Climate and cultural based design and market valuable technology solutions for Plus Energy Houses

Factsheets reporting solution set description and metrics for each climate-cultural geo-cluster

Deliverable D4.7

Dissemination Level: Public
Lead Partner: EURAC
Due date: 30/06/2023
Type of deliverable: Report
STATUS: Final version

Published in the framework of:

Cultural-E - Climate and cultural based design and market valuable technology solutions for Plus Energy Houses

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 870072

Authors:
Francesco Isaia, Eurac Research
Francesco Turrin, Eurac Research
Hermann Leis, Steinbeis-Innovationszentrum energieplus
Roberta Di Bari, University of Stuttgart
Beatriz Pineda, RMIT

Revision and history chart:

Version	Date	Editors	Comment
0.1	01/10/2022	Francesco Isaia	Structure definition and preliminary draft
0.2	30/06/2023	Francesco Isaia (with the contribution of the other authors)	First version
0.3	14/07/2023	Francesco Isaia	Revised version considering a preliminary internal review
0.4	04/08/2023	Roberto Lollini, Wilmer Pasut	Internal review
0.5	21/08/2023	Francesco Isaia	Revised version considering the internal review

Disclaimer:
The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 870072.

Table of contents

List of figures

List of tables

1 Executive summary

The main aim of Cultural-E project is to provide the evidence base and tools to underpin a shift in practice towards Plus Energy Houses becoming a mainstream building product.

Climate and cultural tailored solution sets have been developed to reach the Plus Energy targets in different geoclusters. Solution sets are combination of technologies already present on the market (e.g. photovoltaic/battery systems, thermal insulation materials, thermal mass activation and storage, shading systems, and so on) with the technologies developed within Cultural-E project (the cloud-based House Management System[1], the Active Window System[2], the smart air movement system[3] and the decentralized Packed Heat Pump System[4]). The climate and cultural tailored solution sets consider drivers related to typological building architecture, adapting bioclimatic design strategies to modern architecture, as well as solutions to improve users' (households') cultural practices. A key focus of the work is the integration of technologies within the solution sets, including sizing, coordination and control systems.

The solution sets evaluation is a result of several analysis processes including:

- Energy simulations to assess the energy consumption of different archetypes in different climatic conditions, define two technological solution sets, consider the interaction with the energy grid and the use of the PV system and gave insights on thermal comfort within the built environment (Gazzin R., 2022), (Turrin F., 2022).
- Life cycle environmental impact assessment of the defined cases, with interesting results at different scales (component, solution set, building) and providing both static and dynamic results (Di Bari R., 2022).
- Economical assessment of life cycle cost, which also resulted in a practical excel-based tool, allowed to assess the total annual cost considering a timespan of 30 years (Leis H., 2022).

Cultural-E deliverable D4.7 "*Factsheets reporting solution set description and metrics for each climate-cultural geo-cluster*" aims at merging all the mentioned results in publicly available factsheets for each analysed solution sets. Such solution sets were defined

[1] https://www.cultural-e.eu/cloud-based-house-management-system-hms/
[2] https://www.cultural-e.eu/active-window-system-aws/
[3] https://www.cultural-e.eu/smart-air-movement/
[4] https://www.cultural-e.eu/decentralised-packed-heat-pump-system/

through a structured methodology, whose results were reported in factsheets for which dedicate interpretation were also developed. The aim of the factsheets is to provide a consistent evaluation of developed solution sets to building designers, building system engineers and potentially stakeholders as building energy managers, and developers. The evaluation includes energy consumption, indoor environment quality, life cycle costs and environmental impact. This information will give the reader more insight and sensibility on the effect of the building typology, geo-cluster and set of technological solutions on energy, grid interaction, LCA, LCC and indoor environmental conditions. The energy, grid interaction, and indoor environmental conditions assessment are achieved through the modelling and simulation of the considered cases by a Building Energy Simulation tool (in this case, TRNSYS). LCA analyses were performed with the software GaBi ts, while LCC outcomes come from an ad-hoc developed excel tool.

Moreover, the factsheets improve the reader's awareness on the so-called "*conflicting practices*", rising from cultural and social aspects; this is achieved through examples extrapolated from semi-structured interviews.

2 Introduction

2.1 Scope and document structure

As defined within Cultural-E project, "*A Plus Energy Building is an energy efficient building that produces more final energy than it uses via locally available renewable sources over a time span of one year. Buildings uses include both building operation and user related energy consumption. The positive balance shall be reached while ensuring the lowest greenhouse gas emissions and a good dynamic matching between load and generation, according to economic affordability and to technical viability. The definition applies to all-electric buildings and the energy balance is based on measured or predicted final energy between load and generation*" (Hawila A., 2022).

Main aim of Cultural-E project is to provide the evidence base and tools to underpin a shift in practice towards Plus Energy Houses becoming a mainstream building product.

Climate and cultural tailored solution sets have been developed to reach the Plus Energy targets in different geoclusters. Solution sets are here meant as a combination of technologies already present on the market (e.g. photovoltaic/battery systems, thermal insulation materials, thermal mass activation and storage, shading systems, and so on) with the technologies developed within Cultural-E project the cloud-based House Management System[5], the Active Window System[6], the smart air movement system[7] and the decentralized Packed Heat Pump System[8]). The climate and cultural tailored solution sets consider drivers related to typological building architecture, adapting bioclimatic design strategies to modern architecture, as well as users' (households') cultural practices. A key focus of the work is the integration of technologies within the solution sets, including sizing, coordination and control systems.

In Deliverables D4.3 (Gazzin R., 2022) and D4.4 (Turrin F., 2022), building energy models were reported considering two building archetypes, four geo-clusters and two solutions sets. Control strategies were also developed to have all the technological systems work in a harmonized manner. This allowed to obtain a set of results, which are particularly useful to assess the implications of technological choices (i.e. solution sets) under different boundary conditions (climate/building type).

[5] https://www.cultural-e.eu/cloud-based-house-management-system-hms/
[6] https://www.cultural-e.eu/active-window-system-aws/
[7] https://www.cultural-e.eu/smart-air-movement/
[8] https://www.cultural-e.eu/decentralised-packed-heat-pump-system/

Deliverable D4.5 (Di Bari R., 2022) focused on the life cycle assessment (LCA) of these cases, thus providing insight on the environmental impact of the presented solution sets. The Global Warming Potential (GWP) was assessed with static and dynamic approaches for every archetype and geographical location.

In Deliverable D4.6 (Leis H., 2022), the economic impact of each case was calculated, considering the whole lifecycle of the building (LCC).

Semi-structured interviews were conducted and analysed to determine the so called "conflicting practices" of some residents, that hinder the building energy efficiency and are difficult to eradicate due to deeply rooted cultural behaviours.

This Deliverable, hence, summarizes results coming from specific boundary conditions in different domains (social, energy, environmental, economical) and considering different cases (building type, geo-cluster, technological solution set); this comes, of course, with limitations and the above-mentioned results can be considered as valid under the same conditions and cases. For this reason, executable models will be publicly available to give the possibility to external users to explore a wider range of cases with a user-friendly interface and without a specific background and preparation in building modelling and simulations.

This Introduction will better explain the boundaries within which these factsheets have been produced (i.e. building archetypes, geo-clusters and solution sets). Then, the used methodology is illustrated, although, for further details it is possible to refer to the publicly available Deliverables previously mentioned and referenced. The following chapter provides the factsheets description, with detailed information on the different parts and contents explanation: Energy, load matching and grid interaction, Indoor environmental quality, life cycle assessment, economic impact and social impact. Lastly, conclusions are drawn.

2.2 Building archetypes

Two building archetypes were considered: a low-rise and a high-rise building, representative of the two main typologies of multi-family residential buildings in the European building stock.

The low-rise building (Figure 1) is a 3-storeys building with 7 apartments (total net area of 663 m^2). Each apartment is divided into two thermal zones (day and night). The average temperature of the two zones is used to activate the heating and cooling units.

FIGURE 1. LOW-RISE BUILDING ICON (AS ILLUSTRATED IN THE FACTSHEETS)

The high-rise building (Figure 2) is a 7-storeys building with 6 apartments for each floor except for the ground floor that has 4 apartments (total net area of 2912 m^2). Each apartment is considered as a single thermal zone with one thermostat that is used to activate the heating and cooling units.

