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Shaping Energy for a Sustainable Future

Testing architectural quality Key Performance Indicators for Climate Positive Circular Communities in a new highly efficient residential building

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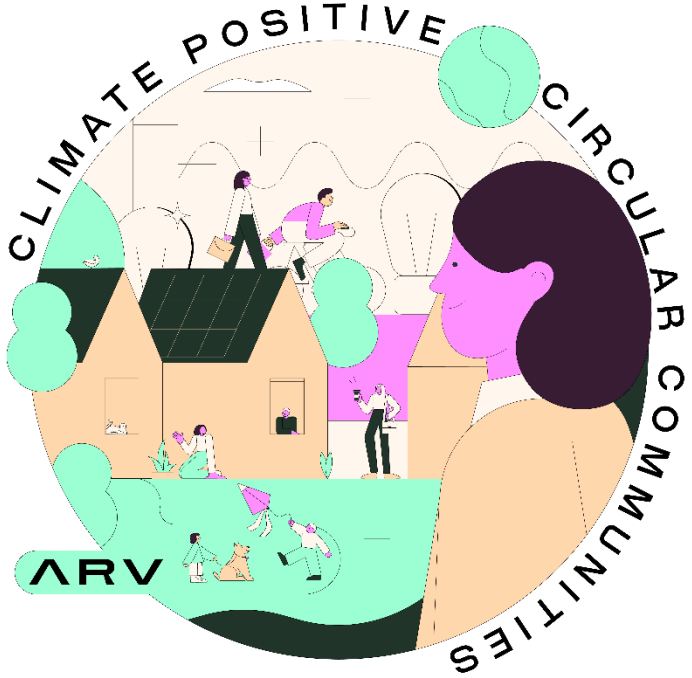
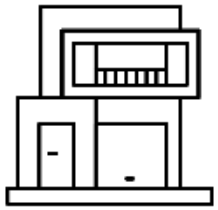


Introduction



Indoor Environmental Quality (IEQ) is a fundamental component in the construction and renovation process

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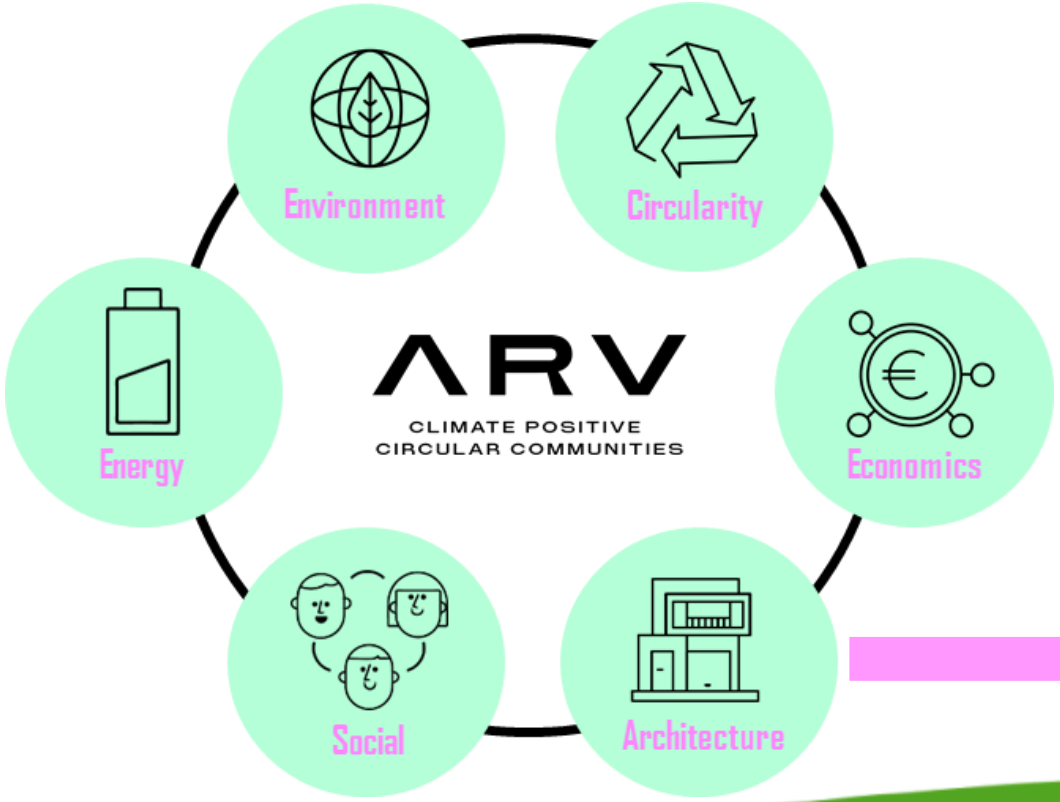
High architectural quality of the building improves the quality of life for occupants' beyond just meeting their basic needs

