WP3 Technology Integration in Smart Managed Plus Energy Buildings and Neighbourhoods

D3.1 METHODOLOGY FRAMEWORK FOR PLUS ENERGY BUILDINGS AND NEIGHBOURHOODS
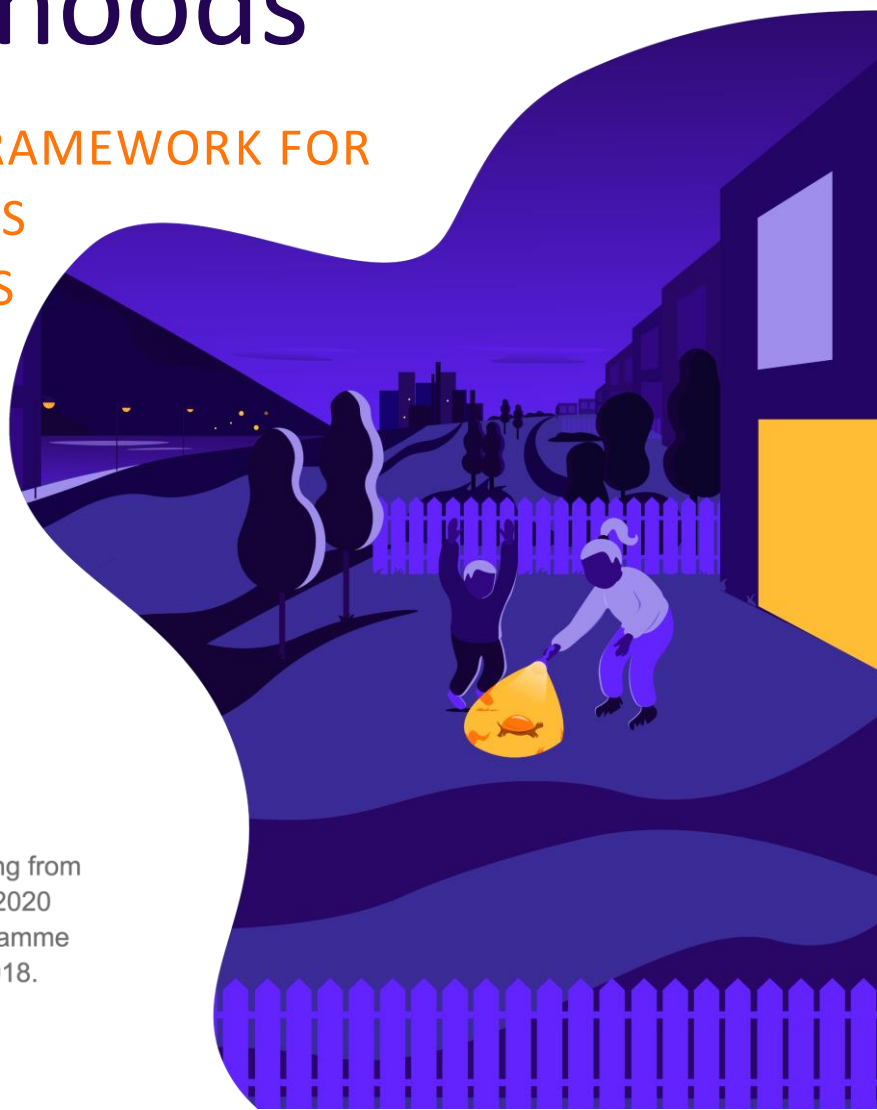
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30-09-2020/M9

Revision Log

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published work has been properly cited.

PROJECT ACRONYM............syn.ikia

PROJECT NUMBER..............869918

PROJECT TITLE ....Sustainable Plus Energy Neighbourhoods

WEBSITE ....www.synikia.eu

Technical References

Deliverable (number)	D3.1
Deliverable Name	Methodology Framework for Plus Energy Buildings and Neighbourhoods
Work Package (number)	WP3
Task number and Title	T3.1 Evaluation Framework for Plus Energy Buildings and Neighbourhoods
Dissemination Level	PU
Date of Delivery	30.09.2020
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Reviewers	TNO
Status	Final