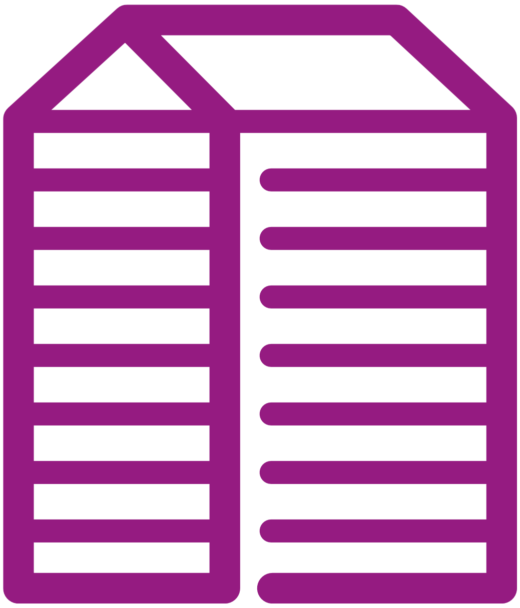

FIGURE 2. HIGH-RISE BUILDING ICON (AS ILLUSTRATED IN THE FACTSHEETS)

The different building surface area to volume ratio (S/V) implies different thermal behaviors. Moreover, the specific roof surface, normalized to the total surface area of the dwellings in the high-rise building is much smaller compared low-rise if normalized to the total surface area of all the dwellings, so PV integration in the high-rise building roof is limited, with relevant implications on important KPIs such as the self-sufficiency and the self-consumption.

2.3 Geo-clusters

Four geo-clusters are taken into account: Sub-arctic, Continental, Oceanic and Mediterranean. This choice allows to consider four representative European climate conditions and was done since the demo cases of the Cultural-E project are placed in different cultural and climate contexts, in: Norway, Germany, France and Italy.

2.4 Solution sets

TABLE 1. SOLUTION SETS SUMMARY

Solution-set	System/service	Technology
Solution set 1 (Centralized)	Ventilation	Decentralized ventilation system
	Space heating Space cooling DHW	Centralized Heat Pump
	Air movement	Ceiling fan
Solution set 2 (Decentralized)	Ventilation	Decentralized ventilation system
	Space heating Space cooling DHW	Compact decentralized Heat Pump unit
	Air movement	Ceiling fan

Two solution sets were identified in order to represent the two main typologies of technological solutions: one centralized and one decentralized (Table 1). These solution sets have been chosen both considering today's common practices (by asking the Cultural-E project's local demo case working group participants) and taking into account two different approaches, each with its pros and cons (e.g. even though the decentralized system is generally less efficient, it is more flexible and in certain cases the only option, as in intervention at single dwelling scale). Further details can be found in Deliverables D4.3 (Gazzin R., 2022) and D4.4 (Turrin F., 2022).

3 Methodology

The climate and cultural tailored solution sets evaluation is a result of several analysis processes, which have been described in detail in other project reports.

To provide a general and fast overview, the main results populating the presented factsheets are coming from energy simulations, life cycle environmental and economic impact, social practice analysis.

Energy simulations

Whole-year dynamic energy simulations were carried out considering two different building geometries (high-rise and low-rise), four different sets of envelope characteristics and temperature setpoints (depending on the climatic zone) and considering various internal gains profiles generated through a stochastic approach, to better reproduce different occupant's habits. TRNSYS was used as Building Energy Simulation (BES) tool, which allowed to define the building and the energy systems in detail. This BES tool also allowed to integrate ad-hoc control strategies to harmonize the functioning of the technological systems. For further details on the energy simulation models please refer to D4.3.

Life cycle assessment

Within CULTURAL-E, a more suitable framework for lifecycle assessment (LCA) has been established, which takes into account the outcomes of latest works and research on PEBs.

As a preliminary step of the carried-out activities, decisions regarding the methodology have been taken. As a first step, LCA was performed on developed technologies: information was gathered for understanding environmental potential and optimization possibilities. This activity led to discussion and recommendation to technologies' providers for guiding their product engineering process. As a second step, parametric LCA models for evaluating the solution sets in buildings have been produced, and presented considering KPI framework, energy related habits, technology solutions). Finally, as a preliminary result of the conducted activities, guidelines on how to understand and re-do the above steps in a specific case are provided.

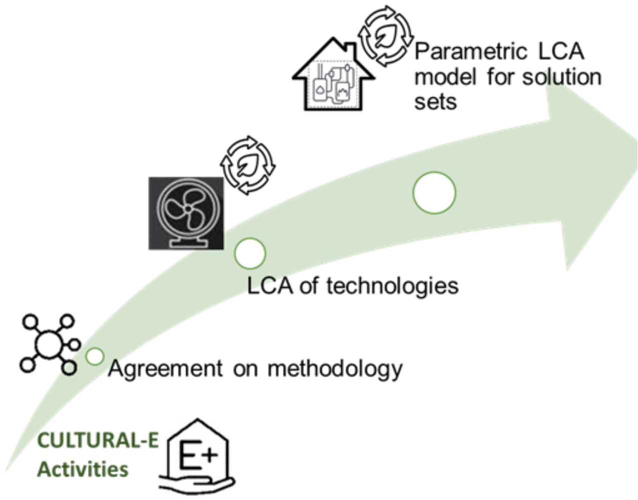

FIGURE 3. LCA STEPS

The following three LCA levels are considered:

- **LCA for technology components**: analysis of each developed technology, as part of the building envelope and HVAC system
- **LCA for solution sets**: analysis of the sets which envisage several elements for heating/cooling/ventilation systems, and, among them, the developed technologies
- **LCA for (Plus Energy) Buildings**: the analysis of the environmental performance of the designed PEB.

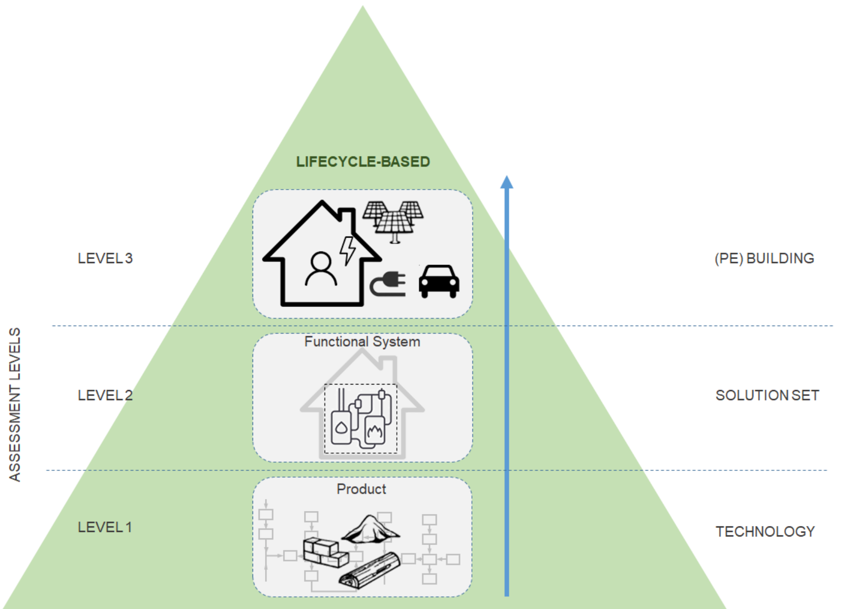

FIGURE 4. SUSTAINABILITY ASSESSMENT LEVELS

In the performed LCA analyses , technologies are "decontextualized" from the building, its use destination, users, and their climate and cultural context. Consequently, the analyses are lifecycle-based, but with reference to product and the technology's service life. Results of these analyses are used for solution sets and buildings assessment. Solution sets and PEB analyses are carried out through assessments which refer to a specific building within a specific climate and cultural context. Furthermore, solutions sets and PEB analyses can take into account time-dependent variations of national energy mix (dynamic assessment).

Economic impact

Regarding the economic impact, the factsheet focuses on the total annual cost within a period of 30 years. A discount rate of 1.0 % is set for the calculation. Here the cost for initial investment, energy, maintenance and replacement in the period are considered. Initial investment and replacement expenditure are capital costs and they are gathered in the corresponding column. Moreover, the savings coming from the self-use of the produced energy and the revenues from selling it are considered here. In particular, replacement due to the limited service-life of the technical components can be significant over the entire service life and is shown here in the section on capital costs. In all cost categories it is possible to consider an individual price increase. Detailed cost data is used for the technologies which differ in the solution sets: PV-panels, battery, heat pumps, boilers, and ventilation units. For all other construction cost the level of detail is lower and based on area specific data. The specific costs are based on the experience of the demo case partners from realized projects of the past years. When a specific product or technology price is not available, prices for similar products that are available on the market are used. The circle diagram shows the initial investment cost, which does not include the cost of replacement.

Social impact

The social impact section that appears in the factsheets provides qualitative insights coming from the analysis of a total of **23 semi-structured interviews** conducted in the four geoclusters covered by the project.

The four-interview series gather residents' daily experiences living in NZBs and passive house buildings and aim at shading some light on their daily practices and their interactions with the technologies installed in their homes. The goal of this social impact section is to allow their voices and testimonies to be heard next to the quantitative data coming from the analysis of energy simulations, LCA and LCC.

In the **French** and **German** interview series, the semi-structured interviews were conducted with **tenants** while in the **Italian** interview series the interviewees were **owners.** In all three series residents live in buildings selected from the project demo owners' building portfolio. This choice was due to the fact that Cultural-E demo buildings, in these three countries, were not built at the time these interviews had to be conducted. In contrast, Cultural-E **Norwegian** demo building has been functioning since 2021 so the interviews could take place in the project pilot, which is a **nursery home** that hosts residents with a variety of disabilities (most of them are unable to communicate verbally) and who need 24 hours care. Therefore, in this case, interviews were conducted with some of the **staff members** working at the nursery home.