One of the objectives of the EU-funded ARV project is to establish **a high level of IEQ conditions** in addition to **high architectural quality of the buildings**

The ultimate objective is to present and validate appealing, robust, and cost-effective solutions that greatly accelerate the implementation of energy and climate measures in the building and energy sectors

Objective

To test **architectural quality indicators**, aimed at evaluating the **design concepts of the building** and the **IEQ conditions of its occupants** at a **new highly efficient residential building** located in Palma, Spain



Architecture

Aesthetics and Visual Qualities
Flexibility and Adaptability
Sufficiency and Adequacy of Space
Solar and Daylight Access
Accessibility
Indoor Air Quality
Thermal Comfort
Overheating Risk
Acoustic Comfort
Outdoor Comfort

Demonstration Site

The Metrovacesa highly efficient multi-family residential building:

- **114 flats** distributed in one- to four-bedroom apartments.
- **2 blocks**, of which block 1 has a north-east (NE) orientation and block 2 a south-west (SW) orientation.
- The building received the **A-energy certificate** and was designed to the **highest standards of efficiency and sustainability.**
- The building's **energy systems** include photovoltaic panels, a centralized air-to-water heat pump system for domestic hot water and air-to-air heat pumps, combined with a mechanical ventilation system with double flow and heat recovery system.

Source: Metrovacesa

Methodology: the Design Team Survey

To access how **architectural quality concepts** were considered in **the design phase of the building**

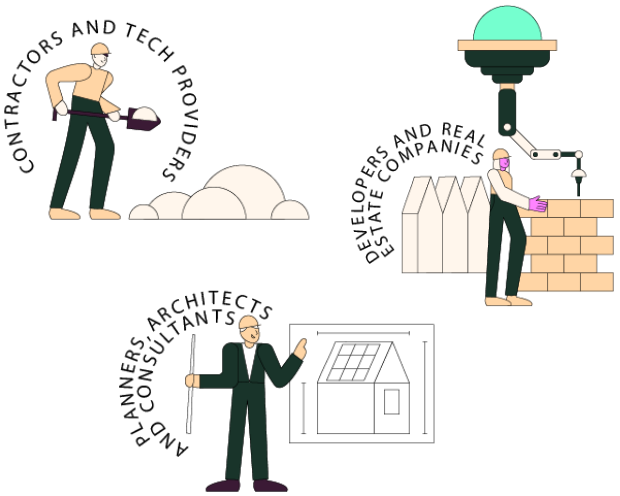
List of KPIs:

- **Aesthetics and Visual Qualities** (overall appearance, materiality/form, detailing, proportion/composition, visual connections, coherence, etc)
- **Flexibility and Adaptability** (how easily building can be modified for a future change in use)
- **Sufficiency and Adequacy of Space** (minimum area requirements depending on the building function)
- **Solar and Daylight Access** (whether these factors are included in the design process beyond code compliance)
- **Accessibility** (significance of accessibility for individuals with varying abilities)
- **Acoustic Comfort** (to evaluate noise protection)
- **Outdoor Comfort** (access to sunlight or shade, depending on the climate, as well as shielding from wind and noise)

Method:

A **Microsoft Forms survey** with 33 questions on **architectural aspects** developed for the ARV project design team.

The **reference population**:



The average **time to answer** was about 25 minutes.

