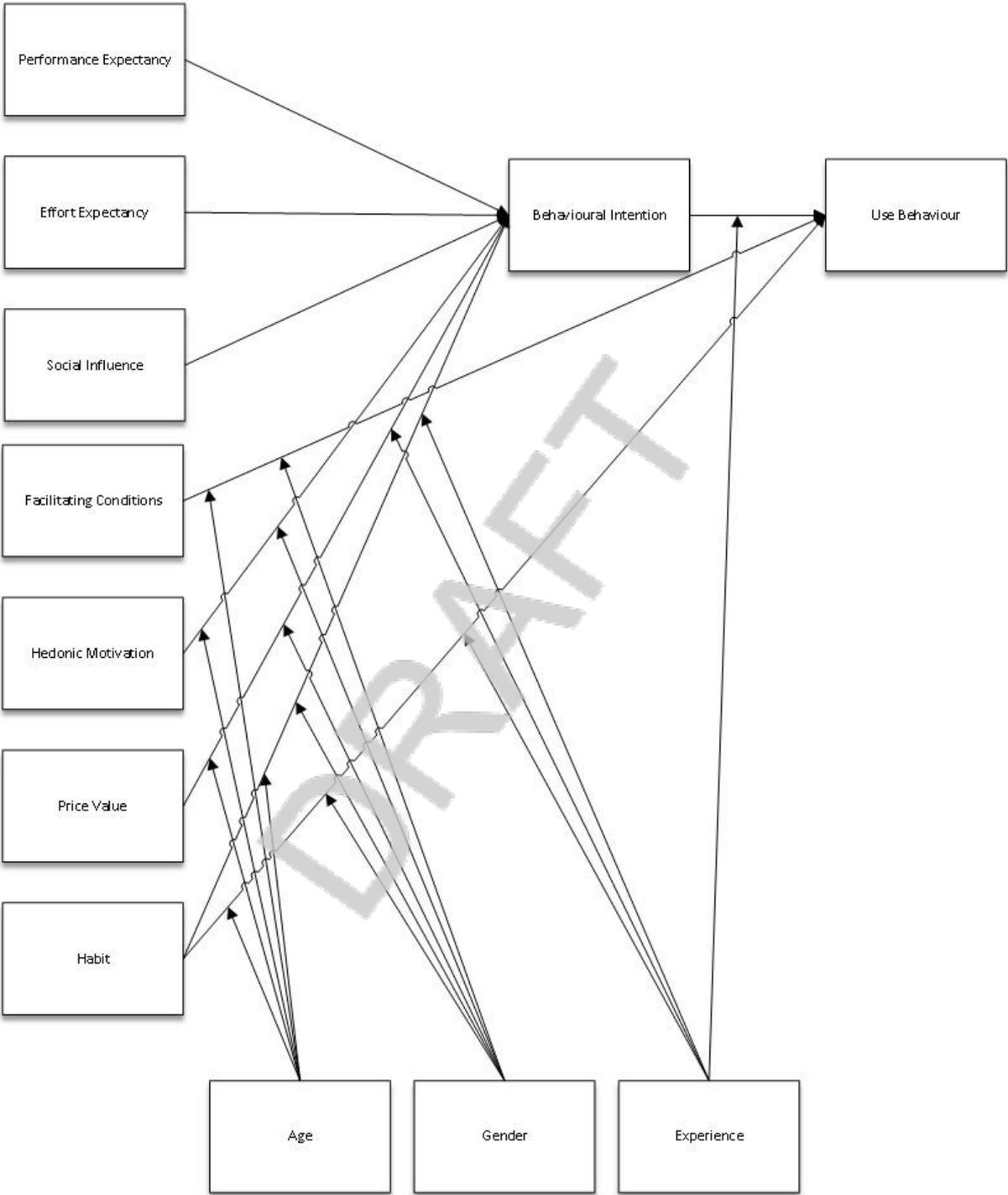


Figure 5. Models of UTAUT and UTAUT2. Source: Marikyan, D.& Papagiannidis, 2025 [9]

For example, in reference to the UTAUT2 framework, research shows that **psychological factors play an essential role in technology acceptance and adoption** [6] [7] [11]. In the context of 5G adoption, several predictors of behavioural intention emerged as vital, such as

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

environmental awareness, curiosity, perceived satisfaction, and hedonic motivation [6]. From a technical perspective, literature highlighted that facilitating conditions positively affected adoption intentions, which in turn, calls for strong supportive infrastructure [6] [7] [11].

For smart grid technologies [12], studies revealed that users have little trust and conservative behaviour, resulting in limited engagement and reduced system performance. While high-use consumers were found to be risk-averse, risk-tolerant/liberal users were more inclined to participate in dynamic tariffs and monitoring systems [12]. The literature suggests that **technical innovations do not solely lead to user adoption and acceptance**, but complementarily **require trust, education, transparency and concrete incentive mechanisms** such as real-time feedback and dynamic pricing [6] [12].

Regarding empirical approaches to investigating user acceptance, scholars often combine surveys with technical monitoring to evaluate the use of technology [7] [8]. Surveys usually employ between five- to seven-point Likert scales. Furthermore, Structural Equation Modelling (SEM) is often employed to test both direct and indirect relationships among factors while correcting for measurement errors [11] [7] [8]. SEM is deemed suitable for TAM, SETA, and UTAUT models because it allows synchronised assessment of multiple predictors, mediators, and moderators [8]. Nevertheless, in applied Living Lab contexts like in oPEN Lab, data heterogeneity and limited sample sizes favour a mixed-method triangulation of descriptive, correlational, and qualitative analyses rather than formal structural modelling.

Several recurring limitations have been identified in the literature, although some of them can be mitigated. For example:

- **Limited samples and scope** – many studies use small, single-country samples, limiting generalisability; in this context, broader, multi-country user bases are needed [11] [8] [7].
- **Uncertain role of user knowledge** – as it is unclear whether knowledge of green technologies predicts acceptance across countries, surveys should first assess whether users are sufficiently informed [8] [6].
- **Self-report bias in models** – most acceptance models, including UTAUT2, rely on self-reported intention-to-use, which can reduce accuracy and validity; self-reports with instrumented monitoring/technical tests should be compared to improve precision [9] [7].
- **Lack of longitudinal evidence** – few longitudinal studies track perceptions over time; such work could reveal how acceptance and adoption evolve [7].

Technology user archetypes

According to research, while occupant behaviour has come into the attention of researchers in recent years with more studies being conducted in the field, **old prejudices regarding occupants persist**. Two strongly held energy consumer archetypes have been found to dominate energy sector thinking about consumer engagement. *Resource Man* is a technically literate, rational economic agent, who actively seeks to optimise energy use in response to price signals, whereas *Indifferent Consumer* is “disengaged, lazy, irrational, ignorant”. [13] However, such simplifications overlook the diversity of competencies, motivations, and social contexts that characterise modern energy users. In reality, everyday life increasingly requires residents to navigate complex systems, interpret feedback, and make informed energy decisions, leaving little room for indifference.

More recent research highlights that **technology adoption in energy retrofits is deeply influenced by residents’ values, routines, and social contexts**. Mooses et al. [14], analysing residents’ experiences in a nearly zero-energy retrofit, identified three user archetypes that illustrate this diversity: technocrats (pro-technology, less environmentally motivated), techno-greens (both environmentally and technologically inclined), and bio-greens (environmentally conscious but less engaged with digital technologies). Each group interprets the meaning and usefulness of retrofit technologies differently and differ in their environmental attitudes, trust in technology, and willingness to engage with smart systems. For instance, while technocrats appreciate automation and comfort benefits, bio-greens are more sceptical about the environmental footprint and data privacy of smart systems, and techno-greens typically balance both views, often acting as “early adopters” who engage actively with new tools and experimentation.

Integrating such archetypes into the technology acceptance analysis helps move beyond generic acceptance models toward a socially differentiated understanding of interaction between occupants and technology. Perceptions of usefulness, ease of use, and trust which are core constructs of TAM and UTAUT/UTAUT2, depend on residents’ environmental and technological dispositions. Technology acceptance thus varies not simply with interface design but with broader orientations toward comfort, control, and sustainability. The same smart home system may be seen as empowering by a technocrat, intrusive by a bio-green, and inspiring by a techno-green.