Method of data collection: The method used was that of **semi-structured interviews.** This is a qualitative research method that combines a pre-determined set of questions with some other more open questions that arise during the interview, allowing the interviewer to explore particular themes or responses further. All interviews were transcribed, and translated into English, when the language spoken during the interview was a different one.

Method of data analysis: **Coding** is a qualitative data analysis method in which the researcher assigns a descriptive label, a code, to pieces of data (words/groups of words) allowing to identify categories and themes across the data, and the relation between them, in order to understand what the data represents.

In this case, the interview transcripts were analyzed using a **social practice theory** lens, which putting it simply means, looking for pieces of data (words/groups of words/quotes) that relate to the **daily practices** that residents mention they perform, such as *ventilating, heating, cooking, cleaning*, etc. After a first round of analysis some patterns started to emerge. Some of the practices mentioned by the residents were conflicting with each other in the sense of decreasing the energy efficiency intended with the building technologies. They were linked and paired under the umbrella concept of **"conflicting practices"**. Each factsheet shows one example of these conflicting practices. The four factsheets per geocluster are four examples of conflicting practices.

It is remarkable to point out that, **no matter which geocluster, residents were overriding the technologies when their needs were not fulfilled**, **even if they were aware of their energy inefficient behaviors** and **knew how to properly operate the technologies.** This proves the point that approaches that aim to change individual behavior by offering rewards or disincentives, or by providing information to users, do not work as expected. Rational choices are constantly jeopardized by both conscious and unconscious responses that happen when residents' needs are not fulfilled.

In contrast, Cultural-E's approach **focuses not on changing individual behaviors but on understanding** these pairs (or triplets, in some cases) of **conflicting practices.** This allows to **anticipate people's needs,** which are at the root of these practices, and discern to which extent these needs are **shaped by climatic and socio-cultural factors**. In this way, this **practice-oriented approach** aims to inform the design of future PEB technologies bringing their design closer to the residents' needs, instead of wishfully thinking that residents will change their behavior and adjust to these new technologies. This practice-oriented approach aims at making future PEB technologies more flexible to the different **types of circumstances** that residents face in their daily lives, aiming at overcoming these conflicts between practices, optimizing energy efficiency.

This is not a one-directional effort, but provides new practices associated to new PEB technologies with the time needed "to be born" and "develop in time", until they become mainstream. For example, *mechanically ventilating a home* is something that is not yet ingrained in the imaginary of most of the residents interviewed. Opening windows is something that, in many contexts, comes culturally more naturally because of the way people have grown up cultivating these habits. It will be a matter of time to see how the practice of ventilating the home evolves. It might be that our human nature will not let us manage to go without opening windows due to our inner need to be in contact with outdoor space/nature (as interviews are showing) or, in a scenario of enhanced awareness, the practice of ventilating mechanically will slowly take over. This will depend on how new skills/knowledge (learning how to use mechanical ventilation systems, change/clean filters, etc.), new technologies (easiness to operate the systems), new meanings/understandings (it mechanically ventilating socially accepted, well perceived, etc.) develop in time and at which pace.

As a final remark, it is worth pointing out that the pairs of conflicting practices that appear in the factsheets do not match either with the building archetype or with the technology sets that structure the factsheets. This is due to the fact that the interviews were conducted with residents living in buildings that differ from the aforementioned factsheet's selection criteria.

However, it is key to show these conflicting practices organized per geocluster in order to show **how some of these pairs repeat in several geoclusters**, such as '*being in contact with outdoor space*/hearing nature' and '*opening windows*', '*taking care of a loved one*' and '*adding an extra heating source (radiator)*' or, to give a last example, '*sleeping with an adequate temperature*' and '*opening windows*'. These findings reflect that people, no matter in which geographical climatic context they live, have similar human needs and ways to cope with technologies when their needs are not fulfilled.

Despite these similarities, **the data shows also some differences per geocluster** that are worth mentioning due to the **cultural and climatic** aspects at their root, among other factors. For example, *sleeping with the windows crack open when it is winter and it is below 20 degrees outside,* it is something that Norwegians are used to do but that people in Italy would not consider. Other Norwegian practice such as *having many different thicknesses of duvets at home* is closely linked to this practice of sleeping with crack open windows, enabling themselves to cope with different situations.

Growing up in a place with specific **cultural and climatic conditions** makes people take for granted certain things, shaping the practices that are performed by most of the local populations. For example, Norwegians have developed *dressing practices* that allow them to be able to be outdoors no matter the weather conditions. As the Norwegian/Nordic saying goes, *"there is no bad weather, only bad clothes*". This ability to be in contact with nature, no matter the weather conditions, influences to a certain extent their need for *opening windows* to have a bit of that *feeling of being outdoors when at home*. As a contrast, their need for warmth, the *need to feel an immediate warmth source* such as the *fireplace*, is engrained in their cultural imaginary and childhood memories. This makes Norwegians have doubts about the diffused heat provided by the *floor heating*, preferring still in many instances, the direct heat provided by an *electric radiator*.

The **examples of conflicting practices** used in the factsheets are thoroughly presented in Annex I, where the need and responses are more extensively explained and a direct quote from the building user is reported. These examples are also identified with a letter and a number (e.g A1, B3, C2) to link the extended description with the shorter one provided in the factsheets.

4 Factsheets description

The presented factsheets are designed to be easily accessible and understandable by different stakeholders, such as designers, potential users, building owners, energy managers and so on.

All the factsheets are built in the same manner to ease the comparison between different cases. The goal, in fact, is to allow the reader to immediately find the information needed and to be able to make comparative analysis at a glance.

4.1 General information

The top part of the factsheet holds the general information on that case. At the very top there is the name of the factsheet, which is composed by the following abbreviations:

- Climatic/geographical zone:
  - MED – Mediterranean
  - ARC – Subarctic
  - OCE – Oceanic
  - CON – Continental
- Building archetype:
  - LR – Low-rise
  - HR - High-rise
- Solution set number:
  - 1 – Solution set 1 (Centralized)
  - 2 – Solution set 2 (Decentralized)

For instance, the factsheet "ARC_LR_2" corresponds to the Subarctic geocluster, considering the low-rise building and the decentralized solution set (Solution set 2).

To allow readers to immediately understand the case study, the information related to the geocluster, the archetype and the solution set are also represented graphically (Figure 5). Moreover, a short description provides further information on the technologies considered for that particular case and the characteristics of that archetype.

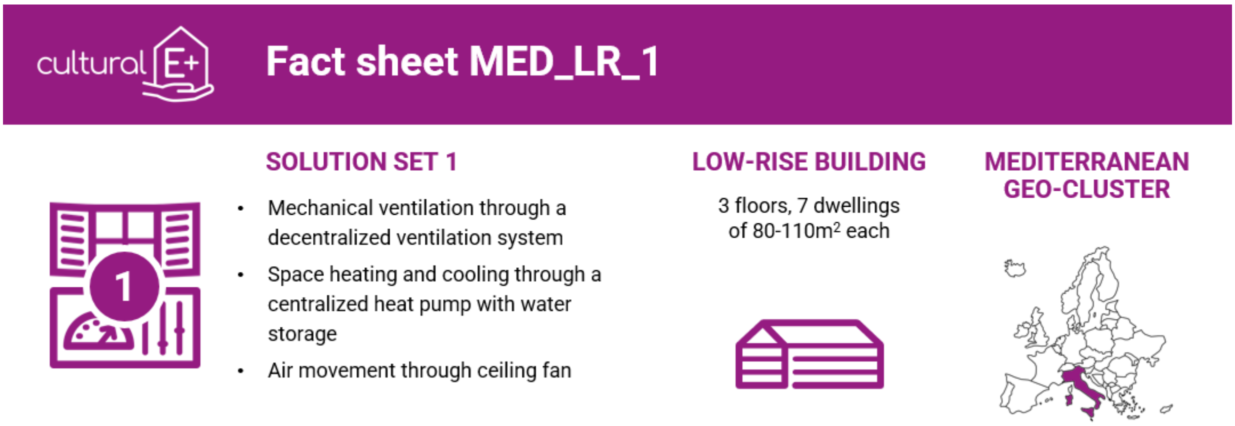

FIGURE 5. EXAMPLE OF THE TOP PART OF A FACTSHEET

4.2 Key Performance Indicators

The bottom part of the factsheet holds all the information related to the energy modelling, LCA and LCC analysis results obtained for that case. The KPIs used are a subset of those described in D4.1 (Abed Al-Waheed Hawila, 2022). The reason why only a subset was considered is twofold: on the one hand, it was neither feasible nor useful to the scope of producing comprehensible factsheets, since clarity and synthesis are required for effective communication; on the other hand, some of the KPIs identified in D4.1 are lagging, meaning that they can only be assess through measurements or starting from real cases. The KPIs considered in the factsheets are summarized in Table 2; the KPIs are divided in categories (e.g. Energy, Environmental Impact, etc.) and for each KPI a description is provided:

TABLE 2. KPIS CONSIDERED IN THE FACTSHEETS AND RELATIVE DESCRIPTIONS

	Name	Description
Energy	Primary energy	Annual primary energy use. It is calculated by multiplying the energy quota from the grid by the primary energy conversion factor and adding to this value the self-consumed energy quota (from PV to the building). The primary energy conversion factor is different for each geo-cluster; official and updated data from each considered country (i.e. Italy=2.42, Germany=1.37, France=2.30 and Norway=2.28) were considered.
	Final energy	Total thermal energy use, considering space heating, cooling and domestic hot water.
Load matching and grid interaction	Self-generation (load cover factor)	Percentage of the energy demand covered by RE production. It refers to load matching. It is calculated as the ratio between the self-consumed generated energy (from PV to the building) and the total annual electric energy use, that takes into account the Heat Pump electric consumption, appliances, lighting, ventilation, ceiling fans, auxiliaries and fan coils.
	Self-consumption (supply cover factor)	Percentage of generated energy which supplies local loads. It refers to load matching. It is calculated as the ratio between the Self-consumed generated energy (from PV to the building) and the total renewable energy generation (energy generated from the PV system). This indicator is influenced by the losses in the electrical storage and supply system and the electrical energy that is sent to the electrical grid.
Indoor Environmental Quality	% Yearly hours within indoor temperature ranges (°C)	Percentage of the hours in which the indoor temperature ranges within the operating temperatures. During the winter operation the lower limit is defined by applying to the setpoint (based on the geocluster, D4.4 (Turrin F., 2022) the dead band of the hysteresis (0.5°C) and an additional temperature tolerance of 0.25°C to account for the delayed response of the heat pump system. During the summer operation the upper limit is defined in the same way and adding an additional 1.8°C to account for the air movement caused by the ceiling fans. In winter the upper limit is set to 26°C while the lower limit in summer is set equal to 21°C.
	% Yearly hours within indoor relative humidity ranges (%)	Percentage of the hours in which the indoor relative humidity within the operating relative humidities. The upper limits are defined applying a maximum mixing ratio of 0.012 kg_v/kg_a in winter and 0.012 kg_v/kg_a in summer (ASHRAE-55). With the considered temperatures, the upper limit varies between 65% and 70% depending on the geocluster and period of the year. The lower limit was imposed equal to 30% by default.
Environmental impact	Total GHG emissions (Global Warming Potential)	Quantity of CO2 eq. emitted by the whole building system over its lifecycle. Within the whole lifecycle of the building embodied emissions entail. - Production process - Building components' replacement over building service life - End-of-Life of Building Operational emissions are calculated based on energy consumptions and energy credits due to PV systems.
	GHG emission reduction	Quantity of CO2 eq. Avoided through credits due to PV system installations.

Economic impact	Investment cost	All initial costs that need to be covered until an energy efficiency measure is fully implemented
	Capital cost	Capital-related cost, including replacement (annuity)
	Energy cost, operational cost	Annual operation cost of the energy resources in the building (annuity)
	Maintenance cost	Maintenance and service cost for technical building services: heating, cooling, ventilation, electricity from PV (annuity)
	Life-Cycle Cost (LCC)	Value of the total cost of building usage for the whole calculation period (annuity)

4.3 Body of the factsheets

The main body of the factsheet holds the information in terms of the chosen KPIs for that particular case. Since in the factsheet itself it is not possible to add written descriptions of what shown, this document provides guidelines for reading and interpreting the factsheets.

Energy, load matching and grid interaction

Results from energy simulation models were used to assess the energy, load matching and grid interaction KPIs. A section containing these KPIs is present right after the general description of the factsheet. An example of this section is shown in Figure 6:

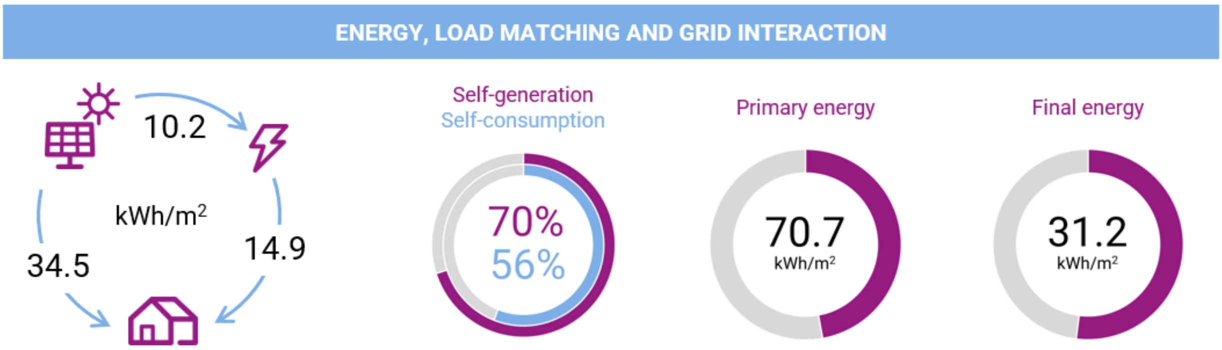

FIGURE 6. EXAMPLE OF THE ENERGY, LOAD MATCHING AND GRID INTERACTION SECTION.

On the left-hand side, an infographic describes the energy exchange between the PV system, the building and the grid over a full year. The top part represents the exported energy to the grid, the bottom-right part the self-consumed energy, and the top-left part the imported energy from the grid. The values are expressed in kWh/m² to normalize the data with respect to the surface area of the built environment.

On the right-hand side, three graphs provide information on:

- Self-generation: the percentage of the energy demand covered by the renewable energy produced by the PV system
- Self-consumption: the percentage of the energy generated by the PV system which supplies local loads
- Primary energy: which includes the consumption and conversion losses in the energy transformations
- Final energy: which refers to what end users actually consume

The illustrated circles show the relative KPI in either purple or light-blue. In the case of percentage values (as self-generation and self-consumption), the ratio between the coloured circle and the background corresponds to the KPI itself (e.g. if the self-generation is equal to 70%, the purple circle will be 70% while the grey one 30%). Regarding the primary and final energy, the same approach was used by first normalizing these values with the respective maximum ones: since the building archetype (high and low rise) and the solution set (one or two) greatly affect the results, four categories where considered, and the maximum values for each category where used for the normalization. This allows the reader to better interpret and compare the different factsheets.

To provide an example, Figure 7 shows a comparison of the final energy considering the low-rise building and the first solution set between the four geoclusters. In this case, the reader can easily compare the four results and understand the differences at a glance.

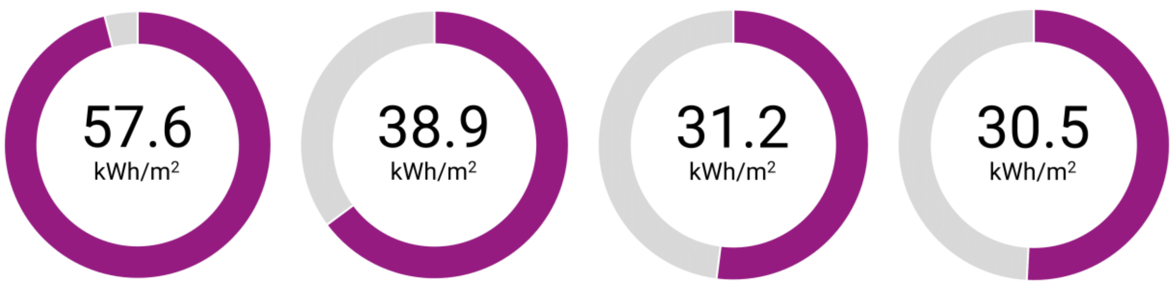

FIGURE 7. EXAMPLE - FINAL ENERGY FOR THE LOW-RISE BUILDING AND SOLUTION SET 1. FROM LEFT TO RIGHT: SUB-ARCTIC, CONTINENTAL, MEDITERRANEAN AND OCEANIC

Indoor environmental quality

Regarding the indoor environmental quality, the factsheet focuses on the indoor environment conditions, which is the only information that can be assessed during simulation and generalized for the entire building, unlike KPIs as the daylight factor or the illuminance levels, which are more space-dependant. In particular, thermal comfort and relative humidity comfort are represented in a scale from 0% to 100%, representing the % of occupied hours in which indoor environment conditions are within temperature or humidity comfort ranges defined in the standard EN 16798-1: 2019. Each parameter is assessed as the ratio between the number of hours in which the temperature or relative humidity is between comfort ranges (20-26°C for indoor temperature and 25-75% for relative humidity) and the total amount of occupied hours. Thus, the higher the value, the more indoor environment conditions are respected over the year. An example of this section is shown in Figure 8.