Methodology: the IEQ Monitoring Campaign

To determine **the comfort conditions of the occupants:**

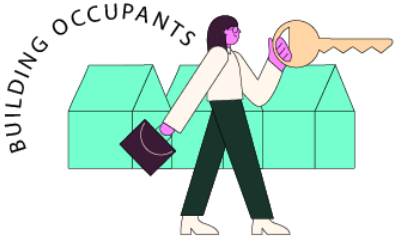
The **European Standard EN16798-1:2019** establishes **four IEQ categories**, corresponding to the degree of expectations of building occupants from the highest to the lowest, IEQ_I **to** IEQ_{IV}, respectively

IEQ KPIs represent percentage of time that each indicator falls into comfort ranges for the different comfort indexes:

- CO_2 concentration (**Indoor Air Quality (IAQ) KPI**)
- Operative temperature (**thermal comfort KPI**)
- **Heat Index KPI** (the result of combining air temperature and relative humidity to represent the human-perceived equivalent temperature in shaded areas)

The IEQ Monitoring Campaign:

From February to September 2023, 13 households, a 15-day IEQ monitoring campaign



A temperature sensor in the bedroom and a temperature, relative humidity, and CO_2 sensor in the living room

Data is captured every two minutes, the weather data is every 30 seconds.

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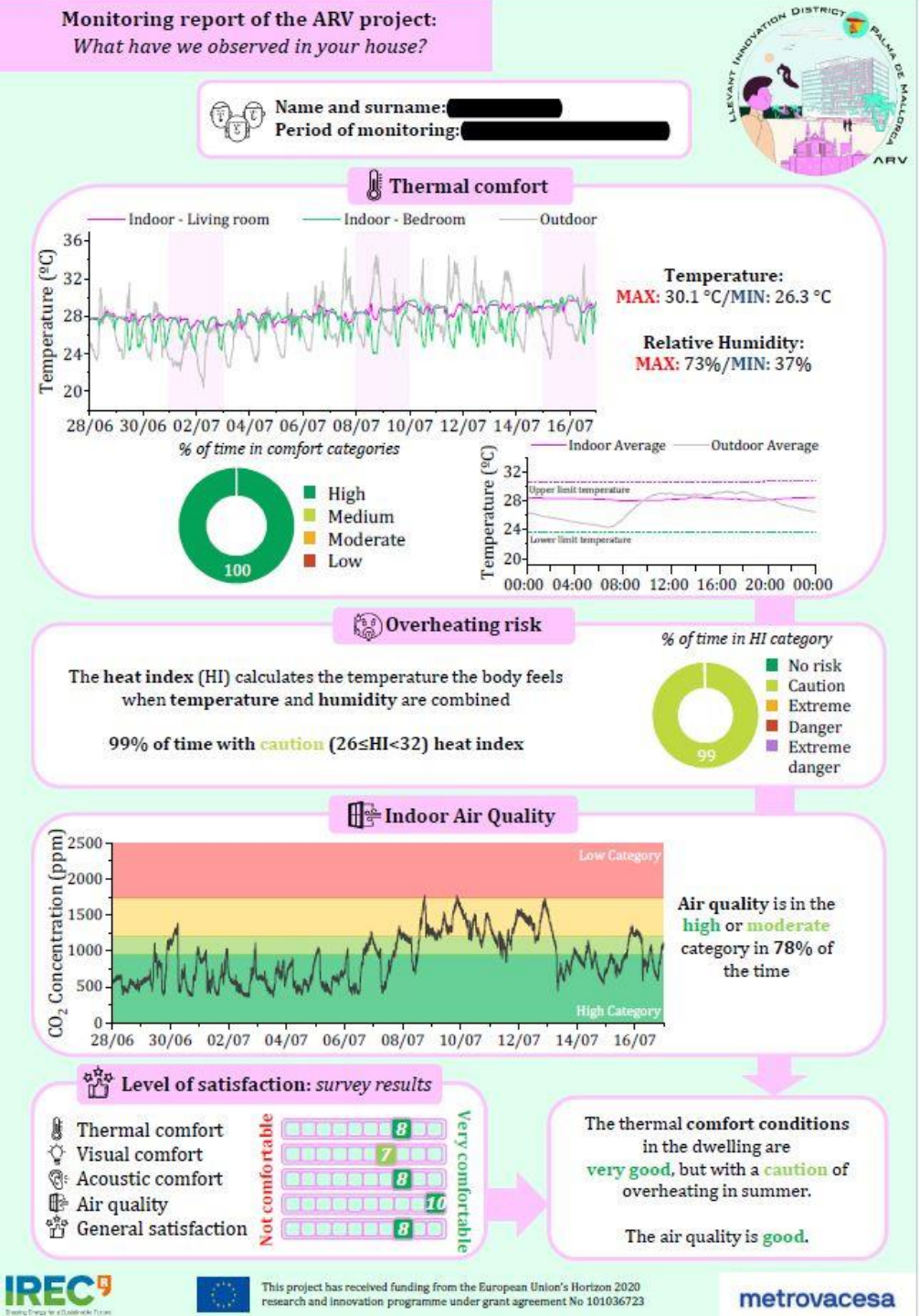
Post Occupancy Evaluation surveys:

Users perception regarding air quality, thermal, visual, and acoustic comfort, as well as overall satisfaction with the IEQ of their households



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Example of the Monitoring Report

Feedback on the findings from the assessment of each household's **indoor air quality, thermal comfort, and overheating/overcooling risk**

The **level of satisfaction section** summarises the survey results, and the correlation between the actual measurements and the user's perception

In addition, volunteers were asked to **attend a group presentation:**

- The compiled results of the monitoring campaign
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- Suggestions for making the optimal use of the mechanical and natural ventilation systems

Results: the Design Survey

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Aesthetics and visual qualities:

…Balearic Islands Mediterranean architecture…
…The harmony of materials and solutions…
…A clear rule of proportion…
…The moving blinds produce a dynamic composition…
…A clear material concept for the building's structure…

During the design process, every aesthetic and visual aspect was considered

Sufficiency and adequacy of space:

…The surfaces of the single rooms are larger than is required by law (2 out of 3 respondents)
…The residential apartments' spaces were intended to accommodate particular purposes... (all)

Accessibility:

…The building's design considers wheelchair or stroller accessibility in accordance with Balearic Islands standards (all)
…The design complied with current regulations and considered individuals with disabilities other than vision impairments (all)

Acoustic comfort:

…The design adheres to Palma's red noise map, and the acoustic insulation has been modified to mitigate airborne noise because of the building's proximity to the airport, in compliance with local regulations…

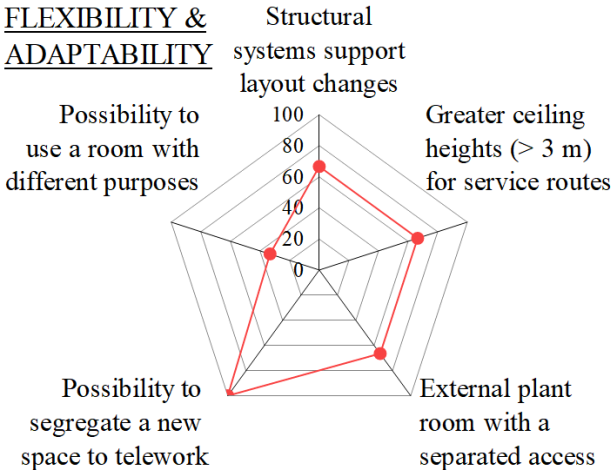
Results: the design survey

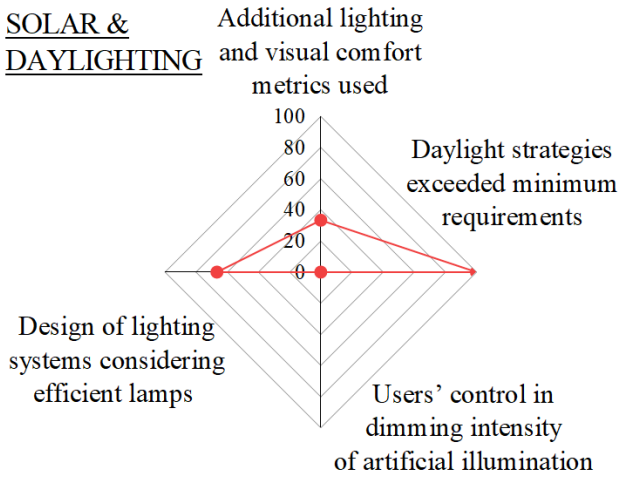
Flexibility and adaptability:

The opinion about building's flexibility and adaptability are not the same for all the respondents.
This can be explained by the detailed technical questions, which not all the stakeholders involved in the design team need to be aware.

Solar and daylight access:

Questions for this KPI are quite specific, which is like flexibility and adaptability KPI can result in questions going unanswered or being misinterpreted.



