ENERGY4ALL
Communities for positive energy districts

Deliverable 5.1.1

Resource Analysis of conceptual planning of co-designed interventions

First version

Driving Urban Transitions

EUROPEAN PARTNERSHIP

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Deliverable executive summary

This Mid-Term Report (M18) captures the current progress of Task 5.1 resource analysis and planning of co-designed interventions, within Energy4All. It offers a dual contribution: it sets out a KPI-based evaluation framework for the Kazán and Megyeri pilot sites and recounts the first co-design workshop held at Kazán on 23 April 2025. Drawing on a literature review of energy communities and Positive Energy Districts, plus reference schemes such as syn.ikia and NetZeroCities, the framework groups required and recommended indicators under six themes: Energy, Environmental, Social, Economic, Digitalisation & Smart Urban Technology, and Indoor Environmental Quality, while flagging whether each KPI is best measured in the design or operational phase. The framework focuses on whole-building monitoring yet remains extensible to neighbourhood level for future collective-energy strategies. The developed framework serves as an initial KPI collection. As the two pilot sites are different in both sizes and implementation stages, the exact KPIs used from the collected ones will be determined for each pilot in the next deliverable.

The Kazán workshop provided the first real-world test bed for the approach. Participants layered technical and behavioural bottlenecks directly onto building plans, then assembled three budget-tiered retrofit packages on pyramid canvases to preserve logical sequencing and avoid lock-ins; afterwards they reshuffled into new groups to devise complementary social measures such as thermostat-training modules and real-time feedback dashboards. The combined outputs will feed ABUD's coupled energy and agent-based models, which will quantify impacts on demand, comfort and community resilience.

Looking ahead, workshop results and behaviour insights will be shared back to participants to reinforce engagement, relevant persons will gather operational data for the KPI evaluation, and the next workshop will explore the legal, economic, architectural and behavioural levers that influence the energy-community vision. Taken together, these actions position Kazán and Megyeri for evidence-based decision-making and scalable replication as the project advances toward its M32 milestone.

1. Introduction

This is the first report at M18 on the resource analysis and on planning of co-desiged interventions. As a first report, this can be considered as a snapshot of current progress, while the report due in M32 will contain the complete version. The purpose is twofold: first, to establish an evaluation framework for assessing the performance of positive energy buildings and energy communities, offering clear guidance for their further implementation at the project's demonstration sites, and secondly to report on the co-design methodology and workshop conducted.

The development of evaluation framework describes the Key Performance Indicators, which identifies required and recommended indicators in the evaluation of pilot projects (Kazán, Megyeri). The methodology of collecting adaptable KPIs has been carried out through a literature review with the scope of Energy communities and Positive Energy Districts, and the KPI framework has been developed on previous projects' assessment framework, such as syn.ika, and NetZeroCities. Furthermore, the unique features and limitations (financial, building type, phase) of the pilot cases have been also taken into account during the selection process.

The report on the co-design workshop held in Kazán community describes how Stakeholders mapped technical and behavioral issues, using existing floor plans as visual support and inspiration. After this, they grouped candidate actions into three budget levels: low, medium, high. Each bundle combined retrofit measures and social interventions. This concise scenario matrix is used at the end to inform decisions and can be scaled easily to neighborhood level as resource and ambitions grow.

The goal of ENERGY4ALL is to develop Energy Communities where energy stands at their centre as a common resource pool through a community-based approach. In order to create a holistic assessment framework which aligns with the goals of Energy4All, different categories besides the primary focus on Energy need to be involved into the monitored list of indicators, such as Social, Environmental, Economic, IAQ etc, see **Hiba! A hivatkozási forrás nem található.**.

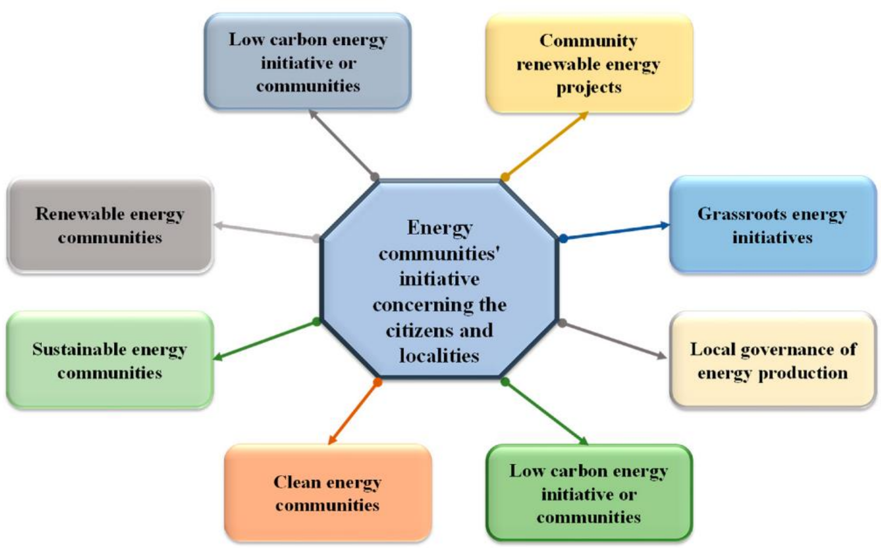
2. Definitions

2.1 Energy Community

The European Commission's (2020) definition of energy community highlights the legal framework and participatory nature, stressing local control and benefits as "legal entities based on open and voluntary participation, effectively controlled by shareholders or members located near the renewable energy projects owned and developed by the community". (Lutsch, 2017) Meanwhile, the International Energy Agency (International Energy Agency, n.d.) offers a more expansive perspective, defining energy communities as "community-driven initiatives focused on the generation, distribution, storage, and supply of energy." To thoroughly understand the concept of 'energy communities,' it is crucial to recognize its diverse interpretations depending on the context.