Document history	V0	J. Salom, M. Tamm	IREC	17.07.20
	V1	J. Salom, M. Tamm	IREC	04.09.20
	V2	J. Salom, M. Tamm	IREC	30.09.20
Small changes after PO review	V3	J. Salom, M. Tamm	IREC	15.12.20

Executive Summary

The main aim of this report is to **present syn.ikia's methodology for the evaluation of positive energy buildings and neighbourhoods**. The common evaluation framework defines the Key Performance Indicators (KPIs) for the evaluation of the demonstration projects which will be implemented at two levels: building and neighbourhoods. The selection of the main assessed categories and KPIs have been based in a holistic and exhaustive methodology which highlights the multiple dimensions when talking about sustainability in districts. At the building scale, the monitoring will be carried out in selected dwellings of the neighbourhoods in each of the four climatic zones and at whole building level. At the neighbourhood scale, the assessment and the monitoring will cover the whole neighbourhood, taking in consideration the interaction of buildings, the common active systems and flexibility strategies. This framework will be implemented during the integrated design and the evaluation of the demo plus energy buildings and neighbourhoods when operational.

The **Sustainable Positive Energy Neighbourhood (SPEN)** is defined as a group of interconnected buildings with associated infrastructure, located within both a confined geographical area and a virtual boundary. A SPEN aims to reduce its direct and indirect energy use towards zero over adopted complete year and an increased use and production of renewable energy according a normalization factor. Additionally, syn.ikia definition of a SPEN cover the following five main objectives:

- the net-zero greenhouse gas emissions and carbon footprint reduction,
- the active management of annual local or regional surplus production of renewable energy and power performance (self-consumption, peak shaving, flexibility),
- the cost efficiency and economic sustainability according to a life cycle assessment,
- an improved indoor environment for well-being and satisfaction for the inhabitants, and
- the social inclusiveness, interaction and empowerment related to co-use, shared services & infrastructure and affordable living

There lies a need for a holistic, multidimensional assessment framework within the wider SPEN process that is able to recognize the technical capabilities of various district resources accommodate various markets and enable the effect of commercial arrangements between the SPEN and commercial partners to be appreciated. The need for balanced targets throughout different dimensions is also provided by the World Energy Council (WEC) as the 'energy trilemma', which describes healthy energy systems as a balanced structure between three equally important priorities: energy security, energy equity and environmental sustainability. Hence, this is handled by identifying five categories that allow addressing this multidimensionality nature according to the goals of the syn.ikia project and the SPEN definition. The five categories defined are:

- **Energy and Environmental**, which address overall energy and environmental performance, matching factors between load and on-site renewable generation and grid interaction
- **Economic**, addressing capital costs and operational costs
- **Indoor Environmental Quality** (IEQ), addressing thermal and visual comfort, as well as indoor air quality
- **Social** indicators that address the aspects of equity, community and people
- **Smartness** and **Energy Flexibility**

For each category, several Key Performance Indicators (KPIs) are defined with details on the calculation procedure and the rationale of their selection. Next tables summarizes the KPIs for each dimension. The evaluation framework will include detailed guidelines on how to calculate and assess the different dimensions and the related KPIs, both during the design phase and the operational phase of a construction project. Therefore, the demo developers will use this methodology to drive their designs (WP2) and to check and evaluate their performance in real operation.

Category	Sub category	KPI
Energy and Environmental performance	Overall performance	Non-renewable primary energy balance
		Renewable energy ratio
	Matching factors	Grid purchase factor
		Load cover factor / Self-generation
		Supply cover factor / Self-consumption
	Grid interaction factors	Net energy/ Net power
		Peak delivered/ peak exported power
		Connection capacity credit
	Environmental balance	Total greenhouse gas emissions
Economic Performance	Capital costs	Investment costs
		Share of investments covered by grants
	Operational costs	Maintenance-related costs
		Requirement-related costs
		Operation- related costs
		Other costs
	Overall Performance	Net Present Value
		Internal Rate of Return
		Economic Value Added
		Payback Period
		nZEB Cost Comparison
Indoor Environmental Quality	Indoor Air Quality	Carbon Dioxide (CO2)
	Thermal Comfort	Predicted Mean Vote (PMV)
		Predicted Percentage Dissatisfied (PPD)
		Temperature (T)
		Relative Humidity (RH)
	Lighting and visual comfort	Illuminance
		Daylight factor
	Acoustics comfort	Sound Pressure Level