Influence of the social setting

These insights also show that energy technologies are not neutral devices but parts of broader social practices that connect meanings, competences, and material artefacts [15]. While models such as TAM, SETA, and UTAUT/UTAUT2 explain why individuals decide to adopt a technology, they are less capable of describing how technologies are lived with once embedded in daily routines. In PENS, smart systems like heating controls, PV monitoring platforms, mobility or storage services are not isolated artefacts but parts of a broader socio-technical environment in which occupants, communities, and infrastructures continually influence one another. Understanding these dynamics requires shifting the analytical focus from intention to practice. Residents’ willingness to use or trust a smart-home panel, for example, depends not only on perceived usefulness or ease of use but also on how the technology fits their everyday routines and values. Contemporary research in building and energy studies has introduced the concept of **domestication** [16] [17]. This is the gradual process through which people integrate technologies into everyday life, negotiate their meaning, and develop routines around them. This process is influenced not only by the technical affordances of devices but also by residents’ capabilities and resources to engage with them [18]. Domestication aligns closely with **social practice theory** [15] [19].

Social practice theory offers a conceptual bridge between individual agency and structural context. It views everyday energy use as the performance of practices composed of three interdependent elements:

- Materials – physical artefacts and infrastructures (technologies, buildings, networks);
- Competences – embodied skills and know-how required to perform the practice;
- Meanings – shared interpretations, values, and social norms that make practices sensible or desirable.

Change occurs when one or more of these elements are reconfigured. For instance, when a new feedback interface (material) alters awareness (competence) and shifts the meaning of “comfort” or “responsible energy use.” This perspective reframes technology acceptance as participation in evolving bundles of practices (e.g. heating, cooking, mobility, or data sharing),

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

where individuals are continuously “recruited” into new patterns of action and may later “defect” from them if technologies fail to align with routines or values. Technologies are not adopted in isolation but through routinised activities, meanings, and competences. Energy management, comfort regulation, and data sharing are embedded in social relations, habits, and material settings. Technology acceptance in this sense is an ongoing negotiation, shaped by learning, adaptation, and dialogue within the household and community [14].

While social practice theory provides a powerful lens for understanding how energy technologies become embedded in everyday routines, it is often critiqued for its limited attention to social justice and human agency. Recent scholarship combines this approach with the capabilities framework to highlight the importance of individuals’ real opportunities to adopt and sustain new practices.

Vasseur et al. [18] propose a **conceptual model that integrates social practices and capabilities** to explain domestic energy use as a function not only of materials, competences, and meanings, but also of residents’ freedom and capacity to act. This combined perspective reveals that the ability to engage in energy-saving or comfort-modifying behaviours depends on contextual conditions, such as time availability, income, health, and access to supportive technologies.

Applying this lens in PENs helps capture how inclusiveness and equity influence technology acceptance: not all residents can participate equally in monitoring, control, or demand-response activities. Recognising these differentiated capabilities ensures that behavioural change strategies remain effective but also socially just.

Empirical evidence from Guaselli et al. [21] also shows that **residents’ engagement with smart energy systems is strongly mediated by social relations**. Users often learn through neighbours, workshops, or community events rather than through interfaces alone. Collective reflection turns private routines into shared experiments, allowing the community to establish new norms of comfort and flexibility. In this light, the drivers of sustained engagement include:

- Competence development – users gain literacy in interpreting data and controlling systems;
- Social reinforcement – peer learning and recognition foster motivation;
- Feedback quality – clear, meaningful feedback helps link actions to outcomes;
- Trust and transparency – open communication from operators and DSOs reduces perceived risk;
- Alignment of meanings – technologies that resonate with users’ environmental or social values become embedded in everyday life.

Such mechanisms are central to current analysis, which seeks to **identify the optimal balance between automation and user agency in PEN operation**. As shown by Guerra-Santin et al. [17] [21] acceptance evolves through iterative feedback between occupants’ expectations of comfort and the affordances of smart systems. Users act as both sensors (providing data) and actuators (modifying settings) within a learning loop that links perceived comfort, feedback, and behavioural adjustment.

Complementing this, Guerra-Santin et al. emphasise **the importance of coupling technical monitoring with co-creation and participatory design in renovation projects**. Their mixed-method approach was linking quantitative sensor data with qualitative interviews and mock-up enactments and demonstrated that household typology, socio-economic context, and everyday routines have measurable impacts on energy performance. Crucially, acceptance and usability increased when residents were involved early through feedback sessions and design iterations. Monitoring became not merely a data-collection tool but a dialogue mechanism fostering trust and awareness.

Integrating individual and collective dimensions

For analytical and methodological purposes, oPEN Lab combines individual-level motivational constructs from UTAUT2 (e.g., performance expectancy, effort expectancy, hedonic motivation, habit, environmental awareness) with collective practice indicators (competence, meaning, material engagement). This integration allows the analysis of:

- Drivers – motivations, expectations, and values that trigger technology engagement;
- Practices – observable behaviours captured through technology interaction monitoring and surveys/interviews;
- Outcomes – comfort, satisfaction, and energy performance improvements.

Consequently, studying acceptance within PENs requires **attention to the co-evolution of technical and social practices** - how residents learn, adapt, and negotiate new forms of control and responsibility. Analysing both is necessary: motivational drivers identified by UTAUT2 and practice-based mechanisms that explain long-term engagement. Technical tests and quantitative survey indicators reveal motivational tendencies, while qualitative observations explain how those motives translate or fail to translate into practical routines.

3.4 Studying occupant-technology interaction

This report investigates how occupants and other stakeholders interact with smart technologies and infrastructures in the emerging PENs of Tartu, Pamplona, and Genk. The methodological design combines technical quantitative monitoring, behavioural surveys, and qualitative enquiry to capture the interplay between technical performance, user engagement, and comfort outcomes. The overall aim is to identify the balance between automation and user control that optimises both system efficiency and resident well-being.

As mentioned previously, smart technologies for energy monitoring and feedback are proliferating both in the private and public spheres. In the past, various methodologies have been applied to study their efficacy: **experiments, analytics, surveys, and simulation**; or a combination of them. Surveys include interviews and questionnaires, which are the most common qualitative feedback methods.

In a meta-analysis of relevant research papers, the most common factors to study occupants' behavioural characteristics via surveys were identified [2]:

- Occupants' behaviours
- Perception of energy consumption and information
- Understanding of feedback content
- Knowledge of energy efficiency
- Attitude
- Awareness of energy consumption
- Literacy
- Motivation
- Demographics
- Social and economic information
- Eco feedback and in-home displays (IHD)
- Interface design preferences

The SmartEnCity project was mentioned above with its one-of-a-kind smart home system that has benefited hundreds of private apartment owners, but other former [Smart Cities and Communities \(SCC\) lighthouse projects](#) have implemented similar solutions over the years both in the ICT and other building energy management categories. The authors reviewed these projects to understand how the acceptance of these technologies was studied or measured.

As expected, monitoring and surveying were the two most common ways of studying the residents' technology use. As monitoring was a compulsory part of SCC projects, all implementers gathered various types of data on domestic energy consumption and most also provided some sort of an **energy feedback system** to the residents to influence behaviour change. To gauge the residents' satisfaction and adoption of new technologies, surveys, interviews, etc. were often held as well to complement the analytical data. Examples of topics covered by the surveys are:

- Behavioral change resulting from managing the heating and cooling of their dwelling ([POCITYF project](#))
- Satisfaction with indoor climate ([MAKING-CITY project](#))
- Changes in thermal, visual and acoustic comfort following smart-system deployment ([SharingCities project](#))
- Household practices and social learning around heating and laundry challenges combining baseline and reflection interviews ([ENERGISE project](#))

As such, both the abovementioned practical approaches and technology acceptance theories suggest that the best combination for understanding the occupant-technology interaction in PENs can be obtained by combining a thorough understanding of the local context with site analytics and surveys.