The term "community," from a linguistic standpoint, denotes a social unit characterized by shared values, and a collective sense of belonging and/or place. Within the context of energy, a "Sustainable Energy Community" (SEC) is defined as a collective of energy utilities that are publicly, privately, or jointly owned and operated within a defined geographical area (Ahmed et al., 2024). In this framework, end-users collaborate to meet their energy needs through cooperative efforts. The literature presents a range of terminologies to describe renewable energy (RE) initiatives driven by citizens and local stakeholders, as illustrated in Figure 1.

1. Figure Energy communities' initiatives



2.2 Positive Energy District

The concept of Positive Energy Districts (PEDs) builds upon frameworks such as Nearly Zero Energy Buildings (NZEBs) and Net Zero Energy Buildings extending these principles from the individual building scale to the district level. This expansion seeks to leverage the synergistic energy interactions among buildings while advancing urban decarbonization objectives (Kozlowska et al., 2024).

Positive Energy Districts (PEDs) are urban areas designed to produce more renewable energy than they consume, playing a pivotal role in transforming urban energy systems toward carbon neutrality. However, as a relatively new concept, the implementation of PEDs presents significant challenges (Krangsås et al., 2021). Four main categories of PEDs have been established based on boundaries and limits, as well as energy exchange (Salom et al., 2020):

1) Auto-PED (PED autonomous)
2) Dynamic-PED (PED dynamic)
3) Virtual-PED (PED virtual)
4) Candidate-PED (pre-PED).

3. Co-design workshop with Kazán case

The Kazán and Megyeri Energy Communities are preparing a renovation roadmap that must integrate both bricks-and-mortar retrofits and human-centred behavioural change. To ground this roadmap in local knowledge, a co-design workshop was held on 23 April 2025 at the Kazán premises. The session set out to (1) identify the most critical technical and social bottlenecks in the existing buildings and operations, (2) assemble coherent "intervention packages" that respect different budget envelopes, and (3) deliver inputs for ABUD's coupled energy and agent-based models, which will later quantify the impact of each package on energy demand, comfort, and community resilience.

3.1 Problem mapping

Participants collectively located issues on large-format plans. Questions explored included "Where is heat loss most acute?" and "Where do user habits or space-use conflicts hinder efficiency?" The result was a layered map that later served as a reference for ranking interventions.

3.2 Identifying technical and social interventions

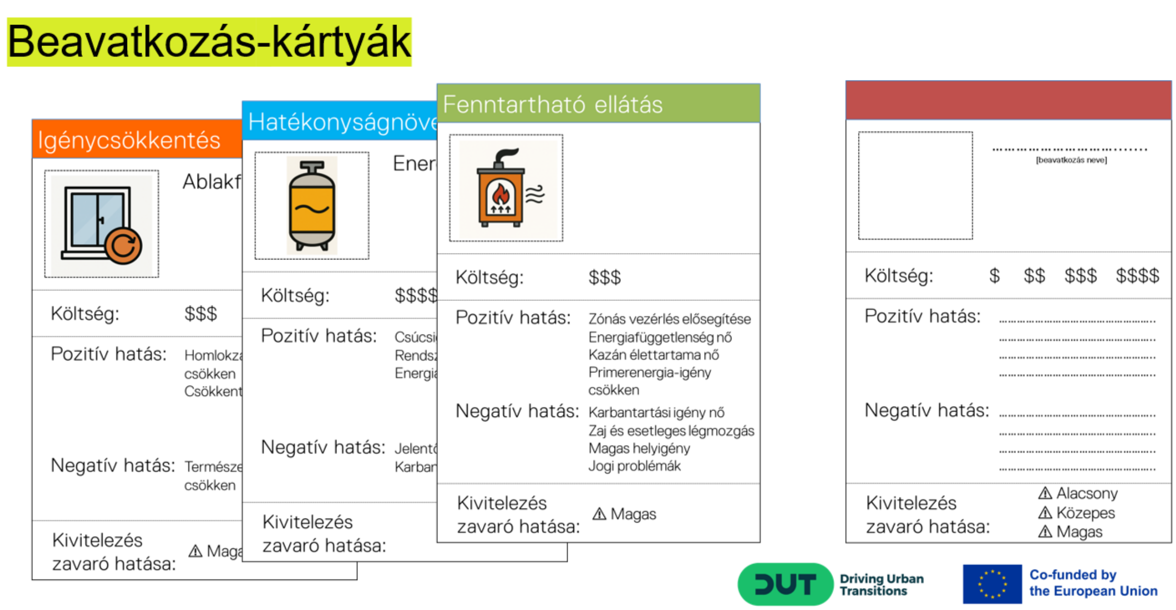
3.2.1 Technical intervention phase

The two small groups received identical decks of "intervention cards" as visible in **Hiba! A hivatkozási forrás nem található.**. Each card stated the retrofit option, its category, prerequisites, synergies, indicative cost level ($ symbols), and potential disturbances. Groups used pyramid canvases to assemble three bundles:

1. Minimal spend, no floor-area expansion
2. Moderate spend, moderate expansion
3. Generous grant scenario, full expansion

The pyramid canvas forced deliberation on sequencing (base measures first, enabling technologies above) and on avoiding negative lock-ins (for instance, installing a heat pump only after adequate insulation).

2. Figure showing the intervention cards design in hungarian, with Cost, Positive, negative potential effects, potential synergies, prerequisites and disturbances.