Category	Sub category	KPI
Social performance	Equity	Access to amenities
		Access to services
		Affordability of energy
		Affordability of housing
		Democratic legitimacy
		Living conditions
		Sustainable mobility
		Universal design
	Community	Demographic composition
		Diverse community
		Social cohesion
	People	Personal safety
		Energy consciousness
		Healthy community
Smartness and Flexibility	Flexibility	Flexibility Index
	Smartness	Smartness Readiness Indicator (SRI)

Finally, the report provides for each of the assessment categories practical guidelines how to implement the calculation of the KPIs in both the design phase and the operational phase of the demo projects of syn.ikia. In specific cases, the guidelines are complemented with developed surveys, checklists and tools to be used in the different phases of the project and to facilitate the common implementation during the auditing processes.

Table of contents

1. Roles and Responsibilities

Name	Role	Responsibility
IREC	Task 3.1 leader. Coordinator of Deliverable contents and edition; Contributor and chapter editor	Definitions and limitations, Energy and Environmental Performance KPIs; Content's review. Edition of Deliverable; Coordination
NTNU	Contributor and reviewer	Review and contributor of Definitions and limitations, Energy and Environmental Performance KPIs and Economic KPIs. Review of Deliverable
SINTEF	Contributor and chapter editor	Economic KPIs
BPIE	Contributor, reviewer and chapter editor	IEQ KPIs, review of the Deliverable
DTU	Contributor and chapter editor	Smartness and Flexibility KPIs
ABUD	Contributor and chapter editor	Multidimensionality aspects, Social KPIs
TNO	Reviewer	Review of the Deliverable
ENFOR	Reviewer	Review of the Deliverable
HOUSING EUROPE	Contributor and reviewer	Social KPIs

2. Introduction

Syn.ikia`s evaluation framework gives an overview of the evaluation process and selection of the Key Performance Indicators (KPIs). A common evaluation framework for Indoor Environmental Quality (IEQ), power and energy performance, CO_2 emissions, life cycle costs and indicators for social sustainability, smartness and flexibility is provided. A common monitoring methodology for the evaluation of the demonstration cases is described: KPIs are described and guidelines for the assessment and additional material, as surveys and examples of visualization of results, are available to facilitate the evaluation in the different phases of the project. The evaluation framework has been ideated to be implemented on two levels: building and neighbourhood levels.

The report starts with the details of the definition of the Sustainable Plus Energy Neighbourhood (SPEN) in the context of the on-going international debate of defining what a Positive Energy District/Neighbourhood is. Then, the holistic nature of the problem is addressed to select the main dimensions which will be addressed in the evaluation framework. For each of the selected dimensions, core KPIs are described with details how they should be calculated. In some cases, sub-KPIs supporting the core ones are also described. For each of the categories guidelines for the assessment is given in each chapter, with the distinction if the KPIs are computed during the Integrated Energy Design phase of the project or in the operational phase where the building and the neighbourhood performance will be measured by detailed monitoring.

Objective

The aim of this report is to provide a joint framework for the evaluation of the performance of positive energy buildings and neighbourhoods, that will give direct indications for further implementation on the demonstration sites of the project. This framework will be adapted and extrapolated to evaluate the performance at the neighbourhood scale. The selection of the Key Performance Indicators (KPIs) to evaluate the demonstration cases has been done in coordination with WP2 (demonstration cases), WP4 (flexibility strategies), WP5 (Task 5.3, multiple benefits of energy efficiency) and WP6 (Task 6.4, market uptake), in order to cover the different stages and points of view of the project.

The calculation of the key performance indicators that are introduced in this report, requires in some cases extensive data collection, especially in the operational phase. This is a task that demo developers should be in charge which may require external assistance for data collection. Therefore, a concept of an auditor is introduced. Auditor could be a technical architect in charge, energy audit company, consulting expert etc. The main role of an auditor is to collect the necessary data and pass it on for further KPI evaluations. The detailed tasks of an auditor are further introduced in KPI explanations, where present.