3.5 oPEN Lab approach to studying technology acceptance and user-technology interactions in PENs

By combining the abovementioned theoretical approaches, the methodological framework of this deliverable is founded on three complementary pillars (Figure 6):

- **Local context** – technology acceptance and motivational models and social practice theory help steer understanding of the local context: the existing social relations and the overall social context of the neighbourhood, socio-economic profile of the residents, past experiences with technology and their motivations towards its use, etc.
- **Qualitative feedback** – to understand the drivers (motivations, expectations, values), practices (observable behaviours) and outcomes (comfort, satisfaction) of the residents, focus groups, surveys, semi-structured interviews, and Living Lab co-creation activities help generate in-depth understanding of residents' experiences, routines, and perceptions.
- **Analytics and monitoring** – technical partners provide monitoring data from sensors, building management systems, and control platforms. Variables include, for example, indoor temperature, system operation states, energy consumption, and user control actions (e.g. manual overrides, dashboard interactions and other user-side actions). These datasets offer objective measures of actual behaviour and system responsiveness that complement survey-based intentions.

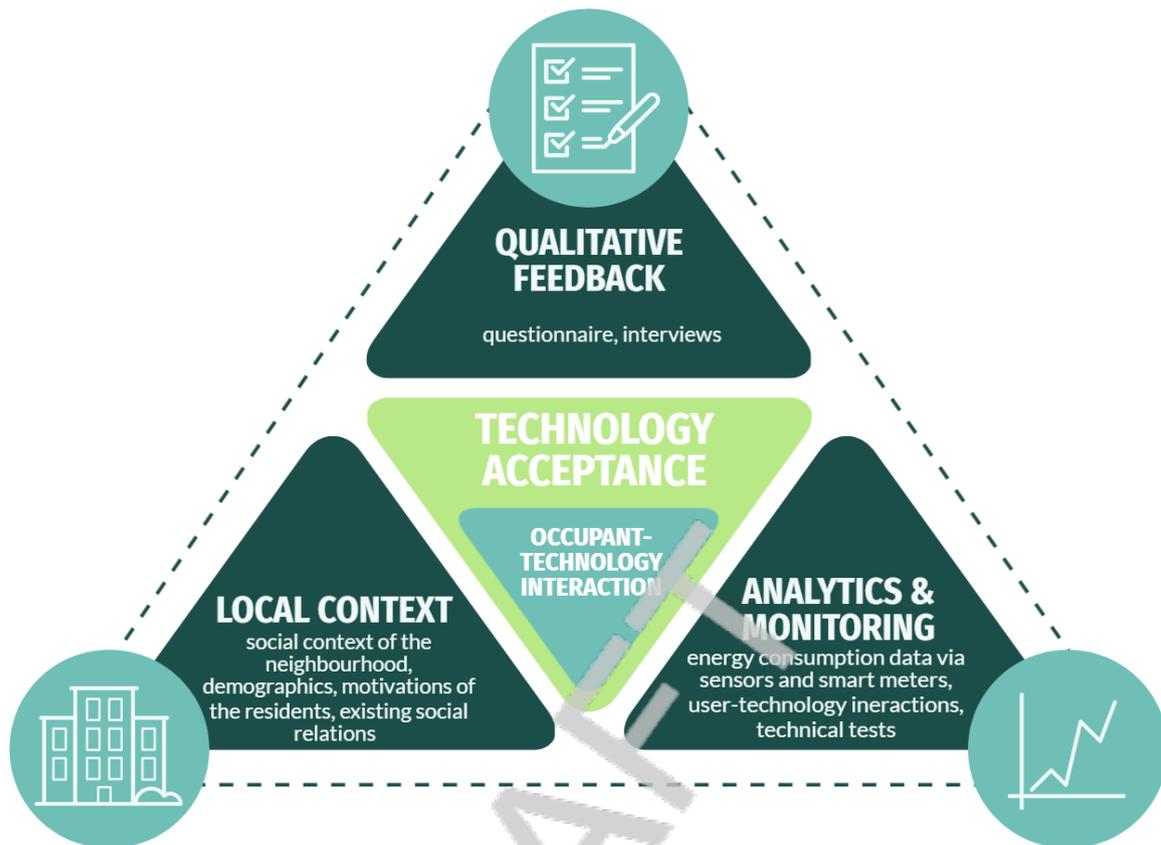


Figure 6. Approach to studying occupant-technology interaction. Source: authors.

In the context of oPEN Lab, the available data from Living Labs and emerging PENs are heterogeneous in scale and design, combining small to medium-sized survey samples with diverse technical monitoring outputs and qualitative insights.

To ensure methodological robustness and comparability across cases, this report adopts a **mixed-method triangulation approach**. Quantitative data from occupant and stakeholder surveys are analysed using descriptive statistics, and comparative tests across user groups and Living Labs. These are complemented by qualitative surveys, interviews or focus groups, and thematic coding to capture the social-practice dimensions of technology use (see Table 3).

| Quantitative component | Technical/quantitative component | Qualitative component |
|--|---|---|
| Surveys (if the Living Labs choose to use the surveys) among residents and operators capture motivational, cognitive, and experiential variables derived from the technology acceptance models and behavioural frameworks. Indicators include: | Technical Living Lab partners and operators provide monitoring data from sensors, building management systems, and control platforms. Variables include for example indoor temperature, system operation states, energy con- | Focus groups, semi-structured interviews, and Living Lab co-creation activities generate in-depth understanding of residents' experiences. Thematic analysis [18] is used to identify recurring meanings and behavioural mechanisms (trust, literacy, learning, and comfort negotiation.) |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | | |
|--|---|--|
| <ul style="list-style-type: none"> • If feasible, motivational drivers: performance expectancy, effort expectancy, hedonic motivation, environmental awareness, curiosity, habit; • Affective and trust-related factors: satisfaction, perceived control, data-sharing willingness, privacy concerns; • Outcomes: comfort, satisfaction with feedback, perceived usefulness of systems. <p>These data are analysed using descriptive statistics and comparative analysis across user types and Living Labs. Such analyses identify contextual patterns.</p> | <p>sumption, and user control actions (e.g. manual overrides, dashboard interactions). These datasets offer objective measures of actual behaviour and system responsiveness that complement survey-based intentions.</p> | |
|--|---|--|

Table 3. oPEN Lab approach to study technology-occupant interaction. Source: authors

This framework operates through four iterative stages. See Table 4 for the research logic.

| Stage | Focus | Main instruments | Expected outcome |
|---|--|--|---|
| 0. Mapping technical interaction points | Identify where and how residents interact with technologies (smart thermostats, PV interfaces, EV charging, DH systems). | Living Lab partner templates on technologies and data streams, see Annexes 1 and 2 | Overview of available monitoring data and interaction types |
| 1. Defining behavioural variables | Translate theoretical constructs into measurable indicators for surveys and interviews. | Resident and operator questionnaires | Harmonised variables across Living Labs for motivation, trust, comfort, literacy, and participation |
| 2. Integrated data collection and feedback | Gather survey and interview data concurrently with monitoring and co-creation activities. | Surveys, workshops, interviews, system logs | Mixed dataset linking attitudes and actual system-use data |
| 3. Cross-analysis and synthesis | Combine technical and behavioural evidence to assess how interaction affects comfort and performance. | Quantitative–qualitative triangulation | Consolidated insights for PEN operation guidelines and lessons learned |

Table 4. oPEN Lab multi-layered mixed-method approach. Source: authors

This structure enables **cross-validation**: comparing, for instance, whether residents who express high curiosity or trust also exhibit more frequent interaction with control interfaces, or whether strong environmental awareness correlates with willingness to accept temperature variations. Surveys include items assessing user understanding of installed systems; interview prompts explore learning and competence development. Survey results are cross-checked with monitored usage data (frequency of control actions, dashboard use) and finally, integration of technical, quantitative, and qualitative evidence captures both objective performance and subjective experience.

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4. Technology and user in the oPEN Lab PENs

Each partner city in the oPEN Lab project has thoroughly familiarised itself with the local context of its chosen neighbourhood, including the demographic and socio-economic background of the local residents.