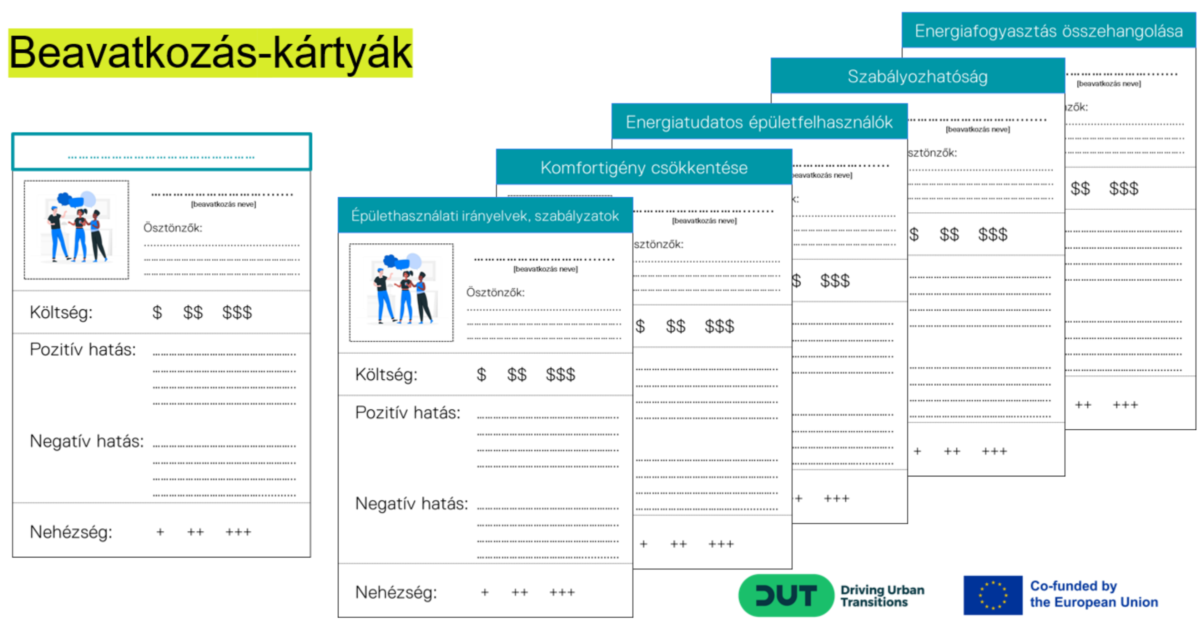
3.2.2 Social intervention phase

Participants re-shuffled into new mixed groups to avoid entrenched thinking. Fifteen blank "social cards" (**Hiba! A hivatkozási forrás nem található.**) were supplied, five of which already carried a category header such as “energy-aware occupants” or “usage guidelines.” Groups proposed concrete actions, for example:

1. Tenant training modules on aligning thermostat settings
2. Shared dashboards for real-time consumption feedback
3. Revised booking rules for community rooms to smooth load peaks

Workshop yielded four key outcomes: annotated problem maps for the Kazán and Megyeri buildings, three-tiered technical intervention packages developed by each small group and later merged into a single consensus set, a suite of social measures and comprehensive documentation sheets detailing costs, benefits and logical dependencies ready for a parametric simulation later on.

3. Figure Social cards showing type of intervention, potential costs, negative and positive effects and level of complexity to implement.



4. Evaluation framework

The KPIs are divided into six categories, namely Energy-, Environmental-, Economic-, Social Performance, Digitalisation and Smart Urban Technology, and Indoor Environmental Quality. There are also several different Sub-categories, which includes the indicators to measure and monitor progress in the project over time. On the other hand, not all indicators can be monitored during each project phase, therefore the table also contains whether the KPIs can be measured in the design and/or operational phase.

The indicators can be also prioritized as required or recommended, which can be useful, if not all KPIs can be measured in the project due to any barriers.

Developing a KPI framework, which covers the aforementioned dimensions is crucial for the project to quantify achivements, among other important perspectives, such as (Giannuzzo et al., 2024):

- Key Performance Indicators facilitate the clear definition of project objectives, ensuring alignment among all team members with these goals.
- By measuring progress against specific KPIs, it is possible to confirm that the project is advancing in the correct direction.
- KPIs ensure that all stakeholders are working toward a unified set of overarching objectives, thus simplifying the prioritization of tasks and decision-making processes.
- KPIs enable the continuous monitoring of project progress over time, which is crucial for making informed decisions regarding necessary adjustments to maintain project trajectory.
- Through the use of KPIs, project managers can ground their decisions in empirical data rather than intuition or speculation, thereby enhancing the efficiency of problem-solving and decision-making.
- KPIs establish performance benchmarks, allowing project teams to evaluate past actions and identify opportunities for improvements in subsequent projects.
- KPIs track the achievement of project milestones and deliverables, fostering transparency and reinforcing trust with stakeholders.

1. Table - KPI Framework of Energy4All as part of T5.1. (Resource analysis of conceptual planning of co-designed interventions)

Category	Sub category	Indicator	Unit of measurement	Functionality	Project phase
Energy Performance	**Overall Energy Performance**	Non-renewable primary energy balance	kWh/(m^2 y)	Required	Design, Operation
		Renewable energy ratio	%	Required	Design, Operation
		Energy autonomy	%	Recommended?	Design, Operation
		Energy consumption per Household / Units	kWh	Recommended?	Operation
	Grid interaction factors	Grid delivered factor	-	Required	Design, Operation
		Net energy/ Net power	kW	Required	Design, Operation

		Peak delivered / Peak exported power	kW	Required	Design, Operation
		Connection capacity credit	-	Required	Design, Operation
Environmental performance	**Environmental balance**	Total greenhouse gas emissions	kg CO_2eq/(m^2 y)	Required	Design, Operation
Social performance	**Equity**	Affordability of energy	% of population	Required	Design, Operation
		Affordability of housing	% of population	Required	Design, Operation
		Universal design	10-pt-scale, BN: % of barrier-free units	Recommended	Design
	Community	Demographic composition	pop, % of pop, pop/ha	Recommended	Operation
	People	Energy consciousness	5-pt-scale	Required	Design, Operation
	Participation	Citizen involvement in co-creation/co-design	Number	Recommended	Design, Operation
		Inclusion of different social groups	Likert (number)	Recommended?	Design, operation
Economic performance	**Capital cost**	Investment costs	€/m^2	Recommended	Design
		Share of investments covered by grant	€/m^2	Required	Design
	Operational cost	Maintenance-related costs	€/m^2/yr	Required	Design, Operation
		Requirement-related costs	€/m^2/yr	Required	Design, Operation
		Operation- related costs	€/m^2/yr	Required	Design
		Other costs	€/m^2/yr	Required	Design, Operation
	Overall economic performance	Net Present Value	EUR	Recommended	Design
		Internal Rate of Return	%	Recommended	Design
		Economic Value Added	EUR	Recommended	Design
		Payback Period	yr	Recommended	Design
Digitalisation and Smart Urban Technology	**Green ICT and Smart Metering**	% of households and buildings with reduced energy consumption as a consequence of installing smart energy metres	% of households	Recommended	Design, Operation
	Smartness	Smartness Readiness Indicator (SRI)	-	Required	Design, Operation
Indoor Environmental Quality	**Indoor Air Quality**	Carbon Dioxide (CO_2)	ppm	Recommended	Operation
	Thermal Comfort	Predicted Mean Vote (PMV)	%	Required	Design, Operation