3. Definitions and Limitations

Background

The syn.ikia definition of a **Sustainable Plus Energy Neighbourhood** (**SPEN**) discloses the main mission of the project according **five main objectives**:

(a) the net zero **greenhouse gas** emissions and carbon footprint reduction,

(b) the active management of annual local or regional surplus production of **renewable energy** and power performance (self-consumption, peak shaving, flexibility),

(c) the **cost efficiency** and **economic** sustainability according a life cycle span,

(d) an improved **indoor environment** for affordable living, well-being and satisfaction for the inhabitants, and

(e) the **social** inclusiveness, interaction and empowerment related to co-use, shared services and infrastructure.

The recognition of the necessity to start widening the scale comes as a response to the growing concerns over the increase of the total population and **environmental impact** that has recently reached critical levels in numerous cities and urban areas worldwide. Additionally, the idea of **shifting scales** stems from a realisation that the sustainability challenge has to do with more than just buildings, but includes numerous complex interrelationships between buildings, open spaces, and transport networks, among others [1]. When it comes to the implementation of the principles of sustainable development in the construction sector and their translation into practical actions, the focus has started shifting from single buildings (micro-scale) to entire neighbourhoods and cities (meso- and macro-scale) (Figure 1).

The shift of scale from single buildings to neighbourhoods means also the need to control and fully understand the **energy flexibility** from clusters of buildings at an aggregated level. A cluster of buildings implies that several buildings can either be located physically next to each other or not be physically connected but have the same aggregator controlling and managing their energy flexibility. An aggregation of the energy flexibility from several/many buildings is thus required, in order to ensure an impact to the energy systems and grids, especially if compared to the limited energy flexibility effect of a single building e.g. in Net ZEBs [2].
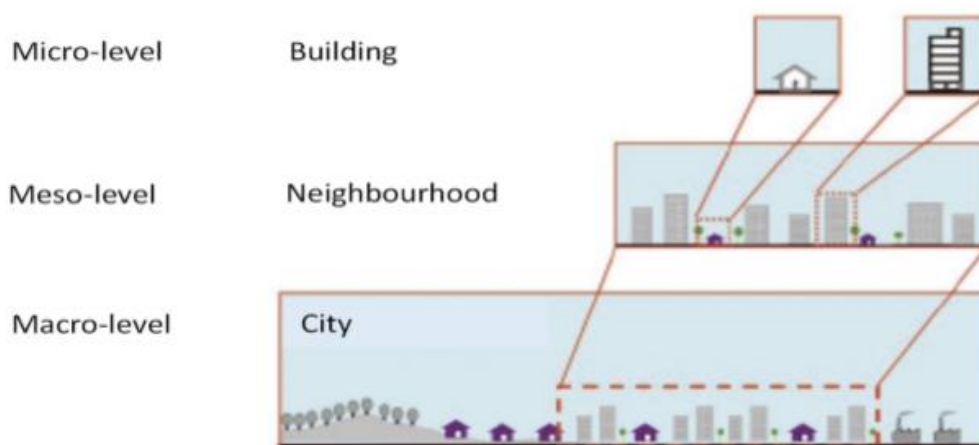
Figure 1. Identification of the neighbourhood scale [3]

The development of sustainable plus energy neighbourhoods is strongly aligned with the broad concept of **Positive Energy District (PED)** stated by the implementation plan of SET Plan Action TWG 3.2. It is inspired by discussions within the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) supported by the European Commission, and especially by the initiative on Positive Energy Blocks and the "Zero Energy/Emission Districts" mentioned in the TWG 3.2 declaration of intent [4]. In this context, a PED is

considered as an "energy-efficient and energy-flexible urban areas or groups of connected buildings which **produce net zero greenhouse gas emissions** and actively **manage** an **annual local or regional surplus production of renewable energy**. They require integration of different systems and infrastructures, and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability".