FIGURE 8. EXAMPLE OF THE INDOOR COMFORT SECTION

Life cycle assessment

For LCA analyses total GWP shows the total GHG emissions in CO2 eq. Related to embodied and operational emissions over a timespan of 30 years, not considering the components' replacement. When PV energy credits are less than the total energy consumption, operational emissions are positive and lead to an increase of total GWP (in Figure in purple and expressed in percentage with respect to the total GWP). When

PV energy credits are higher than energy consumptions, operational emissions are negative and help to decrease over time total GWP and to pay-back the initial environmental investment due to PV installations and innovative building technological components. Emissions increases or decreases are estimated both in a static (left side of Figure 9) and a dynamic matter (right side of figure). Static GWP assessment assumes a non-variable energy mix and constant CO2-eq- intensity factor for each kWh energy consumed. dynamic GWP assumes a variable energy mix over building lifetime.

Static assessments lead to higher operational emissions and to a more conservative approach for the total GWP estimations. Dynamic assessments, even if provide lower operational emissions' increases, as demonstrated in D4.5, can provide longer environmental pay-back time and can be represent future environmental improvements of the energy production in a more accurate matter.

Providing both assessment approaches for the established environmental KPIs, factsheets can support decision making about the implementation of the analyzed solution sets. An example of this section is shown in Figure 9.

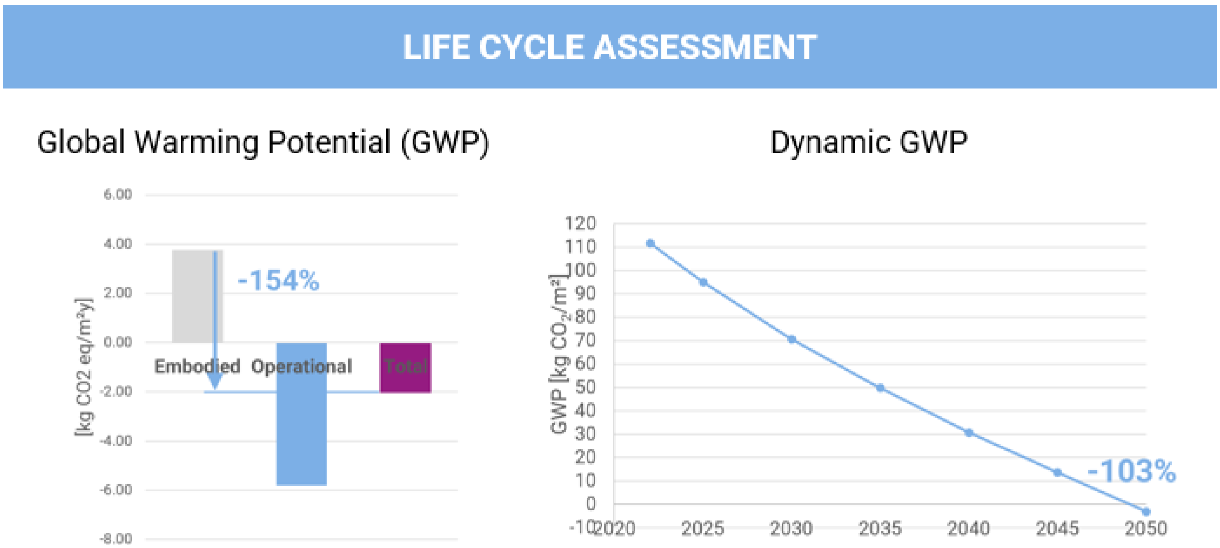

FIGURE 9. EXAMPLE OF THE LCA SECTION

Economic impact

For economic analysis we use total annual cost which is the discounted cost of all cost for investment (replacement included), maintenance, energy and revenues from produced energy during a period of 30 years. The left column shows the total annal cost for investment, maintenance and energy. On the right side, the revenues from the sale of electricity are deducted and the purple column shows the resulting total annual costs.

The circle on the right side shows the initial investment cost for the construction of the building until commissioning in €/m². An example of this section is shown in Figure 10.

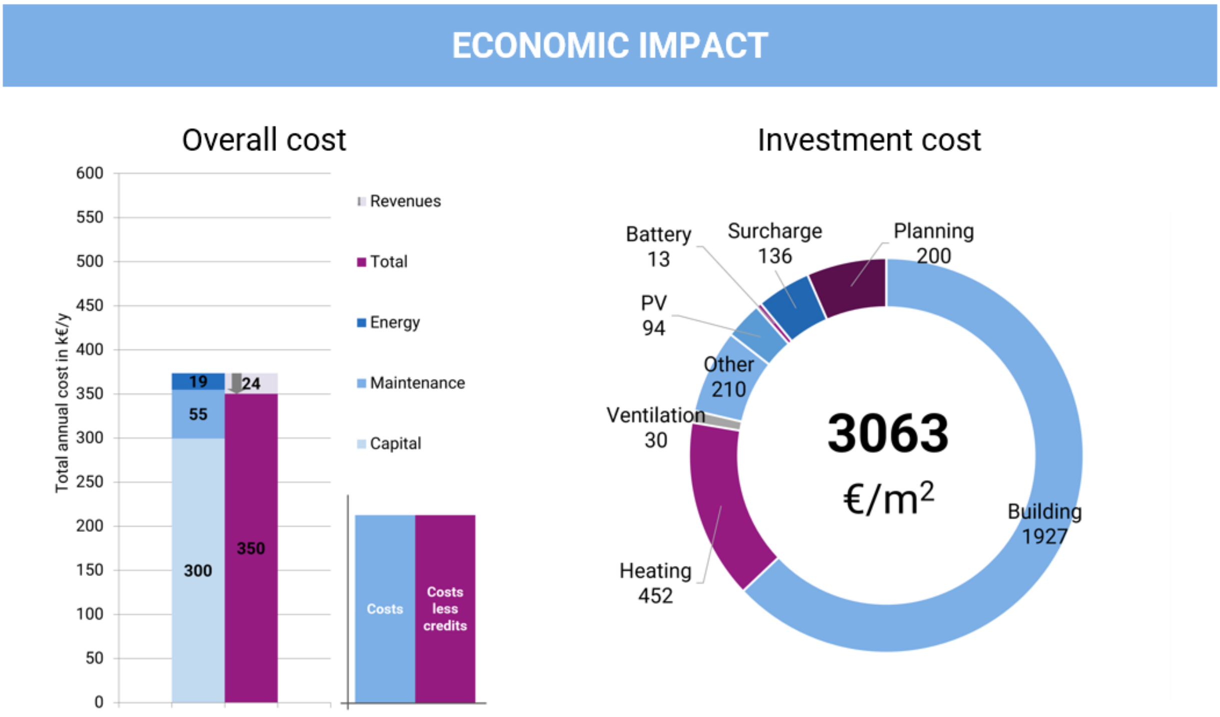

FIGURE 10. EXAMPLE OF THE ECONOMIC IMPACT SECTION

Social impact – Residents' voices

The examples of conflicting practices that affect energy efficiency described in Section 3 - Methodology are condensed in a graphical way in the lower-right part of each factsheet (see Figure 11 for an example).

Each pair of conflicting practices reducing energy efficiency is defined by a "need" and a "response". The "Need" and the relative "Response" are reported in a synthetic manner, using icons to convey the message in a more immediate and visual way.

A little circle with a letter (from A to D), indicating the geocluster, and a number (from 1 to 4), referring to the pair of conflicting practices (e.g. A1, A2, A3, A4, B1, B2, etc.), located at the bottom-right corner of the section directs the reader to the Annex, where more information on these conflicting practices is provided, together with the respondents' quotes that exemplify these different sets of conflicting practices.

This extra information in the Annex allows the reader to get access to the residents' testimonies, their voices. This qualitative data intends to be complementary to the rest of the quantitative data provided by the factsheet, creating a typology of circumstances, per geocluster, to be considered by designers of future PEBs (see Annex I).