		Predicted Percentage Dissatisfied (PPD)	%	Required	Design, Operation
	Lighting and visual comfort	Illuminance	Lux	Recommended	Design, Operation
		Daylight factor	%	Recommended	Operation

The following section outlines the indicators from the six main categories (Energy, Environmental, Social, Economic, Smart Technology, IEQ), thus provides detailed description, further useful information as well as calculation methods for the KPIs. The majority of calculation methods are based on the methodology framework of syn.ikai project, which also focusing on PEDs and ECs, therefore the indicators can be well adapted into the pilot projects of Energy4all.

The key performance indicators outlined in this section often require substantial data collection, especially during the operational phase. This responsibility is primarily assigned to developers of pilot sites, who may need to find external assistance to carry out the data collection effectively. To facilitate this process, the role of an "auditor" is introduced. An auditor may take the form of a technical architect, an energy audit company, a consulting professional, or a similar specialist. Their primary function is to collect the required data and forward it for KPI analysis.

4.1 Overall energy performance

In order to describe the overall energy performance of the buildings, which is measured and/or calculated by hourly/sub-hourly values of the energy flows, as well as by the exchanged energy carriers with the energy networks, the non-renewable primary energy balance and the renewable energy ratio indicators need to get measured.

Non-renewable primary energy balance

The non-renewable primary energy balance includes all types of energy, which is produced or/and consumed by the monitored system, as well as the exchanged energy with the energy network. It is a positive energy system, ff the balance between the delivered and exported energy is lower, than zero. The following calculation can show the differences in the supply chain of various energy carriers, such as electricity, cooling networks or domestic gas (Hernández et al., 2017). RES system energy meter is required for monitoring.

Unit:

- kWh/(m² y)

Calculation:

$$E_{P,nren} = \sum_i E_{p,nren,del,i} - \sum_i E_{p,nren,exp,i}$$
$$= \sum_i \int P_{del,i}(t) \cdot w_{del,nren,i}(t) \cdot dt - \sum_i \int P_{exp,i}(t) \cdot w_{exp,nren,i}(t) \cdot dt$$

where :

$E_{p,nren}$- the non-renewable primary energy, [kWh/ m^2 y];

$E_{p,nren,del,i}$- delivered non-renewable primary energy per energy carrier i, [kWh/ m^2 y];

$E_{p,nren,exp,i}$- exported non-renewable primary energy per energy carrier i, [kWh/ m^2 y];

$P_{del,i}$ - the delivered power on site or nearby for energy carrier i, [kW/ m^2];

$w_{del,nren,i}$ - the non-renewable primary energy factor (-) for the delivered energy carrier i;

$P_{exp,}$i - the exported power on site or nearby for energy carrier i, [kW/m^2];

$w_{exp,nren,i}$ - the non-renewable primary energy factor (-) of the exported energy for energy carrier i;

Renewable Energy Ratio

The Renewable Energy Ratio (RER) represents the share of renewable energy by the building. RER is the percentage of energy from renewable sources in the total energy consumption, which is calculated relative to all energy use in the building, in terms of total primary energy and accounting for all the renewable energy sources. These renewable energy sources can include solar thermal, hydroelectricity and wind etc. The goal of energy efficient buildings is to use as little non-renewable energy as possible, thus using more renewable energy does not mean worse energy performance. RER is proposed in the framework of ISO 52000-1:2017 - Energy Performance of Buildings, where weighting factors can be used as reference. RES system energy meter is required for monitoring renewable primary energy consumption, while households meter is required for monitoring total primary energy consumption.

Unit: Dimensionless [-]

Calculation:

$$RER = \frac{E_{Pren}}{E_{Ptot}}$$

where:

EP_{ren} - renewable primary energy consumption kWh/(m^2 y)

EP_{tot} - total primary energy consumption kWh/(m^2 y)

Energy Autonomy

The energy autonomy is used in the indicator framework of NetZeroCities to calculate the energy autonomy of a city. However, it can also be used on building level, which is at a smaller scale. This indicator describes whether the available energy used in the buildings is sufficient to meet the energy demand of building users, thus the building is energy autonomous or not.

Unit: %

Calculation:

Energy autonomy= Local available energy (MW) / total consumption(MW) x 100/1

Energy consumption per household

The objective of this indicator is to illustrate the energy performance of pilot cases before and after the implemented energy efficient solutions, which can demonstrate the related behavioral changes in households. The energy consumption per households can be obtained through metred data, energy bills or directly from energy companies. The collected data can be compared on quarterly or annually. The measured tendency of a household's energy consumption is in Kwh.

Unit: Kwh

Calculation: Energy consumption per household= Power used in households (kW)* hours (h) household devices are used per day, per week or per month

However, this information can be acquired through metred data as well.

4.1.1 Grid interaction factors

Grid delivered factor

The grid delivered factor demonstrates the ratio between the energy delivered from the grid and the total energy used by the system over a time period. It displays the buildings' dependency from the grid.