This concept represents the result of **several working groups and on-going initiatives at European level** that involve members from its network, among which:

- the JPI Urban Europe that aims at aligning different approaches towards the implementation of energy and climate strategies in the urban context, and supports cross-country comparisons consultations with city representatives and other urban stakeholders within the "AGORA" platform, creating the space to meet and exchange experiences and knowhow for urban actors. This network is currently supporting the planning, deployment and replication of 100 "positive energy districts" sustainable urbanisation by 2025 [4];
- the European Energy Research Alliance Joint Program on Smart Cities and the Smart Cities Information System that aim to accelerate new energy technology development by cooperation on pan-European programmes project and to bring together developers, cities, institutions, industry and experts from across Europe to exchange data, experience know-how and to collaborate on the creation of smart cities and energy-efficient urban environment [5];
- the European Innovation Partnership on Smart Cities and Communities [6], the European Regions Research and Innovation Network [7] and Eurocities [8] that support the design of guidelines and the mobilisation, replication and mainstreaming of several cities involved in the development of smart city processes and projects focused in the realization of the Urban Agenda launched in 2016;
- the International Energy Agency EBC Annex 83 "PEDs" launched in February 2020 and focused on developing an in-depth definition of PED, the technologies, the planning tools and decision-making processes related to Positive Energy Districts [9];
- the COST Action CA19126 "PED-EU-NET (Positive Energy Districts European Network) supporting open collaboration among researchers, innovators and other relevant stakeholders across different domains and sectors to drive the deployment of Positive Energy Districts in Europe [10].

Despite the above mentioned efforts, there is still no standard definition of the PEDs concept, even if a shared draft definition, developed by the EERA JPSC together with the JPI Urban Europe within the SET-Plan TWG 3.2, integrates a wide vision of different projects and programs in Europe that gathers the main characteristics of the PED projects and precursors of PEDs [11]. Such contributions are referred to a multidimensional R&D&I perspective - i.e. the "Booklet of Positive Energy Districts in Europe" - and other specific contribution from workshops on PEDs, lesson learnt from the lighthouse projects under H2020 program on Smart Cities and Communities (SCC) and the co-financed initiatives of the ERA-NET. According to this work, four categories of PEDs have been established based on **two main aspects**:

- The **boundaries and limits** of the PED in order to reach a net positive yearly energy balance.
- The **energy exchanges** (import/export) in order to compensate energy balance for surpluses and shortages between the buildings or the wider grid outside [12].

The four main categories of PEDs are defined as:

1) **Auto-PED (PED autonomous):** "plus-autarkic", net positive yearly energy balance within the geographical boundaries of the PED and internal energy balance at any moment in time (no imports from the hinterland) or even helping to balance the wider grid outside;
2) **Dynamic-PED (PED dynamic):** net positive yearly energy balance within the geographical boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages;

3) **Virtual-PED (PED virtual)**: net positive yearly energy balance within the virtual boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages;

4) **Candidate-PED (pre-PED):** no net positive yearly energy balance within the geographical boundaries of the PED but energy difference acquired on the market by importing certified green energy (i.e. realizing a zero carbon district) [12].

The syn.ikia definition of positive energy building (PEB)

The syn.ikia definition of a Plus Energy Building (PEB) follows up on the concept of a building that produces more energy from renewable sources than it consumes to achieve appropriate indoor environmental quality and cover the building energy needs (excluding plug loads). Furthermore, the PEBs should contribute to the roll-out of renewable heating and energy recovery systems (solar thermal, aero/geo-thermal, biomass), as well as to the production of renewable electricity from different sources (solar panels, wind, cogeneration, etc.).

Energy use and energy production must be shown to balance over a one-year period in order to facilitate a clear understanding of the seasonal variance in consumption. To calculate the energy balance (Figure 2. The energy flows at building level and delivered energies classified according to the concept perimeters (origin or destination) [13].), imported and exported energy is multiplied by appropriate site-to-source conversion factors, which are generally named as weighting factors (e.g. primary energy factors).