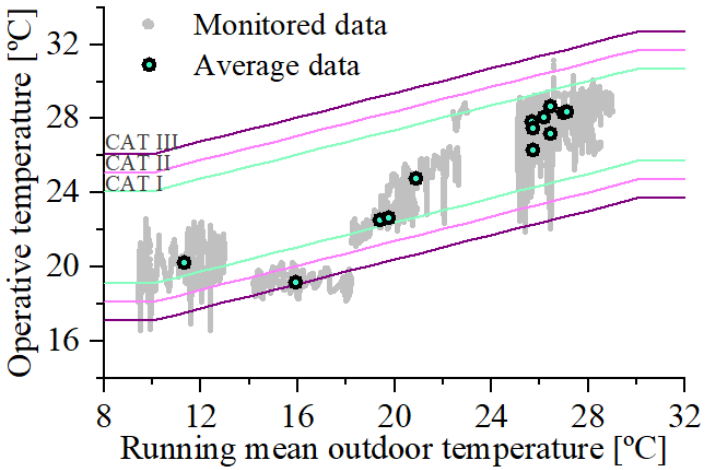


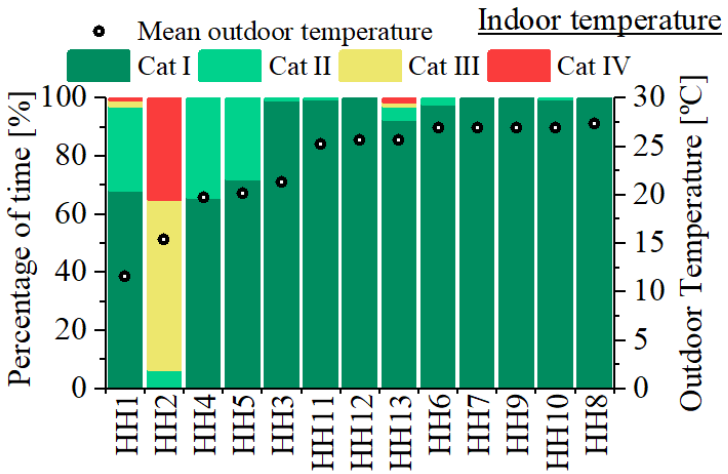
Outdoor comfort:

Sun, shade, wind, and noise were considered (one positive response for each of the parameters) + the building can provide shade from the sun and/or wind to the surrounding areas

Results: the IEQ monitoring campaign

Indoor operative temperature of monitored households as a function of running mean outdoor temperature (left) and percentage of time in each thermal comfort category (right).





Key findings:

- Most of the time, **households fall into at least medium category** (IEQ_{II}).
- **Twelve of the thirteen** households, according to the results, spend **more than eighty percent** of their time in categories **IEQ_{I}** and **IEQ_{II}**.
- Despite the HH2's relatively poor thermal conditions, the household's residents still rated it 9 out of 10. It may demonstrate that the **household finds these conditions to be comfortable**.

Results: the IEQ monitoring campaign

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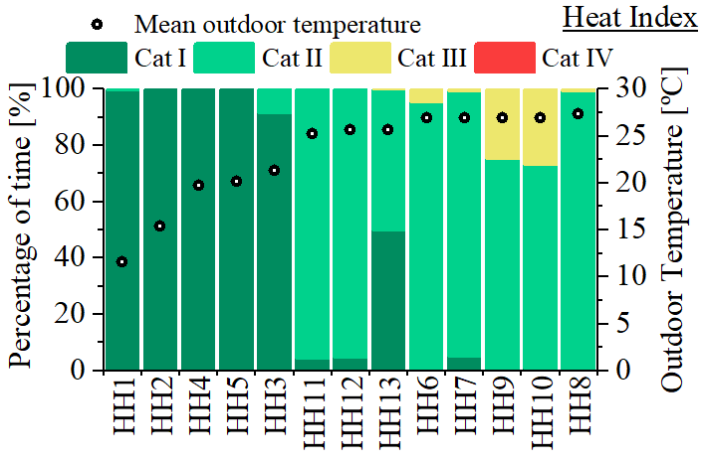
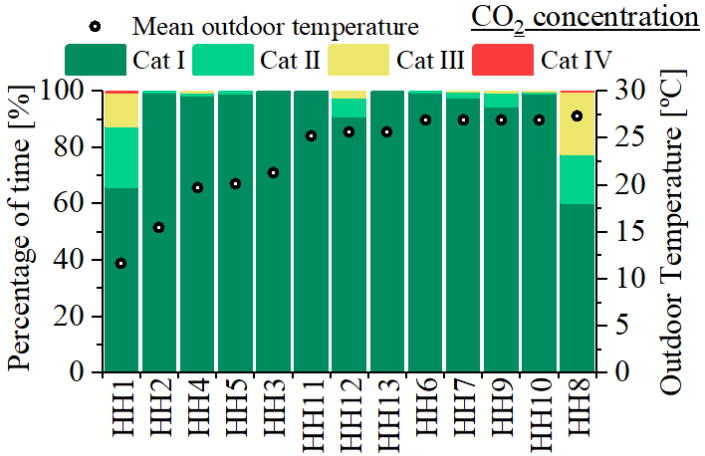
Percentage of time in each Heat Index category (left) and percentage of time in each air quality category based on CO_2 concentration (right).