Unit: Dimensionless [-]

Calculation:

$$\gamma_{grid} = \frac{E_{del,grid}}{E_{used,tot}} = \frac{\int max\left[P_{used}(t) - P_{prod}(t), 0\right] dt}{\int P_{used}(t)\, dt}$$

where:

$E_{del,grid}$ – delivered energy form the grid (kWh)

$E_{used,tot}$ – total energy used by the system (kWh)

P_{prod} - on-site produced power (kW)

P_{used} – on-site used power (kW)

Net energy / Net power

In the case of energy community, the net energy is the balance between the total amount of energy produced and the total amount of energy consumed within the community over a defined period (a day, week, month or year). Therefore, this indicator is easily visualized on a duration curve, which represents the distribution of power as well as the discrepancy between different energy carriers.

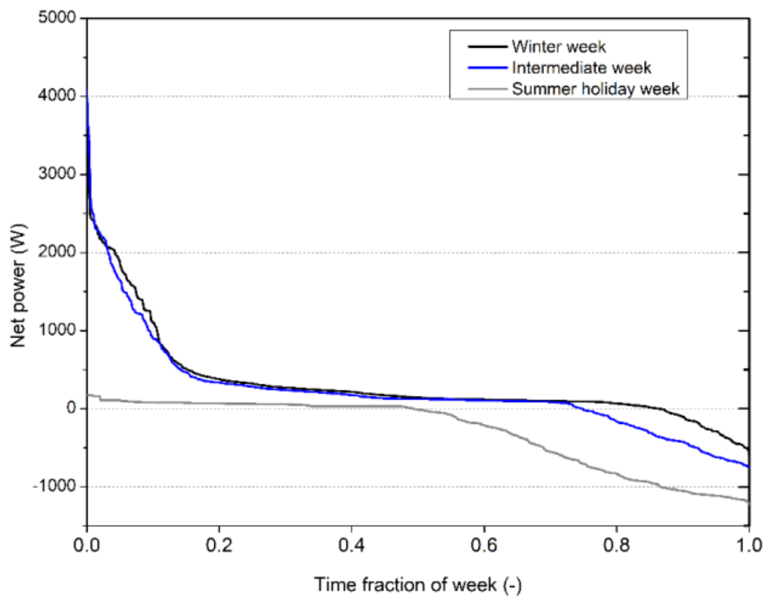
Net zero energy occurs when the system generates an amount of energy equivalent to its consumption, achieving a balanced energy state. If there is more energy generated (net positive energy), it needs to be stored or exported to the grid, when the community consumes more energy than it produces (net negative energy), energy must delivered from the grid to the system.

Unit: Power - kW; Energy - kWh

Calculation:

$$E_{net,i} = \int P_{net,i}(t) \cdot dt = \int \left[P_{del,i}(t) - P_{exp,i}(t)\right] dt$$

4. Figure – Example of net energy duraton curve from syn.ikia for three different weeks in a building from measurements



Connection capacity credit

The connection capacity credit is an indicator, which measures the capacity of a system in order to decrease its energy demand or power consumption during a specific timeframe. It measures how much energy consumption - defined as the percentage of grid connection capacity - can be reduced without compromising essential functionality and/or stability of the system.

Unit: Dimensionless [-]

Calculation:

$$CC = 1 - \frac{\max|P_{net,i}(t)|}{P_{max,ref}}$$

where:

CC – connection capacity credit

$P_{net,i}$ – net power of energy of net energy duration curve of energy carrier i

$P_{max,ref}$ – reference power

4.2 Environmental balance

Capital cost

Capital cost refers to the total expenditures (one-time expenses) associated with building construction to establish the necessary system and infrastructure to enhance the building's energy efficiency, like facade elements integrated with photovoltaic systems or solar panels, heat pumps, energy storages and batteries (Salom et al., 2020). The capital cost is interconnected with other economic dimensions, this means, for example higher capital cost in the construction stage can results savings with lower operational costs in operational stage (Kjendseth Wiik et al., 2022).

Unit: CapEx €/m^2

Calculation:

$$CapEx = \frac{(Inv - Grant)}{Area}$$

where:

$CapEx$ - Capital cost per conditioned area (€/m^2)

Inv - Total investment (€)

$Grant$ - Grants received for the building or any assets or items pertaining to the total investment (€)

$Area$ - Total floor area of the system built/ renovated (m^2)

Operational Cost

Operational costs in the evaluation framework encompass capital-related expenses (i.e. depreciation, interests, repairs and replacements), requirement-related expenditures (i.e. power costs, auxiliary power costs, fuel costs, and costs for operating resources), and operation-related costs (i.e. costs of using the installation and costs of servicing and inspection), as well as maintenance and additional costs, which can emerge and fluctuate annually (Ntafalias et al., 2022).

Unit: OpEx €/ m^2/yr

Calculation:

$$OpEx = \frac{(CapCost + ReqCost + OpCost + OtherCost)}{Area}$$

where:

$OpEx$ - Operational cost per conditioned area per year (€/m^2/yr)

$CapCost$ - Costs related to depreciation, interests, replacements and repairs caused by the investment per year (€/yr)

$ReqCost$ - Costs related to power costs, auxiliary power costs, fuel costs and costs for operating resources per year (€/yr)

$OpCost$ - Costs associated with using the installation as well as servicing, inspection and cleaning per year(€/yr)

$OtherCost$ - Costs such as insurance for the investment (€/yr)

$Area$ - Total floor area of the system built/ renovated (m^2)

4.3 Overall Economic Performance

Net Present Value

Net Present Value in the framework represents the project feasibility, „the difference between the present value of cash inflows and the present value of cash outflows over the project's lifetime (€)" (Giannuzzo et al., 2024).

Cash flows are represented by the annual savings generated through participation in the Energy4All pilot project. These savings can be discounted using a risk-adjusted rate of return to estimate their present value, reflecting the equivalent value as if the investors received the savings at the time of the initial investment. The discount rate should be determined based on those applied in comparable projects or derived from stock market data (Salom et al., 2020).