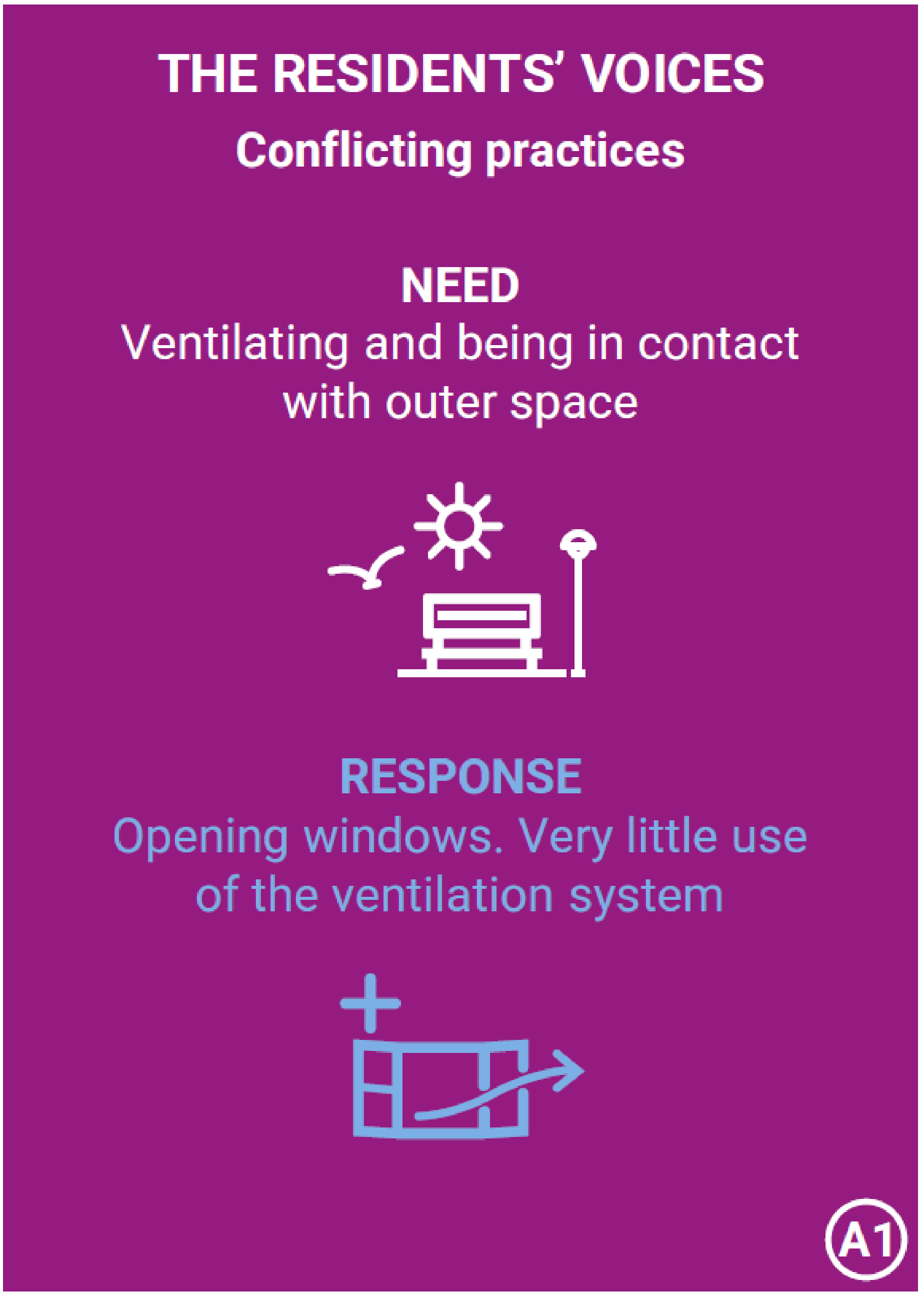

FIGURE 11. EXAMPLE OF THE RESIDENTS' VOICE SECTION

5 Conclusions

This deliverable presents the factsheets that were designed to summarize many of the results obtained within WP4 of the Cultural-E project. These factsheets target mainly at building designers and building systems designers, but can also be useful for other stakeholders, such as building energy managers, developers or even expert users. The factsheets enable the aforementioned target users to easily and quickly get an overall picture of the main Key Performance Indicators in different domains: energy consumption, load matching, grid interaction, indoor comfort, LCC, LCA and social aspects related to a series of considered cases, with different technological solution sets, located in different geo-clusters and with two different building archetypes. Their use will also allow comparative analysis, understanding the impact of the considered variables on the various KPIs.

6 References

Abed Al-Waheed Hawila, C. P. (2022). *Evaluation framework for PEBs - Deliverable 4.1.*

Di Bari R., J. O. (2022). *Guidelines and calculation methods for Lifecycle Environmental Impact Assessment of Plus Energy Buildings - Deliverable D4.5.*

Gazzin R., T. F. (2022). *Repository of reference building models and related solution-sets - Deliverable D4.3.*

Hawila A., P. R. (2022). Plus energy building: Operational definition and assessment. *Energy & Buildings*.

Leis H., P. C. (2022). *Tool for economical assessment of life cycle cost in PEBs - Deliverable D4.6.*

Turrin F., B. G. (2022). *Report on multi-system - Deliverable D4.4.*

Annex I – Examples of conflicting practices per geocluster

The present Annex gathers some of these **examples of conflicting practices** that affect energy efficiency. Each pair (or triplet) of conflicting practices is illustrated with quotes extracted from the interviews, together building a **typology of circumstances per geocluster:**

Examples of conflicting practices per geocluster:

A. Mediterranean geocluster (from the Italian interview series)

A1. **Conflicting practices**: **Being in contact with outer space & Opening windows**

- **Need:** be in contact with outdoor space.

- **Response:** opening windows. Cultural and climatic aspects influence the way mechanical ventilation is intended. This resident likes to open the windows. It is a habit influenced by the benign conditions in southern Europe and the need to be in contact with outdoor space.

- Quote: *" I must say that **I use it very little [the mechanical ventilation system]** because **I like to open the windows** […] It is a habit but also a necessity because in the end it is the **relationship with outdoor space**, if there are good climatic conditions, of course"* (retrieved from an interview with a user in Modena_2022-03-15).

A2. **Conflicting practices: Sleeping comfortably (right temperature/no noise from mechanical ventilation) & Heating / Cooling down**

- Need: sleep properly with an adequate temperature. The bedroom is too hot at night. This household has thermostats in all rooms except the bathrooms and the bedroom, which is next to the bathroom, gets heated by proximity, reaching temperatures of 22 degrees, which is too hot for a bedroom, according to this resident's testimony.

- Response: opening windows because even after turning off the heating, the bedroom does not cool down. This resident regrets not having installed air conditioning to be able to fulfil this need.

- Quote: *"the most heated room is my bedroom, which is basically southwest, and **I have to open the windows** in the winter, **despite not turning on the heaters,** to let the house cool down."* (retrieved from an interview with a user in Modena_2022-03-22).

"One problem I find in this house is that I have thermostats in all the rooms. Except than the bathrooms, and so the bathrooms automatically heat up whenever the heat pump

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 870072

starts to bring the water up to temperature, and you are just fine in the bathrooms. ***However, 22 degrees for me in a bedroom is too high****."* (retrieved from an interview with a user in Modena_2022-03-22).

A3. **Conflicting practices: Taking care of a loved one & Extra heating**

EXAMPLE 1

- Need: Having a baby changed the way this household uses the home, increasing their energy consumption:

- **Response:** extra heating to make sure the baby is not cold, extra electricity for appliances (washing machine) and extra hot water for hygienic purposes.

- Quote: *"I had a* ***child two years ago and it has changed my electricity consumption completely*** *[...] and so obviously the heating maybe you bring it a little bit higher and the electricity that is used to clean, to sanitize [...] has increased and the hot water has increased"* (retrieved from an interview with a user in Modena_2022-05-09)

EXAMPLE 2

- **Need**: bedroom where daughters sleep is too cold in winter.

- **Response**: adding an electric heater to complement the floor heating. Floor heating seems not to respond to the needs of this household, due to different requirements of each room/orientation.

- Quote: *"The girls' room is the coldest in winter and the hottest in summer, unfortunately" [...] One inconvenient thing in my opinion about this type of heating [referring to the floor heating] is that there is no possibility to differentiate it between living and sleeping areas"* (retrieved from an interview with a user in Modena_2022-03-10).

A4. **Conflicting practices: Cleaning (with cleaning products) & Opening windows vs. Mechanical ventilation**

- **Need:** to get rid of cleaning products' smells (chemicals) and not being sure if mechanical ventilation will suffice.

- Response: opening windows to ventilate. Even if this resident is very happy about the mechanical ventilation, she is not yet used to this practice and opening windows comes more naturally to her as a response to fulfil her need to clean the air.

- Quote: *"I have to say that I, despite the fact that they* ***had trained us to keep the windows closed as much as possible****, [...]* ***I actually do it a little bit****. For example, when I have to do some* ***cleaning****, I do admit it [...] I have been told that the moment you have to do cleaning you increase the value of the mechanical ventilation. Honestly, maybe a little bit* ***because of cultural factors, to me it just comes to open [the windows]"*** (retrieved from an interview with a user in Modena_2022-05-05(2)).

<u>**B. Oceanic geocluster (from the French interview series)**</u>

B1. **Conflicting practices**: **Being in contact with outer space ("hearing nature" & Opening windows)**

- **Need:** be in contact with outer space (to hear nature).

- **Response**: opening windows.

- **Quote:** *"yes, I try to ventilate, open the windows so that the wind comes in and* ***even to hear nature*** *["D'entendre la nature"]* (retrieved from an interview with a user in Carquefou_2021-11-24).

B2. **Conflicting practices: Sleep comfortably (right temperature/no noise from mechanical ventilation) & Heating / Cooling down**

- Need: to sleep comfortably with an adequate temperature. In the case of the resident this need of having a comfortable fresh temperature extends to the whole day.