With support from project partners, the local project partners have also identified the actors in their Quadruple Helixes and completed a thorough stakeholder mapping exercise.

As each Living Lab and their PEN context is different, the stakeholders and technologies used are different as well. The emerging PENs and the overall PEN ecosystems are thoroughly described in *Deliverable 2.4 Benchmarking and categorisation of PEN organisational models* which also includes a case study for each of the project’s PENs which have informed the compilation of this report as well.

This chapter focuses on mapping both the building and district level technologies that the users can interact with, the internal technical tests needed for optimisation and fine-tuning, and the user responses to these technologies, collected either quantitatively or qualitatively.

Technologies in oPEN Lab PENs

Table 5 provides a quick-glance overview of the building and district level technologies deployed in oPEN Lab PENs.

| <i>Technology</i> | <i>Genk</i> | <i>Pamplona</i> | <i>Tartu</i> |
|--------------------------------|-------------|-----------------|--------------|
| EV charging | X | | X |
| Electric bike charging | X | | |
| District heating | | | X |
| Smart metering | X | X | X |
| Smart sensors | X | X | X |
| PV technology | X | X | X |
| PV battery | X | X | X |
| Deep energy renovations | X | X | X |
| Ventilation | X | X | X |
| Cooling | | X | X |

Table 5. The district and building level technologies deployed in oPEN Lab PENs

A more thorough description of the installations, their technical details and impact on the PENs can be found in the forthcoming oPEN Lab reports on building and district level PEN integrations⁹.

4.1 Genk PEN local context

Living Lab Genk is targeting the district of Waterschei, which is a historically significant and socially vulnerable district in Genk’s north-eastern area, and the social housing area known as Nieuw Texas, constructed in the 1990s. Genk, a post-industrial city in Flanders severely affected by the decline of coal mining and the 2014 Ford plant closure, faces **persistent socio-**

⁹ First drafts of “Report on demonstrated technologies at building and neighbourhood level in three demonstration areas” and “Report on building integration” have been reviewed internally for the purposes of this deliverable.

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

economic challenges – particularly in Waterschei, where high unemployment, low incomes, and limited mobility hinder residents’ ability to afford deep housing renovations despite available subsidies.

Profile of the residents

The residents of the Genk Living Lab form a diverse community that includes families with children, single adults, and elderly couples. Participants in the Nieuw Texas neighbourhood live in social and affordable housing managed by Wonen in Limburg (WiL), the regional public housing organisation for Limburg. The community in Nieuw Texas mainly consists of low-income households that meet the eligibility criteria for social housing, such as limited income and assets and no home ownership.

Residents generally show varying levels of digital literacy. While some are familiar with basic digital tools, others require more personal and practical support when interacting with new technologies. The multicultural background of the residents also influences uptake, i.e. unlearning old habits. Therefore, the Genk Living Lab follows an “unburdening” approach, providing clear guidance and easy-to-use interfaces that allow residents to benefit from technological innovations without added complexity.

Digital literacy and affinity with technology of the residents

Before the renovations, most residents in the Nieuw Texas neighbourhood had limited experience with smart home technologies. Digital literacy levels varied widely across households: while a small number of younger residents were comfortable using smartphones and simple digital tools, many participants - especially elderly residents or those with lower educational backgrounds - were less familiar with connected devices or app-based systems.

Residents were generally not accustomed to actively managing energy systems such as thermostats, ventilation units, or smart meters. Instead, they relied on traditional, manual use and appreciated straightforward control options, like manually opening and closing radiator valves.

This situation underscored the importance of the Living Lab’s “unburdening” approach, focusing on intuitive technologies, hands-on demonstrations, and personal guidance rather than complex automation. However, it is important for the residents to understand their role in shaping consumption patterns – through direct control they can impact their energy bill, thus finding an optimal balance between their home comfort levels and the inherent cost. The participatory sessions (such as Energy dates and Living room talks) were therefore designed to build confidence, increase understanding, and foster gradual behavioural change rather than expecting residents to self-navigate advanced systems.

4.1.1 Qualitative feedback gathering in the Genk LL

Tables 6 to 10 provide details on the qualitative feedback gathering methods in GENK PEN.

| General Information | |
|---------------------|--------------|
| Name of test: | Energy dates |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|--|--|
| Applies to | <input checked="" type="checkbox"/> Genk <input type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Genk: | WiL, VITO |
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Explain: Feedback gathered during the Energy dates is shared with relevant external stakeholders, such as contractors and technical suppliers responsible for specific systems, as well as the maintenance company. The aim is to provide them with insights from residents' experiences, so they can address identified issues or improve technical performance. |
| Timeline when conducted (months): | March 2025 & October 2025 |
| Expected outputs / datasets / reports: | |
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input type="checkbox"/> Common methodology for all LLs <input checked="" type="checkbox"/> Site-specific adaptation (please explain differences) The energy dates focus on the individual consumption behaviour of the tenants, thus making it possible to study and assess the data per family. This allows the one-to-one contacts to provide highly personalised tips and tricks to the tenants. |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | The Energy dates are designed to provide residents with personalised insights into their energy consumption and daily habits, encouraging more energy-efficient behaviour while improving overall comfort. During these sessions, we discuss individual monitoring results and participants receive practical tips to better understand and manage their energy use. The activity also aims to explore residents' energy-related concerns and their interaction with home energy systems - such as heating, thermostats, and ventilation - in order to identify comfort barriers and opportunities for improved user guidance. |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|--|--|
| <p>Setup – Which systems, sensors or users are involved? Describe briefly the configuration.</p> | <p>Individual conversations with participants in the anchor point (W29). Topics included comfort, thermostat use and energy bills.</p> |
| <p>Data capture – Which variables are logged? Specify frequency, duration, and storage method.</p> | <p>An overview has been made of the invoices received from the energy suppliers for each individual tenant. From this, the amounts of the advance payments and final settlements for electricity, injection and water consumption since the renovation can be extracted and compared with the forecasts.</p> <p>An overview is created of who benefits from the social tariff in order to be able to adjust the advance payments to the correct unit prices for electricity.</p> <p>The tenants' comfort preferences are also reviewed and noted. This allows settings to be adjusted in the future, taking into account the desired comfort requirements.</p> |
| <p>Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)?</p> | <p>Thematic analysis to identify recurring issues, behavioural patterns, and user needs. Results will complement technical monitoring data.</p> |
| <p>Occupant interaction and data aspects</p> | |
| <p>Link to user interaction – How does this test connect to user behaviour or feedback?</p> | <p>Direct user–researcher dialogue on comfort and control experiences, complemented by the active involvement of the social innovator and the project leader from the social housing company. Their participation ensures that residents' feedback is directly translated into actionable insights for both social and technical improvements.</p> |
| <p>Complementary qualitative data – What additional surveys or interviews could complement this test?</p> | <p>Short comfort and behaviour questionnaire (oPEN Lab Task 6.3)</p> |
| <p>GDPR and data sharing – Does this test collect personal or user-related data? How is it handled?</p> | |
| <p>Please attach any relevant visual materials (schematics, dashboards, screenshots)</p> | |