Unit: €

Calculation:

$$NPV = INV - \sum_{t=1}^{T} \frac{Sav_t}{(1+r)^t}$$

where:

NPV *- Net Present Value of the investment.*

INV *- Investment*

Sav_t *- Savings in year t*

r *- Required rate of return*

T *- Total expected life of the building*

Internal Rate of Return

The Internal Rate of Return (IRR) is defined as the discount rate (δ) at which the Net Present Value (NPV) of an investment equals zero. Since no explicit formula exists to determine the IRR, numerical methods are typically used to calculate it.

Unit: €

Calculation:

$$INV = \sum_{t=1}^{T} \frac{Sav_t}{(1+\delta)^t}$$

Find δ such that

INV *- Investment*

Sav_t *- Savings in year t*

T *- Total expected life of the building*

Economic Value Added

The Economic Value Added is calculated as the difference between the annual savings and the minimum required savings.

Unit: €

Calculation:

$$EVA_t = Sav_t - \mathrm{r} \cdot \mathrm{INV}$$

where:

EVA_t *- Economic Value Added for year t.*

INV - Investment

Sav_t *- Savings in year t*

r *- Required rate of return*

Payback Period

The payback period can be calculated by counting the number of years it takes before the cumulative savings equals the initial investment. There is no closed formula for finding its value and numerical methods are normally employed.

Unit: yr

Calculation:

$$\text{find T such that } \sum_{t \geq T} \mathrm{Sav_t} \geq \mathrm{INV} \textit{ and } \sum_{t<T} \mathrm{Sav_t} < \mathrm{INV}$$

where:

INV - Investment

Sav_t - Savings in year t

4.4 Digitalisation and smart urban technology

Percentage of households and buildings with reduced energy consumption as a consequence of installing smart energy metres

Smart energy meters can optimize energy usage, reducing greenhouse gas emissions while also helping individuals save money on their energy bills. Digital innovation serves as a key tool in making urban services more efficient, greatly benefit from aggregated and anonymized data on monthly energy consumption per building. With this in mind, the following indicator set aims to assess the extent of smart metering in cities for both energy and water, as well as its associated impact (Neumann et al., 2022).

A smart meter is an electronic device that records data, such as energy consumption, and transmits this information to both the consumer and relevant suppliers. This indicator aims to track the impact of any associated behavioral changes in energy consumption following the installation of a smart energy meter in building unit. which is a valuable tool for assessing the potential for real-time analysis.

Unit: % of households

Calculation:

Total number of building units with reduced energy consumption following the installation of smart energy meters in year B (comparison year) divided by total number households and buildings prior to the installation of smart energy metres during year A (baseline year) multiplied by 100 (Neumann et al., 2022).

4.5 Indoor environmental quality

4.5.1 Indoor air quality

The proposed evaluation framework can be applied during the design phase, predicted indoor environmental quality (IEQ) characteristics will be assessed through calculations and simulations. In contrast, the operational phase will focus on evaluating actual IEQ performance using on-site measurements, checklists, and questionnaire surveys. This dual-phase approach facilitates an assessment of whether plus-energy buildings achieve their design objectives and establishes a connection between intended design outcomes and performance. The table below summarizes the different activities related to the KPIs of IEQ in the design and in the operational stages of the projects.

High indoor air quality (IAQ) is characterized by air free of harmful concentrations of contaminants, such as carbon dioxide, carbon monoxide, particulate matter, and volatile organic compounds (VOCs) (ISO, 2008). These contaminants originate from various sources such as indoor combustion processes, activities like cooking and smoking, emissions from furniture, cleaning products, construction materials, and even occupants themselves (e.g., carbon dioxide released through respiration) (European Committee for Standardization, 2007). Moreover, IAQ is influenced by outdoor air pollution, which can infiltrate indoor environments through windows, air leaks, or mechanical ventilation systems. Numerous studies have established a strong association between poor IAQ and adverse health outcomes, including asthma, eczema, and allergic conditions. Commonly reported building-related health symptoms include irritation of the eyes, nose, skin, and throat, upper respiratory issues, fatigue, and headaches (Joshi, 2008).

2. Table - Activities related to the different stages of the pilot project (Source: *(Dodd & Donatello, 2021)*).

Project stage	Related activities

Design phase (based on calculations/simulations)	Design of the building structure and HVAC systems to meet ventilation rate (CO2 concentrations) and thermal comfort targets Ventilation design aiming to control sources of humidity and other pollutants In case of renovation projects: Identify problems related to dump, mould and cold bridging Calculation of CO2 concentrations Prediction of daylight factor Prediction of sound pressure levels
Operational phase (based on measurements, surveys and checklists)	On-site measurement of T, RH, CO2, illuminance, sound pressure level Post-Occupancy evaluation surveys Checklists to evaluate parameters that cannot be measured

Carbon Dioxid

Increased indoor carbon dioxide (CO_2) concentrations, relative to outdoor levels, are commonly used as an indicator of adequate ventilation. CO_2 serves as an effective proxy for indoor air quality, offering insights into the ventilation rate within a given space (Table 6). For areas predominantly occupied by sedentary individuals, CO_2 concentrations in the range of 800–1000 ppm typically corresponds to a ventilation rate of 10 liters per second per person (l/s/p) (CIBSE, 2013).

CO2 (in ppm) will be the KPI of the IAQ, it will be measured in all of the building units, CO_2 levels will be monitored across all building units, and their concentration ranges will be used to assess IAQ in accordance with the four quality categories outlined in Table 6. The percentage of time that CO_2 concentrations remain within these specified ranges should be calculated. Following the methodology of the TAIL index from the Aldren project, the four quality categories requires that CO_2 levels do not exceed the defined ranges for more than 5% of the occupied time, for this continuous monitoring is necessary.