- Response: having a fan always on to feel good, even in winter when she sleeps. The interviewee is originally from Senegal and her cultural upbringing shapes her need for thermal comfort.

- Quote: *"I love my fan". [So a fan that blows air. It's a small standing fan I guess.] "Yes, but here's the thing. So* ***I still need that to feel good****. Well, there's the. It's true that* ***the fan***

***is always on**. Okay, but even in the winter after that, it's really because I'm weird, but I sleep with the fan all the time”* (retrieved from an interview with a user in Lille_2021-06-15).

B3. **Conflicting practices: Taking care of a loved one & Extra heating**

- Need: special needs/practices of care (for a loved one, a baby in this case, with asthma).

- Response: extra heating/electricity to make sure the baby is not cold. In extra cold days, the resident uses a small space heater so that the young son does not get cold. He has asthma so the mother is extra careful with him.

- Quote: *“I have a **small space heater** that I used to use in the morning in the winter [...] to get my son ready [...] **so he doesn't get cold** [...] and then I turned up the heat in my main room, via the thermostat”* (retrieved from an interview with a user in Lille_2021-05-06)

B4. **Conflicting practices: Ventilating & Having health issues (asthma, allergies) and a personal feeling of ‘being cold’**

- Need: to ventilate while taking into account health concerns and the (personal) ‘feeling of being cold’.

- **Response:** opening windows for a very limited time and only the bedroom window in the early morning to air the room and the kitchen window when cooking.

- Quote: *“So in winter, it's complicated because I have to keep the house warm and I'm cold, so in winter it's very, very complicated for me to air. So what I do is I basically air out my room. So what I do is I open the window very very early in the morning. I never open the window during the day because of the pollution peak. So **I have asthma and a lot of allergies so I'm careful** about that. So what about the kitchen? Anyway, I have to open the window when I'm cooking because the VMC doesn't work properly. So I open the living room and almost always, even in winter, I open it. On the other hand my room, as I want it to stay warm, I am careful and I close.”* (retrieved from an interview with a user in Lille_2021-05-03).

C. Continental geocluster (from the German interview series)

C1. **Conflicting practices: Relaxing (“hanging out”) & Heating**

- Need: to "hang out" in the outdoor balcony all year round. Need to be in contact with outdoor space.

- Response: In winter, using an electric heater on the balcony. Even if aware of his skyrocketing energy consumption levels (he has been contacted by the building manager), he prioritizes his lifestyle.

- Quote: *"The most important thing to me was, that's why I'm happy about my personal apartment, the balcony. Like even in winter, I even* ***bought a little heating box for the winter and I can like hang out.*** *I also like to* ***smoke.*** *[...] even if like we're having a snowfall, I can get on my balcony [...]*

"And yeah, the consumption, especially this is my personal critical point, because in this case I know this is actually good that the house management always tries. But still in a Let me say humane. Uh, because sometimes they said like the consumption maximum should be. Maybe these are the average consumption, but sometimes the like. He presented the value. We should let the target value was a bit like too unrealistic like this is was not realistic because they said a normal person could like use that much KWS [...] Uh, I could have never actually made it because ladies, ***I'm sorry because yeah again they they these these targets were not in my personal life concept****."* (retrieved from an interview with a user in Stuttgart_2022-05-03).

C2. **Conflicting practices: Sleep comfortably (right temperature/no noise from mechanical ventilation) & Heating / Cooling down**

- Need: to sleep with an adequate temperature. Temperature does not go down by lowering the thermostat.

- Response: Turning off the heating + Opening windows + Changing dressing habits.

- Quote 1: *"in winter. I've even* ***tried to turn it off*** *[the heating], but no, I mean, I set it at 15 degrees anyway and the house is very hot. My neighbors also have it all on. It's hot, which* ***makes you open the window*** *more or ventilate in winter. In winter, but two minutes and then when you do it again. And at bedtime it affects you, I mean, you have to take blankets off or you have to* ***change your dressing habits****".* (retrieved from an interview with a user in Stuttgart_2022-06-08).

- **Quote 2:** *"Temperature in the room itself. Like during night can be a bit. Better regular regulated. Otherwise, of course,* ***keep your window open****, cool your room at least refresh it* *for at least 30 minutes. That's what I do. Then I just go for a walk and then I can sleep in a cooler like call cold room."* (retrieved from an interview with a user in Stuttgart_2022-05-03).

C3. **Conflicting practices: Practices of care (having visitors) & Extra heating**

- Need: to please visitors with a warm house when being the host. This could be linked to issues of status/identity, but the data collected doesn't show this.

- **Response:** When he has visitors, he adjusts the temperature to their visitors' thermal comfort expectations:

- **Quote:** *"Hmm. UM, I think I had only in one case where a visitor coming from. A warmer. Environment and then he came over. Where Germany, to him is a little bit cold, so I had to. And I had to use an extra, uh energy consumption to adjust the temperature of the house, but that was only in one case. So,* ***depending on which kind of guest I'm having****. Then I have the need to adjust the conditions of the of the room."* (retrieved from an interview with a user in Stuttgart_2022-07-18).

C4. **Conflicting practices: Cooking (fried foods) & Ventilating naturally / mechanically / Turning lights on**

- Need: to get rid of cooking smells (fried foods) in a small studio. Conflicting practices in a small studio: sleeping, living and cooking areas are too close, plus noisy and polluted outdoor environment that does not allow her to fulfil her indoor air quality needs.

- **Response:** combining mechanical ventilation (by opening the bathroom door and turning on the bathroom light) with natural ventilation (creating a draught).

- Quote: *"Especially when I* ***cook something with oil*** *I always use the extractor [...] I see the smoke dissipate throughout the kitchen. So then I open the bathroom door and [turn on the light to] turn on the exhaust fan so that the particles go into the bathroom. In the end, I do always have to* ***open the balcony to really change the air*** *[...] the* ***smell of fried food, that stays****."* (retrieved from an interview with a user in Stuttgart_2022-06-08).

D. Sub-artic geocluster (from the Norwegian interview series)

In this last geocluster, the demo building is a nursery home hosting 12 residents with special needs and most of them with disabilities that impede them from communicating verbally. Therefore, the information regarding how the building is used has been collected mainly via interviews with staff members. The first three examples of conflicting practices apply to the demo building while the fourth does not directly but has been included in this list due to its applicability to the Norwegian context.

D1. **Conflicting practices: Heating (floor heating) & Adding an extra electric radiator & "Feeling the heat"/ Missing a direct warmth source (fireplace)**

- **Need:** Heating, coming from the floor heating, does not meet the residents' thermal comfort expectations in winter, some of them still feel cold. Residents at the Norwegian demo building, which is a health facility, have very diverse needs due to array of disabilities.

- **Response:** Adding an extra electric radiator to compensate for this lack of warmth. A radiator seems to provide them with this direct source of warmth needed, more comparable to the culturally engrained tradition of having a fireplace in the home.

- **Quote 1:** "*T: I don't look at the system, but yeah, I don't understand so much of it (laughs). Well, I prefer the electric radiator but we can't use it here… but there are no radiators here because you have this technology (laughs).*

MI: Why would you prefer the radiator?

T: Because I don't feel like… sometimes when it's like… when you have 24 degrees ***, I don't feel like it's 24 degrees.*** *Like in the winter.*

MI: Do you feel colder?

T: Yeah, sometimes.

MI: Do you have to wear an extra sweater here?

T: In the winter yes, and someone thinks, who lives here in the first floor, was very cold, sometimes.

MI: A resident was complaining a bit.

T: So, we had to ***take the radiator and we had to heat extra****."* (retrieved from an interview with Baerum Kommune staff members on 2023-04-20).

- **Quote 2:** *"I1: [...] you can raise the temperature a degree or two but no more, for example one of the users is cold and this is not enough for him, so how do they solve this,* ***by putting an individual heater*** *that alters the system... because the house understands that it is too hot and lowers the temperature.*

[...] I1: but then if not, he freezes to death. So, there are two residents specifically on the second floor that ***have individual radiators because without them they are cold****. The temperature that the house gives them is not enough for them and of course it is a struggle because the radiator is supposed to be fighting with the automatic system of the house. But of course, we have no choice because they are cold."* (retrieved from an interview with Baerum Kommune staff members on 2023-04-20).

Quote 3: *"H: if we would live in this type of building, we would not need the radiator. Because I moved to a new apartment bit over a year ago, they have floor heating and also has a ventilation system, much the same as in Eiksvein, I don't need anymore.* ***Perhaps in the winter, we were use to fireplaces, you know? With logs of wood****. Now we have this electric fireplace just to maintain that, 'oh, this is feeling cozy'.*

MI: and is it the same?

H: no... [...] have you seen, do you know Netflix? You can see three or four types of fireplaces, that go for an hour or two, it looks nice, you can hear the sound but it's not the same, it'll never be the same.

MI: is it because of the heat source that when you're next to a fireplace...