Table 6. Qualitative feedback gathering method 1 in Genk

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| General Information | |
|--|--|
| Name of test: | Living room talks |
| Applies to | <input checked="" type="checkbox"/> Genk <input type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Genk: | VITO, WiL, Stebo |
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Explain: During the Living room talks, residents receive practical information on how to use and manage their installed technologies. While external stakeholders are not directly involved in the sessions, the content and guidance provided are based on technical inputs. Relevant feedback from participants may also be communicated back to these stakeholders for improvement purposes. |
| Timeline when conducted (months): | The timing corresponds to the completion of each renovation phase where participants were equipped with similar technologies, which took place in 2024. |
| Expected outputs / datasets / reports: | <ul style="list-style-type: none"> • Insights on user understanding and handling of installed technologies. • Recommendations for improving communication materials and guidance on smart systems. • List of questions and practical concerns raised by residents, grouped by technology type. |
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input type="checkbox"/> Common methodology for all LLs <input checked="" type="checkbox"/> Site-specific adaptation (please explain differences) |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | To engage small resident groups in informal “living room” discussions. The Living room talks aim to inform residents about the use of newly installed technologies and their cost implications while gathering input on their housing experiences and information needs. |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|--|---|
| <p>Setup – Which systems, sensors or users are involved? Describe briefly the configuration.</p> | <p>Low-threshold sessions were organised in small groups to maximise interaction and peer learning. Participants were grouped according to the technologies installed in their homes (e.g. individual heating systems, collective installations). Each session included live demonstrations, such as adjusting settings directly on thermostats, supported by visual slides and technical handouts specific to each case. Emergency contact information and technical guidance were also provided to ensure residents feel supported.</p> |
| <p>Data capture – Which variables are logged? Specify frequency, duration, and storage method.</p> | |
| <p>Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)?</p> | <p>Thematic analysis to identify recurring issues, behavioural patterns, and user needs. Results will complement technical monitoring data.</p> |
| <p>Occupant interaction and data aspects</p> | |
| <p>Link to user interaction – How does this test connect to user behaviour or feedback?</p> | <p>The Living room talks enable direct, practical engagement with residents, allowing them to share their daily experiences and learn from peers using similar technologies. Participants actively interact with their devices during demonstrations and receive tailored advice on optimal use, promoting behavioural understanding and self-efficacy.</p> |
| <p>Complementary qualitative data – What additional surveys or interviews could complement this test?</p> | <p>Short follow-up surveys or individual interviews could complement the group sessions by measuring whether residents' understanding and comfort levels improved after participation.</p> |
| <p>GDPR and data sharing – Does this test collect personal or user-related data? How is it handled?</p> | |
| <p>Please attach any relevant visual materials (schematics, dashboards, screenshots)</p> | |

Table 7. Qualitative feedback gathering method 2 in Genk

| | |
|-----------------------------------|--------------------------|
| <p>General Information</p> | |
| <p>Name of test:</p> | <p>Loomy lamp</p> |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|--|---|
| | |
| Applies to | <input checked="" type="checkbox"/> Genk <input type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Genk: | WiL, VITO, Stebo |
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Explain: The company Loomy developed and supplied the colour-changing lamp used in this pilot. The Genk Living Lab team collaborates directly with Loomy to ensure correct installation, app functionality, and performance. Installation and setup were supported on-site with tailored manuals and hands-on guidance for residents. Feedback on usability and operation can be shared with Loomy and other technical partners. |
| Timeline when conducted (months): | July 2025 |
| Expected outputs / datasets / reports: | |
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input type="checkbox"/> Common methodology for all LLs <input checked="" type="checkbox"/> Site-specific adaptation (please explain differences) The Loomy Lamp pilot is specific to Genk, tailored to the installed technologies and resident profiles in the Belgian Living Lab. The test focuses on behavioural engagement. |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | To explore whether a simple, real-time visual cue can increase residents' awareness of energy flows (solar, battery, or grid electricity) and encourage energy-smart behaviour. The pilot tests how visual feedback and practical tips can support autonomy, motivation, and understanding of energy use. |
| Setup – Which systems, sensors or users are involved? Describe briefly the configuration. | Participants received the Loomy Lamp device, connected to their home energy systems (+ app interface). Customised manuals were provided for |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

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| | <p>four housing types (individual/collective systems with or without battery).</p> <p>Hands-on support was offered during installation and app setup to ensure proper functioning and user confidence.</p> |
| Data capture – Which variables are logged? Specify frequency, duration, and storage method. | The accompanying app keeps track of data on electricity consumption, solar power and peak consumption. Only the tenant has access to this data via a private login. |
| Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)? | <p>Analysis could compare pre- and post-installation awareness and self-reported behavioral changes.</p> <p>Key indicators include:</p> <ul style="list-style-type: none"> • Residents' understanding of energy source signals and availability of renewable energy. • Reported behavioural changes (e.g., shifting consumption to solar periods). • Perceived usefulness and aesthetic acceptance of the device. |
| Occupant interaction and data aspects | |
| Link to user interaction – How does this test connect to user behaviour or feedback? | <p>The pilot directly connects visual feedback to residents' energy behaviour, making abstract energy flows tangible.</p> <p>By linking lamp colours to real-time energy sources, the activity helps residents understand their consumption patterns and act upon them, thus fostering energy awareness and self-regulation.</p> |
| Complementary qualitative data – What additional surveys or interviews could complement this test? | Follow-up interviews or surveys could further assess long-term behavioural change |
| GDPR and data sharing – Does this test collect personal or user-related data? How is it handled? | |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

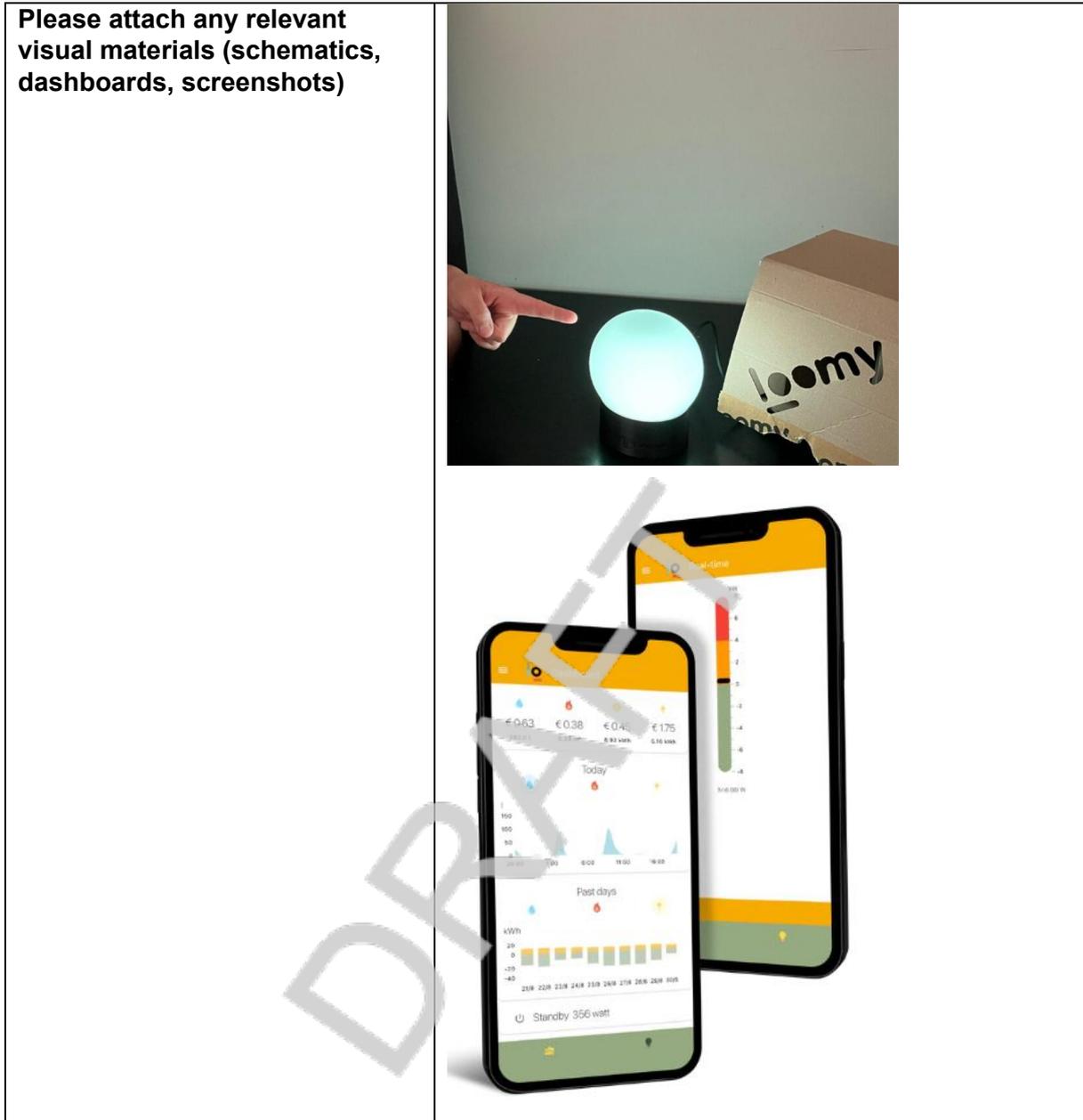


Table 8. Qualitative feedback gathering method 3 in Genk

| General Information | |
|---|---|
| Name of test: | Resident questionnaire (linked to WP6) |
| Applies to | <input checked="" type="checkbox"/> Genk <input type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Genk: | KU Leuven, VITO, WiL, Stebo, Stad Genk |
| Does this test involve or affect external stakeholders (DSO, | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