3. Table - CO2 concentrations per category (Source: (EN ISO 16798-1-2019)

Category	Carbon Dioxide concentrations above outdoors during full occupancy (outdoor level assumed to be equal to 400ppm)
IEQ_{I}	≤ 550 ppm
IEQ_{II}	>550 and ≤ 800 ppm
IEQ_{III}	>800 ppm and ≤1350 ppm
IEQ_{IV}	>1350 ppm

Unit: ppm

Calculation:

$$C(t) = C_v + (C_o - C_v) exp\left(-\frac{Q_v t}{V}\right) + \left(\frac{G}{Q_v}\right)\left[1 - exp\left(-\frac{Q_v t}{V}\right)\right] x10^6$$

where:

$C(t)$ is the CO_2 concentration in ppm at time t,

Cv is the outdoor CO_2 concentration in ppm (~400ppm without much fluctuation during the day)

Qv is the outdoor air flow rate in m^3/h (depends on air tightness of the building envelope, wind and stack effect and HVAC system design),

V is the volume of the conditioned space in m^3,

G is the CO2 generation rate in m^3/h (~0.3 l/min/person for activity level of 1.2 met),

Co is the initial concentration which can be approximated to Cv at the beginning of the day.

4.5.2 Thermal comfort

According to the EN ISO 7730, 'thermal comfort is that condition of mind which expresses satisfaction with the thermal environment' (International Organization for Standardization, 2005). Extreme temperatures and relative humidity (either too high, or too low), are linked to SBS symptoms, reduce the perceived air quality by building occupants and are also associated to reduced productivity and bad sleeping quality (Seppänen et al., 2006).

Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD)

The level of thermal comfort experienced by occupants is often quantified as the percentage of individuals who are satisfied or dissatisfied with the thermal conditions. The most widely used metrics for this purpose are the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD), which will serve as key performance indicators (KPIs) for evaluating the thermal environment. The formulas for calculating PMV and PPD, as outlined in ISO 7730 and ASHRAE Standard 55, where PMV *levels need to be within +/- 0.5, and PPD ≤ 10%*.

Determining the metabolic rate and clothing insulation requires specific information about the activities performed by occupants and the clothing they wear. During the design phase, these parameters can be estimated based on seasonal conditions, whereas during the operational phase, they can be obtained through post-occupancy evaluation surveys. In cases where detailed data are unavailable, the mean radiant temperature is typically approximated as equal to the air temperature, and the air velocity is assumed to remain constant at 0.1 m/s. These indexes can also be theoretically estimated during the design phase of a project.

According to ISO 7730 and ASHRAE Standard 55 the PMV and PPD indexes can be estimated using the following formulas:

$$PMV = \left[0{,}303 \cdot \exp(-0{,}036 \cdot M) + 0{,}028\right] \cdot$$

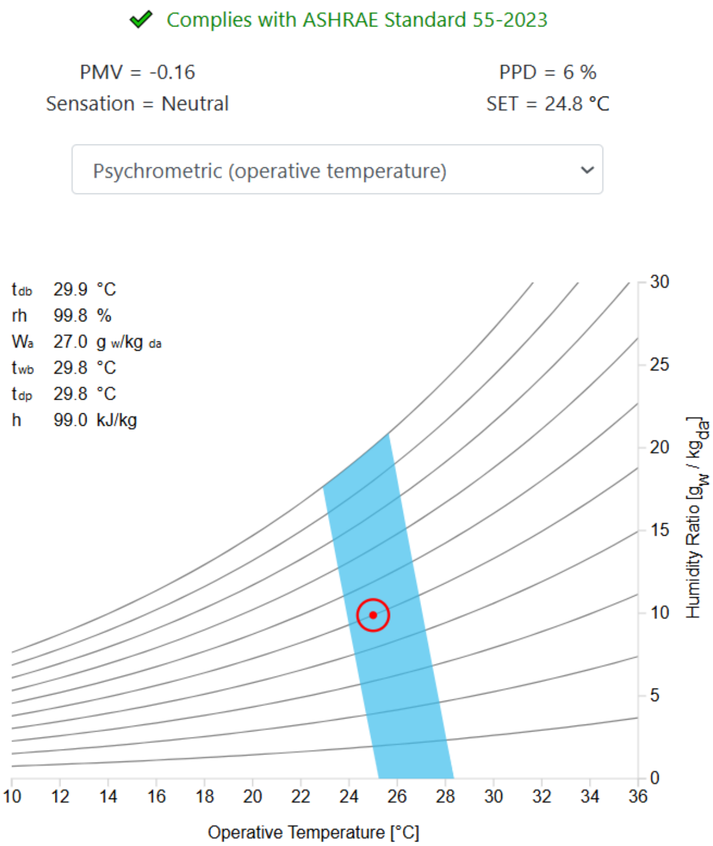
$$\left\{\begin{array}{l} (M-W) - 3{,}05 \cdot 10^{-3} \cdot \left[5\,733 - 6{,}99 \cdot (M-W) - p_{\mathrm{a}}\right] - 0{,}42 \cdot \left[(M-W) - 58{,}15\right] \\ -1{,}7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_{\mathrm{a}}) - 0{,}0014 \cdot M \cdot (34 - t_{\mathrm{a}}) \\ -3{,}96 \cdot 10^{-8} \cdot f_{\mathrm{cl}} \cdot \left[(t_{\mathrm{cl}} + 273)^4 - (\bar{t}_{\mathrm{r}} + 273)^4\right] - f_{\mathrm{cl}} \cdot h_{\mathrm{c}} \cdot (t_{\mathrm{cl}} - t_{\mathrm{a}}) \end{array}\right\}$$

$$t_{\mathrm{cl}} = 35{,}7 - 0{,}028 \cdot (M-W) - I_{\mathrm{cl}} \cdot \left\{3{,}96 \cdot 10^{-8} \cdot f_{\mathrm{cl}} \cdot \left[(t_{\mathrm{cl}} + 273)^4 - (\bar{t}_{\mathrm{r}} + 273)^4\right] + f_{\mathrm{cl}} \cdot h_{\mathrm{c}} \cdot (t_{\mathrm{cl}} - t_{\mathrm{a}})\right\}$$