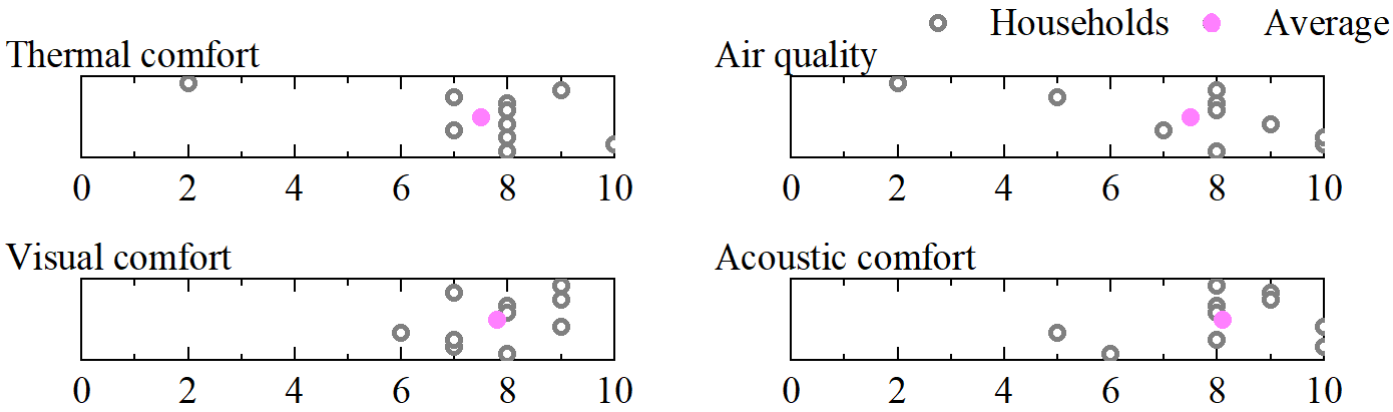
Key findings:

- Apart from HH9 and HH10, which have a moderate risk of overheating due to a high relative humidity, **the majority of the households are not at risk of overheating.**

- **Twelve of the thirteen** households, according to the results of the air quality KPI, spend **more than eighty percent of their time in high (IEQ_I) and medium (IEQ_{II}) categories.** HH8, which has a slightly lower percentage of time (78%), is the only exception.

Results: the IEQ monitoring campaign

Indoor environmental comfort perception of inhabitants



Key findings:

- With the majority of the dotes falling **between 6 and 9** and an **average of 7.5-8**, **users are generally satisfied with the IEQ conditions** (air quality, thermal, visual, and acoustic comfort) of their households.

- With the **exception of HH1**, who scored poorly (2 out of 10) on both thermal comfort and air quality. However, the monitoring campaign's results showed that, in **98% and 88% of the time**, respectively, HH1's **thermal comfort** and **air quality fell into the high or medium category.**

- As a result, the monitoring campaign's **overall findings demonstrate a high degree of IEQ conditions** that complies with **EU standards.**

Discussion

The design team survey:

The survey was completed nearly two years after the construction phase concluded **->** Challenging to get in touch with some of the original members of the design team	The survey should therefore be completed as soon as the construction process is complete.
The quite technical nature of some of the questions pertaining to some of the KPIs (like flexibility and adaptability or solar and daylight access) **->** Misinterpretation or leave questions unanswered	To adapt survey´s questions / reconsider a reference population

However, it was feasible to get thorough responses and conduct a detailed analysis of the design team's goals.