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|--|--|
| <p>ESCO, maintenance company)? Please specify their role:</p> | <p>Explain: The questionnaire targets residents directly and does not involve external technical or service stakeholders. However, aggregated results may be shared with relevant project partners to inform user support, communication, and energy management strategies.</p> |
| <p>Timeline when conducted (months):</p> | <p>2023-2024, 2026</p> |
| <p>Expected outputs / datasets / reports:</p> | <ul style="list-style-type: none"> • Quantitative dataset of residents' self-reported comfort, control, household behaviour, satisfaction, and willingness to provide demand response (e.g. using Likert scales). • Correlation analysis between subjective responses and objective monitoring data from WP6. • Summary report for inclusion in D5.4 and WP6 (Monitoring and performance evaluation) deliverables. • Insights into behavioural patterns and perceived effectiveness of smart technologies. |
| <p>Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations.</p> | <p><input type="checkbox"/> Common methodology for all LLs</p> <p><input type="checkbox"/> Site-specific adaptation (please explain differences)</p> |
| <p>Methodology: Please answer the following sub-questions clearly</p> | |
| <p>Purpose – What is the main research or optimisation question of this test?</p> | <p>To quantify residents' comfort perception, behavioural tendencies, and satisfaction with their living environment, and to compare these perceptions with monitored indoor conditions and energy use data. Additionally, it enables estimating the extent to which the households are willing to provide demand response.</p> <p>The test aims to link subjective experience (comfort, control, usability) with objective measurements from WP6 (Monitoring and performance evaluation) to improve user engagement and system optimisation.</p> |
| <p>Setup – Which systems, sensors or users are involved? Describe briefly the configuration.</p> | <p>The questionnaire targets all participating residents in the Genk Living Lab. It is administered in person.</p> <p>It covers topics such as indoor comfort, temperature control, ventilation, perceived energy efficiency, and satisfaction with installed technologies.</p> |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

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| Data capture – Which variables are logged? Specify frequency, duration, and storage method. | During the monitoring phase, each participant completes a paper survey once before and once after the renovation. |
| Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)? | The survey responses are analysed using both descriptive and statistical methods. These analyses focus on the survey data solely as well as their relationship to the monitoring data from WP6 (Monitoring and performance evaluation). |
| Occupant interaction and data aspects | |
| Link to user interaction – How does this test connect to user behaviour or feedback? | The questionnaire directly captures residents' self-assessment of comfort, control, behaviour, satisfaction and willingness to provide demand response in relation to their home technologies. It helps understand how users experience smart energy systems and how personal perceptions align (or diverge) from measured performance. |
| Complementary qualitative data – What additional surveys or interviews could complement this test? | The survey is administered in person, allowing households to provide additional information orally while completing it. This information is noted down and/or recorded. |
| GDPR and data sharing – Does this test collect personal or user-related data? How is it handled? | Yes. The study was approved by the Ethics Committee of KU Leuven (SMEC). Personal data cannot be shared with others. |
| Please attach any relevant visual materials (schematics, dashboards, screenshots) | |

Table 9. Qualitative feedback gathering method 4 in Genk

| General Information | |
|--|--|
| Name of test: | Myth vs fact cards |
| Applies to | <input checked="" type="checkbox"/> Genk <input type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Genk: | WiL, VITO |
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Explain: Feedback from the sessions can be shared with technical partners to improve user information |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

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|---|---|
| | materials and address recurring misunderstandings about technical systems. |
| Timeline when conducted (months): | April 2025 |
| Expected outputs / datasets / reports: | Updated set of myth vs. fact cards; recommendations for improved user communication. |
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input type="checkbox"/> Common methodology for all LLs <input checked="" type="checkbox"/> Site-specific adaptation (please explain differences) Myths and facts are tailored to Genk’s systems and social context, while the participatory method could be replicable across all Living Labs. |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | To raise awareness, correct misconceptions, and stimulate discussion on energy use, comfort, and maintenance after renovation. |
| Setup – Which systems, sensors or users are involved? Describe briefly the configuration. | Interactive group discussions guided by moderators using printed cards; each card presents a myth or questions on one side and the factual explanation on the other. |
| Data capture – Which variables are logged? Specify frequency, duration, and storage method. | |
| Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)? | |
| Occupant interaction and data aspects | |
| Link to user interaction – How does this test connect to user behaviour or feedback? | Residents actively engage in group discussion, expressing their understanding, doubts, and daily experiences related to energy use. |
| Complementary qualitative data – What additional surveys or interviews could complement this test? | Feedback is combined with insights from Energy dates and Living room talks. |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|---|--|
| GDPR and data sharing – Does this test collect personal or user-related data? How is it handled? | |
| Please attach any relevant visual materials (schematics, dashboards, screenshots) | |

Table 10. Qualitative feedback gathering method 5 in Genk

4.1.2 Technology-occupant interactions in the Genk PEN

In the Genk PEN, the occupant has five points of interaction with the technologies. On the building level, these include (Table 11):

| Name of setpoint/indicator | Interface | Expected behaviour change |
|---|---------------------------------|---|
| Temperature in all rooms (installed during renovations 2024-2025) | Digital wall-mounted thermostat | Awareness and comfort |
| Relative humidity (RH) in all rooms in all rooms (installed during renovations 2024-2025) | Digital wall-mounted thermostat | Awareness and comfort, understand necessity of ventilation system |
| CO ₂ in all rooms in all rooms (installed during renovations 2024-2025) | Digital wall-mounted thermostat | Awareness and comfort, understand necessity of ventilation system |
| Solar electricity production (installed in 2025) | Loomy lamp | Use electricity when cheaper solar electricity is available |

Table 11. User-technology interactions in the Genk PEN

On the district level, EV and bike chargers are planned to be installed in 2026, which the user can interact with via a dedicated mobile application. The new chargers are expected to facilitate the uptake of sustainable transportation modes.

4.1.2.1 Internal systems testing: analytics and monitoring in the Genk PEN

To be specified in the final and second version of this Deliverable delivered in 2026.

4.2 Pamplona PEN local context

The oPEN Lab demonstration area is situated in Rochapea, a historic, working-class district of Pamplona, the capital of the Autonomous Community of Navarre in northern Spain. The district lies close to the city centre, bordered by the river Arga, and is **one of Pamplona’s most densely populated neighbourhoods**.

Originally developed in the 1940s as an industrial and workers’ neighbourhood, Rochapea’s urban fabric still reflects its past, with industrial-era architecture interspersed among residential

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

blocks. The area features a mix of industrial heritage sites, housing estates and newer community buildings, giving it a layered urban identity that blends older manufacturing structures with modern urban uses.

Profile of the residents

The residents in Pamplona’s oPEN Living Lab are primarily households living in multi-family apartment buildings located in the San Juan and San Jorge neighbourhoods – typical examples of post-war urban residential districts. These areas have a population that includes long-term owner-occupants, elderly residents living on fixed incomes, and younger families benefiting from social or cooperative housing schemes, most notably in the San Pedro district which is predominantly social housing. Many households face moderate energy vulnerability due to ageing building stock, low energy efficiency and rising energy costs.

Demographically, the neighbourhoods represent a **socially mixed** but predominantly stable population, with strong local identity and community networks developed through decades of co-residence.