$$h_{\mathrm{c}} = \begin{cases} 2{,}38 \cdot \left|t_{\mathrm{cl}} - t_{\mathrm{a}}\right|^{0{,}25} & \text{for} \quad 2{,}38 \cdot \left|t_{\mathrm{cl}} - t_{\mathrm{a}}\right|^{0{,}25} > 12{,}1 \cdot \sqrt{v_{\mathrm{ar}}} \\ 12{,}1 \cdot \sqrt{v_{\mathrm{ar}}} & \text{for} \quad 2{,}38 \cdot \left|t_{\mathrm{cl}} - t_{\mathrm{a}}\right|^{0{,}25} < 12{,}1 \cdot \sqrt{v_{\mathrm{ar}}} \end{cases}$$

$$f_{\mathrm{cl}} = \begin{cases} 1{,}00 + 1{,}290\, l_{\mathrm{cl}} & \text{for } l_{\mathrm{cl}} \leqslant 0{,}078\ \mathrm{m}^2 \cdot \mathrm{K/W} \\ 1{,}05 + 0{,}645\, l_{\mathrm{cl}} & \text{for } l_{\mathrm{cl}} > 0{,}078\ \mathrm{m}^2 \cdot \mathrm{K/W} \end{cases}$$

There are also approved online tools, which can be used for the PPD and PMV calculations, such as: http://comfort.cbe.berkeley.edu/



5. Figure - Example of PPD, PMV calculations in the Berkeley online tool

4.5.3 Lighting and visual comfort

As it is defined in EN 12665, visual comfort refers to "a subjective condition of visual well-being induced by the visual environment." Lighting in buildings should enhance the aesthetic appeal of spaces, ensure the safe movement of occupants, and support the productivity of building users. For instance, exposure to daylight through windows has been shown to significantly improve sleep quality. Since people spend circa 90% of their time indoors (Klepeis et al., 2001), a well-designed visual environment, characterized by appropriate natural and artificial lighting levels and minimized glare, contributes positively to occupant well-being and productivity (Skeldon et al., 2017).

Recent studies highlight the adverse health effects associated with inadequate illumination. Insufficient lighting levels have been linked to negative outcomes such as circadian rhythm disruptions, which can result in sleep deprivation, depressive symptoms, reduced alertness, and impaired cognitive performance (Kent et al., 2009). Increased glazing use can lead to higher heat losses in buildings, necessitating a careful balance between thermal efficiency and daylight availability.

Illuminance and Daylight factor

Lighting design criteria are typically defined in terms of maintained illuminance for various building types. In this project, illuminance and the daylight factor will be measured and simulated to assess the visual environment, serving as key performance indicators for lighting and visual comfort.

Illuminance refers to the total quantity of light delivered onto a surface, originating from either natural daylight or artificial light sources. The light levels of an indoor space can increase the building occupant's ability to perform tasks.

The daylight factor is a metric expressed as a percentage, representing the ratio of available daylight within a room compared to the daylight available outside under overcast sky conditions (Boubekri et al., 2014).

4. Table Recommended lighting design criteria of dwellings from syn.ikia

Dwellings	Maintained illuminance (lux) at the appropriate working height
Living rooms	50-300
Bedrooms	100
Kitchen	150-300
Bathrooms	150

Unit: Illuminance: Lux,

Daylight factor: %

Calculation:

$$DF = \frac{E_I}{E_O} \times 100\%$$

where:

DF is the daylight factor measured at a specific point (%)

E_i is the available lux indoors at a specific point on a working plane (lux)

E_o is the simultaneous available lux outdoors under a CIE overcast sky (lux)

To assess the adequacy of daylight, the average daylight factor can be used:

$$Average\ DF = \frac{W}{A}\frac{T\theta}{(1-R^2)}$$

where:

W area of the windows (m2)

A total area of the internal surfaces (m2)

T glass transmittance corrected for dirt

Θ visible sky angle in degrees from the centre of the window (deg)

R the average reflectance of area A

Daylight factors can be estimated by calculating the values on a horizontal surface 0.85 meters above the floor, using the methodology of the TAIL index from the Aldren project. According to BS 8206, rooms with a daylight factor of 2% or higher are classified as daylit, although artificial lighting may still be required for certain tasks. Rooms with a daylight factor of 5% or more are likely to require no electric lighting during the day. The recommended average daylight factors are at least 1.5% for living rooms, 1% for bedrooms, and 2% for kitchens, even if a predominantly daylit environment is not essential (Salom et al., 2020).

5. Challenges, difficulties and gaps

One of the greatest challenges for the Kazán Energy Community is the active involvement of community members in the E4A project. At the first workshop, only a few community members attended due to the tight schedule and the general end-of-year rush. This may have impacted on the diversity of input collected during the workshop. For future workshops and other engagement activities (such as surveying), extra effort will be made to actively involve more community members by targeted advertisement by ABUD and SEC.

6. Further directions and actions

As a first step, the summary of the workshop results, along with insights into participants' behaviors, will be shared with them. This will help participants gain a more comprehensive understanding of their roles and actions, further supporting their engagement and development.

The insights gathered at the 1st workshop will shape the upcoming workshop, planned for the first quarter of 2025, and help build a collective knowledge base within the Kazán Energy Community. The workshop will be about the elements of the socio-technological system (e.g. legal, economic, architectural, mechanical, behavioral, etc.) that influence the achievement of the vision of the EC, and their connections and interactions.

Furthermore, over the next few months, surveys will be sent to participants of the Hungarian pilot projects to gather deeper insights into their energy behaviors. This survey is necessary because there was not enough time to explore participants' energy behaviors during the first workshop. The data collected will not only enhance the understanding of participants' habits but also contribute valuable findings to WP5.

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