H: yes, you can ***use your hands on the radiator and you will feel the warmth,*** *the heat from it, but it's not the same as the floor heating or if you have a fireplace. You know,* ***feel the heat*** *[...] But the lack of a natural heating from burning wood, I think this is very deep in our roots in Norway because Norwegians are 'cold' people. We see us as 'cold' people"* (retrieved from an interview with a Baerum Kommune (technical) staff member on 2023-04-21)

D2. Conflicting practices: Being in contact with outdoor space ("hear the birds") & Smoking & Opening windows & Heating (floor heating) & Ventilating mechanically

- **Need:** Being in contact with outdoor space and (in the case of some residents), smoking.

- Response: Opening windows which interferes with the floor heating and the mechanical ventilation systems.

Due to the need to be in contact with the outdoor space, staff members open the windows and balcony doors for the residents to access the terrace, being in contact with outdoor space, etc. This action of opening windows interferes with the floor heating and the mechanical ventilation systems. Ideally, residents would not need to open windows because the mechanical ventilation system cleans and renovates the air and the floor heating system keeps the apartment warm. Floor heating is set up at 21 degrees, in general, and the mechanical ventilation temperature two degrees lower, at 19 degrees, so that there is not a lot of heavy air going down. The floor heating can be easily adjusted, via a computer, until 25 degrees, no more, in case a user has different needs (some live on the floor).

- Quote 1: *"H: I think in Eiksvein, the users, I don't they don't open the [windows] too much* ***but everyone has a balcony and can go outside from their apartments, on the first level you can go out to enjoy the terrace, so a lot of them have the inside doors open*** *but if they want to open the balcony doors they will destroy the system with the ventilation, yes, so I think when they open the outside door the pressure will go down and the system will try to speed up a bit and when they close it they will try to take it down a little bit but this will happen 50 times a day so it's not an easy thing to maintain. For us it's better to maintain a decent temperature from the floors and perhaps use the ventilation system a bit too much so it goes a bit higher of what you think you need"* (retrieved from an interview with a Baerum Kommune (technical) staff member on 2023-04-21).

- **Quote 2:** *"now [referring to spring-summer time] they can have the doors open, the windows open, they will feel the lightness of the air in a much better way. Again, because* ***we are in Norway, we like to open the windows*** *and the door in spring and in the summer* *like, what she said,* ***to hear the birds***." (retrieved from an interview with a Baerum Kommune (technical) staff member on 2023-04-21).

- *Quote 3 (need to "feel nature", to be outdoors):* *"M: But* ***here in Norway, we walk in the woods*** *and everywhere and that's an activity that's sometimes is a little bit difficult to get for people from some places to understand why it's that. And to* ***feel the nature*** *and the you know. That's some special ohh Norway in the mountains like in the coast and the yes you know. [go for] small walks during the day, maybe one hour or two hours. [Need to be outdoors] Then you have to and even the some of the residents, like when it's a little bit rainy and blowing in the with the wind. So, you* ***we use to say it's uh, not bad weather, only bad clothes****"* (retrieved from interview with staff member manager at Baerum Kommune in Eiksvein 116 on 2023-04-28).

- **Quote 4:** *"M: And sometimes saying there's in summer times they open their outdoor terrace door and we have* ***a couple of residents that are smoking and we can't deny them to do that. So, they go out on their terrace****"* (retrieved from an interview with staff member manager at Baerum Kommune in Eiksvein 116 on 2023-04-28).

- Quote 5: *"K: Yeah, that's the everyday life in Norway. One day we have maybe 8 degrees outside and one of the that we don't see* ***goes out to have a smoke****. That's the door open. Uh, the whole apartment is cooled down, the system thinks it's, uh, something wrong and a lot of heat going in. So, it's. Yeah, a bit* ***difficult to have rules to say that they can't do that"*** (retrieved from interview with project manager on 20230-5-23).

D3. Conflicting practices: Working easier with the residents (walking in and out faster, hearing them, not having to unlock doors with a key every time) & **Leaving apartment main doors open** & **Mixing two independent mechanical ventilation systems** (apartments and common areas) & **Interacting wrongly with the technologies** to adjust apartment temperature.

- Need: Working easier with the residents. Due to the residents' special needs staff members need to go in and out the apartments very frequently.

- Response: Leaving apartment main doors open to facilitate their work. This has an unintended consequence that jeopardizes the way mechanical ventilation is intended to work in the building, mixing the two different mechanical ventilation systems in place, the one for the apartments and the one for the common areas. This translates into a constant overriding of both systems leading to an undesirable and inefficient energy behavior of the building. In turn, this leads to multiple situations in which staff members try interacting with the technologies in the apartments to adjust, for example, the apartment temperature in order to meet residents' needs (e.g., feeling cold). Their low levels of understanding of the technologies at hand lead to yet again undesirable system overriding. For example, some staff members confuse the mechanical ventilation temperature with the floor heating temperature, raising the mechanical ventilation temperature to 22-25 degrees when it should be at 19 degrees, in most cases, two degrees below the desirable floor heating temperature (21 degrees).

- Quote 1: *"H: What a lot of **people are mistaking is that the ventilation system is actually to heat the room** but that's not the case. We're trying to tell them that **it's the heating on the floor**, that's the main heating source in the room and we have said that to the people who work on the building, **you don't need to push all these bottoms,** it's ok, to find out, it can be fantasy, what is this? But you shouldn't have to do it because we can do it in a proper way [via a computer program]"* (retrieved from an interview with Baerum Kommune (technical) staff member on 2023-04-21).

- **Quote 2**: *"T: I've never touched a system (laughs)*

J: I touched a little bit the [...] because someone was complaining that he was freezing...

MI: and where is this panel that you were interacting with?

J: It's in the technical room at his apartment.

MI: and you, as staff members, have you been trained to know how to interact with these technologies or do you just try...?

J: I wasn't reading much (T laughs a bit) but I heard from someone...

MI: from whom?

J: I think someone who works here…

MI: so, someone told you that you could go to this panel and adjust the temperature.

J: yeah. (retrieved from an interview with Baerum Kommune staff members on 2023-04-20).

D4. Conflicting practices: Sleeping comfortably with an appropriate temperature & opening windows ("leaving a crack open", "having cracked open windows") & having appropriate duvets

- **Need:** to sleep with an adequate temperature.

- **Response:** leaving the windows "crack open" and having appropriate bedding clothes (different duvet thicknesses) to fulfill different needs during the long winters.

Even when it is freezing outside, Norwegians are used to sleep with their windows "crack open" because Norwegian bedrooms are smaller (lower ceilings) than in other European countries and need to renew air more frequently. Also, due to their preference for sleeping in a "fresher environment". Norwegians are better prepared for the cold and have many different types of duvets (thicknesses) that allow them to sleep with the windows a bit open "even if it's -20 degrees outside".

- **Quote 1:** "*IB: we open the windows at night in many homes.*

MI: tell me about it. Why is that?

IB: that depends on who you're asking.

MI: do you open windows at night in your home?

*T: in my home or here? **In my home I always open it**.*

IA: in winter too?

*T: sometimes (laughs) because **I like it, the fresh air**. But I close it again later in the night.*

MI: so when you go to sleep it's open and then you close it in the middle of the night?

T: yeah.

MI: is this something you saw your parents doing…?

T: well, I'm very hot in the night. I like to have fresh air.

MI: and you?

J: you're talking about, me at home?

MI: yes

J: I have the windows open all the time, in the summer.

MI: and in winter?

J: when it gets cold, I close them, so.

MI: but you also have them open when you're sleeping?

J: yeah.

I usually have them open for many hours a day. I usually don't close them in the summer because… yeah, not wide open but like a little bit open.

IC: ***leaving a crack open, it's very normal in Norway to have 'cracked open' windows.***

IB: I think, if I can explain, some of the reason is that we'd like to have a little lower temperature when we are sleeping. And also, in the older buildings in Norway they don't have any ventilation in the bedroom, it's the window, and some rooms have a special 'air aid??' that you can open instead of the window. So, you can open the window, this is very typical, you open the window if you're a warm person to get the temperature down. It's also very common that we have the windows more open during the summer than in the winter. When it's getting really cold, we let in some fresh air and we close it when the temperature it's dropping too much. You also have people that are sleeping with the window open even when the temperature is -20 degrees. And then it's also a habit of the Norwegians to have 'dyne' [duvet] that ***we don't use blankets for our beds, we have thick duvets and they can be bought in different thicknesses*** *depending if you like it hot or less.*

MI: with goose feathers.

IB: yes! Even some homes change the 'dyne' and have the summer version and the winter version." (retrieved from an interview with Baerum Kommune staff members on 2023-04-20)

- Quote 2: *"M: You know, if I should live here, I would have opened my bedroom window. In my home I open,* ***I have the window open till I have to take out the ice inside the window. And my nose is very cold in the morning, only the nose in the winter, when it's like minus 10 degrees****. But uh, nobody here [at the nursery home] are opening the windows in night as far as I know. No, they are not. Well, maybe a couple of them were used it before. I don't know if they do it. I don't think so."* (retrieved from an interview with the staff member manager at Baerum Kommune on 2023-04-28)