Digital literacy and affinity with technology of the residents

Before the oPEN Lab interventions, residents’ familiarity and comfort with digital and smart-home technologies were generally low to moderate. The majority had limited prior exposure to energy monitoring systems, smart meters or home automation. Among elderly residents, digital literacy tended to be lower, with some scepticism toward technology perceived as complex or intrusive.

4.2.1 Qualitative feedback gathering in the Pamplona PEN

Table 12 describes the qualitative data collection method – the tenants survey – in the Pamplona PEN.

| General Information | |
|--|---|
| Name of test: | Tenants survey before moving in, energy and home automation previous knowledge and expectations |
| Applies to | <input type="checkbox"/> Genk <input checked="" type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Pamplona: | PAMPL |
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Explain: Feedback gathered during the Energy surveys is shared with the domotics installation company and the maintenance company. The aim is to provide them with insights from residents’ experiences, so they can address identified issues or improve technical performance. |
| Timeline when conducted (months): | Ongoing with each resident entry |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|---|--|
| Expected outputs / datasets / reports: | Data on energy and energy efficiency related knowledge of residents |
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input type="checkbox"/> Common methodology for all LLs <input checked="" type="checkbox"/> Site-specific adaptation (please explain differences) |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | The Energy surveys are designed to get information about the knowledge and experience of new residents on building renovation, renewable energy, electric mobility, energy billing, energy consumption habits, energy efficiency technology, etc. |
| Setup – Which systems, sensors or users are involved? Describe briefly the configuration. | Individual conversations with participants at their homes, when they start leaving in the San Pedro flats |
| Data capture – Which variables are logged? Specify frequency, duration, and storage method. | Structured and unstructured data is registered using Google questionnaires, each time a new resident start leaving in a flat |
| Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)? | Analysis to identify recurring issues, behavioural patterns, and user needs |
| Occupant interaction and data aspects | |
| Link to user interaction – How does this test connect to user behaviour or feedback? | The Energy surveys provide direct information from the users about their knowledge and experience on building renovation, renewable energy, electric mobility, energy billing, their energy consumption habits, energy efficiency technology, etc. |
| Complementary qualitative data – What additional surveys or interviews could complement this test? | About 6 months after living in the San Pedro flats, a new survey collecting information on their experience living in a renovated flat with innovative energy efficiency technology will be developed |
| GDPR and data sharing – Does this test collect personal or user-related data? How is it handled? | Each resident signs a data sharing consent document |

Table 12. Qualitative feedback gathering method 1 in Pamplona

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

4.2.2 Technology-occupant interactions in the Pamplona PEN

In the Pamplona PEN, the occupant has several points of interaction with the technologies. On the building level, these include (Table 13):

| Name of setpoint/indicator | Interface | Expected behaviour change |
|--|---------------------------------|---|
| Temperature in all rooms (installed in 2024) | Digital wall-mounted thermostat | Awareness and comfort |
| Electricity consumption | Smart interface | Optimise electricity usage |
| Room CO ₂ level | Smart interface | Acceptance of the ventilation system |
| Room air humidity level | Smart interface | Acceptance of the ventilation system |
| Hot and cold water consumption | Smart interface | Optimise water usage and heating/cooling consumption |
| Heating/cooling level | Smart interface | Optimise heating/cooling consumption |
| Windows shutters control | Smart interface | Reduce heat entry by programming shutters closure when necessary to increase or avoid solar gains |
| Ventilation level | Smart interface | Reduce windows opening and rely instead in modulation of ventilation rate according to CO ₂ levels |
| Rolling blinds from crepuscular sensor | Smart interface | Reduce heat entry by programming rolling blinds closure when necessary to increase or avoid solar gains |
| Daily forecast about energy generation/consumption | Smart interface | To follow forecast recommendations to improve energy efficiency |
| PV production/usage | Smart interface | Adjust and optimise electricity usage |

Table 13. User-technology interactions in the Pamplona PEN

4.2.2.1 Internal systems testing: analytics and monitoring in the Pamplona PEN

Table 14 describes the internal systems testing method, i.e. the means of controlling the shutter and rolling blinds, in the Pamplona PEN.

| General Information | |
|---|---|
| Name of test: | Shutter and rolling blinds from crepuscular sensor |
| Applies to | <input type="checkbox"/> Genk <input checked="" type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Pamplona: | PAMPL |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|--|--|
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No Explain: |
| Timeline when conducted (months): | September |
| Expected outputs / datasets / reports: | Included in the BMS user manual |
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input checked="" type="checkbox"/> Common methodology for all LLs <input type="checkbox"/> Site-specific adaptation (please explain differences) |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | Optimise the user's role in control: automation vs manual |
| Setup – Which systems, sensors or users are involved? Describe briefly the configuration. | Shutters and blinds actuators and their motors, sensors, meteorological station, BMS and user (s) control at home |
| Data capture – Which variables are logged? Specify frequency, duration, and storage method. | Status of the shutters and rolling blinds, buttons of actuation, wind velocity, solar radiation, crepuscular sensor. |
| Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)? | User's role in control vs comfort level? TBD |
| Occupant interaction and data aspects | |
| Link to user interaction – How does this test connect to user behaviour or feedback? | Decisions on automation vs manual control |
| Complementary qualitative data – What additional surveys or interviews could complement this test? | Education on home automation systems |
| GDPR and data sharing – Does this test collect personal or user-related data? How is it handled? | Yes, residents agree by contract |

Table 14. Internal systems testing method 1 in Pamplona

Other tests to be specified in the final and second version of this Deliverable delivered in 2026.

4.3 Tartu PEN local context

The oPEN Living Lab in Tartu is situated in Annelinn. Built mainly in the 1970s and 1980s, Annelinn is dominated by 5- and 9-storey prefabricated panel apartment blocks, set out in an amphitheatre-like layout rising from the Emajõgi floodplain. Today, the area remains a classic late-Soviet large housing estate, which suffers many issues due to poor planning. The district is known for being a **densely populated, mixed community** where the key challenges are aging infrastructure, parking problems, energy efficiency, and social cohesion.

Current policy emphasis is on preventing decline by fostering renovation, improving services, and integrating the district more fully into Tartu’s development trajectory.

Profile of the residents

Socio-economically, Annelinn is diverse but carries a distinct profile within Tartu. Statistically, majority of Tartu’s Russian-speaking residents are concentrated there, making the district culturally and linguistically diverse.¹⁰

Digital literacy and affinity with technology of the residents

While Estonia is known for its digitalisation accomplishments, it is likely the older population has little affinity with smart technologies. More precise data on the residents’ attitudes and behaviours towards technology will be obtained during the project.

4.3.1 Qualitative feedback gathering in the Tartu PEN

Table 15 describes the qualitative data collection method – the tenants survey – that is planned in the Tartu PEN.

| General Information | |
|--|--|
| Name of test: | Pre-renovation survey among Uus 1 residents |
| Applies to | <input type="checkbox"/> Genk <input type="checkbox"/> Pamplona <input checked="" type="checkbox"/> Tartu |
| Person/org. responsible for test in Pamplona: | TARTU, UTAR, IBS, TALTECH |
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No Explain: |
| Timeline when conducted (months): | Planned for early 2026 |
| Expected outputs / datasets / reports: | An understanding of the residents’ attitudes towards zero energy renovation and their current satisfaction with their dwelling pre-renovation |

¹⁰ As no renovations have taken place in Annelinn, Tartu, yet, the precise socioeconomic profile of the residents or the residents’ prior affinity with technology remains to be determined.