The IEQ monitoring campaign:

The users' perception of comfort conditions didn't always align with the monitoring campaign's outcomes **->** user's satisfaction with thermal conditions is determined by subjective evaluation and the IEQ categories represent a probability to be in comfort conditions.

An effective monitoring campaign, personalised reports, and group presentations have shown to be helpful resources for residents' involvement, which is a common problem in many energy and sustainability surveys.

Conclusions

- The monitoring campaign's findings have demonstrated that, according to the European standard EN16798-1:2019, the majority of the demonstration project's IEQ indicators fall into the high and medium comfort categories.

- A good correlation has been validated between the use of POE surveys conducted through the inclusion of key questions in post-sale satisfaction procedures in the real estate company and the detailed monitoring.

- The systematic use of POE surveys reveals to be a good and affordable way for the real estate sector to get feedback about the IEQ in their promoted buildings.

- The building's high level of architectural quality and occupant comfort were attributed to the consideration of architectural quality indicators during the building's design phase.

- In summary, the suggested methodology has been effectively implemented in the actual case study and has proven to be a helpful framework for evaluating the building's design concepts and the IEQ of the occupants.

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Supporting Slides

Envelope properties of the building.

Parameter	Value	Unit
External wall, U-value	0.29	W/m²K
Roof, U-value	0.17-0.24	W/m²K
Floor, U-value	0.48	W/m²K
Window, U-value	1.36	W/m²K
Window, SHGC	0.31	-

Configuration of energy systems.

Energy system	Parameters
PV production	PV production: 17 060 kWh/y, 36 PV panels (78.2 m^2), total power: 15.84 kWp, slope: 30º (South oriented panels with 10º towards West).
Heating and cooling: air-to-air heat pumps multi-split in each apartment	Coefficient of performance (COP): 4.1 to 4.84. Energy efficiency ratio (EER): 3.24 to 4.82. Capacity: 2 to 5.6 kW (bedroom or living room) in heating mode, 2 to 5.3 kW in cooling mode.
Domestic hot water (DHW): centralized air-to-water heat pump system	COP: 3.44. Capacity: 2 x 39.2 = 78.4 kW.
Ventilation: individual mechanical ventilation in each apartment	Crossflow with heat recovery. Ventilation flow from 60 m^3/h to 120 m^3/h.

Supporting Slides

Table 3. Comfort ranges for the different comfort indexes: CO_2 concentration, operative temperature, and Heat Index.

Cat.	Expectation	CO_2[1] [ppm]	T_{op} [°C]	HI Category	HI [°C]
IEQ_I	High	≤ 550	$T_{op} = 0.33 \cdot T_{o,rm} + 18.8 + 2$[2] $T_{op} = 0.33 \cdot T_{o,rm} + 18.8 - 3$	No risk	<26
IEQ_{II}	Medium	>550 and ≤ 800	$T_{op} = 0.33 \cdot T_{o,rm} + 18.8 + 3$ $T_{op} = 0.33 \cdot T_{o,rm} + 18.8 - 4$	Caution	26-32
IEQ_{III}	Moderate	>800 and ≤1350	$T_{op} = 0.33 \cdot T_{o,rm} + 18.8 + 4$ $T_{op} = 0.33 \cdot T_{o,rm} + 18.8 - 5$	Extreme	32-41
IEQ_{IV}	Low	>1350	-	Danger	41-54
IEQ_V	-	-	-	Extreme danger	>54

[1] Corresponding CO_2 concentration above outdoors (350–500 ppm).
[2] $T_{o,rm}$ is the running mean outdoor temperature of the daily mean outdoor air temperature.

Supporting Slides

Table 4. Technical characteristics of the sensors.

	Characteristics	Measuring Range	Resolution	Accuracy
Comet U3430	Air temperature (°C)	−20 – 60	0.1	±0.4
	Relative Humidity (%)	0 – 100	0.1	±1.8
	CO_2 concentration (ppm)	0-5000	1	±50 + 3%
Elitech	Air temperature (°C)	−30 – 70	0.1	±0.5