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|---|--|
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input type="checkbox"/> Common methodology for all LLs <input checked="" type="checkbox"/> Site-specific adaptation (please explain differences) |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | The aim is to establish a baseline for the post-renovation survey in the Tartu PEN. |
| Setup – Which systems, sensors or users are involved? Describe briefly the configuration. | Residents of Uus 1 will be engaged via a paper and online survey and additional interviews. |
| Data capture – Which variables are logged? Specify frequency, duration, and storage method. | Data will be captured via survey platform and on paper, and during interviews. The survey process will most likely take 1-2 months. |
| Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)? | The results will be analysed, and they will feed into intervention planning, relevant KPIs and further monitoring plans. |
| Occupant interaction and data aspects | |
| Link to user interaction – How does this test connect to user behaviour or feedback? | The pre-renovation survey will help establish the user's current energy behaviour and their attitudes towards new technologies and energy-efficiency. |
| Complementary qualitative data – What additional surveys or interviews could complement this test? | Additional interviews will be conducted with some residents. |
| GDPR and data sharing – Does this test collect personal or user-related data? How is it handled? | Yes, data collection will adhere to all GDPR regulations and oPEN Lab project instructions. |

Table 15. Qualitative feedback gathering method 1 in Tartu

4.3.2 Technology-occupant interactions in the Tartu PEN

As the Tartu PEN focuses on large apartment buildings, technologies are installed on the apartment, building and district level. The following Table 16 summarises these:

| Name of setpoint/indicator | Interface | Expected behaviour change |
|--|---------------------------------|---|
| Room temperature (everything will be installed in 2026) | Wall-mounted tablet, mobile app | Adjust temperature feeling with measured data |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | | |
|---|--|--|
| Room temperature setpoint | Wall-mounted tablet, mobile app | Encourage energy saving and awareness of consumption; improve comfort control |
| Room temperature schedules | Wall-mounted tablet, mobile app | Encourage energy saving and awareness of consumption; improve comfort control |
| Room CO₂ level | CO ₂ meter panel, wall-mounted tablet, mobile app | Open windows in case of too high level, trust automated ventilation |
| Room air humidity level | CO ₂ meter panel (may depend on model), wall-mounted tablet, mobile app | Report to housing association in case of extreme values to make adjustments for ventilation or heating |
| Window shutter position | Mechanical switch, wall-mounted tablet, mobile app | Protect rooms from extra heat, improve comfort control |
| Staircase door videophone | Wall-mounted tablet, mobile app | Improve security and comfort |
| Staircase door lock | Wall-mounted tablet, mobile app | Improve security and comfort |
| Date, time, outdoor temperature, wind direction and speed, solar radiation | Wall-mounted tablet, mobile app, staircase digital panel | Adjust and optimise everyday actions |
| Hot and cold water consumption | Water meter panel, wall-mounted tablet, mobile app | Optimise water usage |
| Water leaks alerts | Wall-mounted tablet, mobile app | Check water leaks |
| Electricity consumption | Electricity meter panel, wall-mounted tablet, mobile app | Optimise electricity usage |
| Current PV production | Wall-mounted tablet, mobile app, staircase digital panel | Adjust and optimise electricity usage |
| Current electricity source (grid, PV or battery) | Wall-mounted tablet, mobile app | Adjust and optimise electricity usage |
| Annual energy use of the building per m² | Wall-mounted tablet, mobile app, staircase digital panel | Understand building energy savings |
| Announcements | Wall-mounted tablet, mobile app, staircase digital panel | Get important information from housing association |

Table 16. User-technology interactions in the Tartu PEN

On the district level, EV chargers are planned to be installed, which the user can interact with via a dedicated mobile application. The new chargers are expected to facilitate the uptake of sustainable transportation modes and provide more opportunities for charging, especially in residential neighbourhoods.

4.3.2.1 Internal systems testing: analytics and monitoring in the Tartu PEN

To be specified in the final and second version of this Deliverable delivered in 2026.

5. Lessons learnt on occupant-technology interaction in the PENs of oPEN Lab: technology optimisation and user responses

To be compiled in the final and second version of this Deliverable delivered in 2026.

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Future updates

This report is the first draft version of the deliverable and represents the current status of the work within Task 5.4.

Several updates and additions are planned for the final report:

- **Data collection** – both quantitative and qualitative data collection will continue.
 - **Qualitative** – already held surveys, interviews, etc. will be reviewed and analysed, and post-renovation surveys prepared in cooperation with Task 6.3 (User experience and feedback). As both Pamplona and Genk Living Labs felt that post-renovation survey/interviews can be held once the residents have had time to live in the new houses and technical issues have been resolved, these are planned for the first half of 2026. In case of Tartu, where renovations have not taken place yet, a pre-renovation survey will be additionally prepared and launched dependent on the timeline of renovations.
 - **Quantitative** – monitoring of deployed solutions will continue. Technical test methodology discussions have already begun with WP5 (Building and districts energy systems in PEN environment) and Living Lab partners and will be continued to achieve a common understanding. A first mapping of technology-occupant interactions in PENS has been completed and will continue as needed. In case of Tartu, current plans may be subject to change as renovations are launched, and the technological set-up established.
- **Annexes** – the surveys and interview questionnaires used with the residents will be added to the annexes.

The final deliverable will be delivered end of 2026.

References

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D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

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Annex 1: Data collection template for technologies/setpoints/indicators

Please list the technologies/setpoints/indicators that have been or will be installed (indicate *current status in brackets*) in your LL on a property level (apartment or building; T5.1) OR on district level (T5.2) that the residents can monitor or control:

- Please complete one column per technology or indicator that residents in your Living Lab can monitor or control at building level.
- Include both installed and planned systems.
- Use the guiding questions in the comments to describe the technology clearly and indicate what data are automatically available and what resident feedback might still be needed.

Please upload any screenshots of interfaces, screens, etc. that the resident can interact with, in addition to other pictures, videos, graphs or visual materials of these technologies to WP5 folder -> WP5 -> Task 5.4 -> D5.4 Pictures and other visuals.

Name of setpoint/ indicator

Property level (apartment or building or district)

Type(s) of interface

Can the resident see it in real-time?

How can the resident control it?

Can the resident see historical data?

Expected behaviour change

User interaction logging

Data logging and its frequency

Data owner

Any comments on the previous table:

1. Who are the residents in your LL, i.e. what is their sociodemographic profile (if you know)? For example, families with small children, elderly, low-income households, etc. Feel free to provide as much detail as you can!

2. How would you characterize your residents' affinity with smart home technology prior to the renovations (if you know)? For example, young professionals with high digital competences, elderly who are eager to learn, young people who prefer app-based solutions, etc. Feel free to provide as much detail as you can!

3. Which resident (or other stakeholder/target group) surveys have you conducted in your LL? Please list them and provide references to results:

Annex 2: Data collection template for technical tests planned/conducted

The purpose of the following template is to collect detailed information from LL technical partners about the methodology, data sources, and monitoring setup of each technical test related to occupant–technology interaction in the oPEN Lab PENs.

Please fill in the template for each test that you are planning or already conducting in your Living Lab related to occupant–technology interaction. If you have several different tests, copy and complete a separate template for each one.

| General Information | |
|--|---|
| Name of test: | |
| Applies to | <input type="checkbox"/> Genk <input type="checkbox"/> Pamplona <input type="checkbox"/> Tartu |
| Person/org. responsible for test in Genk: | |
| Person/org. responsible for test in Pamplona: | |
| Person/org. responsible for test in Tartu: | |
| Does this test involve or affect external stakeholders (DSO, ESCO, maintenance company)? Please specify their role: | <input type="checkbox"/> Yes <input type="checkbox"/> No Explain: |
| Timeline when conducted (months): | |
| Expected outputs / datasets / reports: | |
| Uniformity – Is the methodology common for all LLs or site-specific? Explain any variations. | <input type="checkbox"/> Common methodology for all LLs <input type="checkbox"/> Site-specific adaptation (please explain differences) |
| Methodology: Please answer the following sub-questions clearly | |
| Purpose – What is the main research or optimisation question of this test? | |
| Setup – Which systems, sensors or users are involved? Describe briefly the configuration. | |
| Data capture – Which variables are logged? Specify frequency, duration, and storage method. | |
| Analysis – How will the results be interpreted or validated (KPIs, comparisons, etc.)? | |
| Occupant interaction and data aspects | |

D5.4 Lessons learnt on occupant – technology interaction in nearly zero energy buildings and districts (DRAFT)

| | |
|---|--|
| Link to user interaction – How does this test connect to user behaviour or feedback? | |
| Complementary qualitative data – What additional surveys or interviews could complement this test? | |
| GDPR and data sharing – Does this test collect personal or user-related data? How is it handled? | |
| Please attach any relevant visual materials (schematics, dashboards, screenshots) | |

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