> *Positive Energy Balance: (weighted exported energy) – (weighted imported energy) > 0*
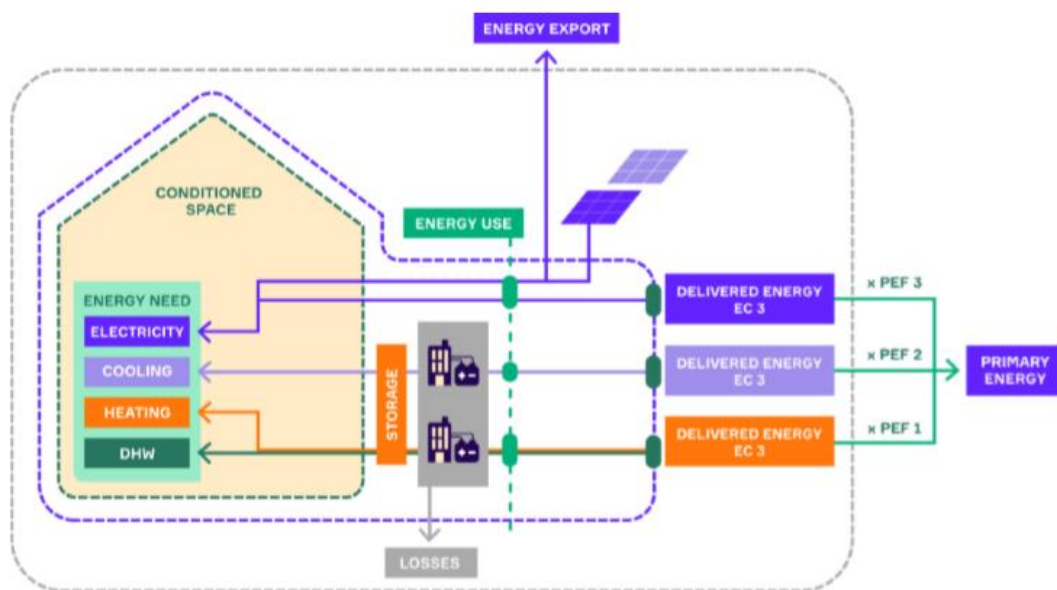
Figure 2. The energy flows at building level and delivered energies classified according to the concept perimeters (origin or destination) [13].

The balance is calculated taking into account all building operational energy uses: space and domestic hot water heating, space cooling, ventilation, and fixed lighting, but excluding household appliances (plug loads). The calculation of the energy performance follows EN ISO 52000-1:2017.

The **renewable energy** consumed in a **positive energy building must mainly be produced on-site**. Onsite refers to energy sources that are in, on, under, or adjacent to the building. As a rule of thumb, the generation of energy must take place within the perimeter of the development, property, in a closed grid, or within a specific distance from the perimeter of the building. However, electricity generated by dedicated renewable energy systems in the region, as well as biomass which is supplied, is not necessarily regarded as an import.

Positive Energy Buildings and Neighbourhood Assessment

The ISO 52000-1:2017 is the overarching EPB standard, providing the general framework of the EPB assessment. In order to evaluate the Positive Energy Balance, a set of EPB standards play a key role to assess the energy performance as defined in the recast of the Energy Performance of Buildings Directive (EPBD)[1]. Each of these five EPB standards describes an important step in the assessment of the energy performance of single buildings and a building portfolio [14][2].

Therefore, because each parameter calculated has a strong impact on the applicability of the EPB assessment, they may be directly or indirectly related to national or regional regulations. The flexibility in the calculation of the energy performance (EP), offered by the choices provided in "Annex A" of the ISO 52000-1, enables specific assumptions and possibilities under the shared umbrella of syn.ikia project partners, without missing peculiarities from the national or regional context regulations.

The overarching EPB standard establishes a systematic, comprehensive and modular structure for assessing the energy performance of new and existing buildings. It takes into account the specific possibilities and limitations for the different applications, such as building design, new buildings "as built", and existing buildings in the use phase as well as renovations. It is applicable to the assessment of overall energy use of a **building**, by measurement or calculation, and the calculation of energy performance in terms of primary energy or other energy-related metrics. According the EPBD and the EPB standards, for the calculation of the energy balance, all common energy uses in a building are considered, including heating, cooling, ventilation, dehumidification, domestic hot water and lighting (Figure 3. Flow chart of the set of EPB standards with position of the five "overarching" EPB standards (Source: REHVA_The new EN ISO 52000 family of standards to assess the energy performance of buildings put in practice) [15].). Essential services (i.e. elevators, etc) could also be included in larger buildings, while the EPB assessment do not refer to loads typically considered related to the user, i.e. cooking or plug loads.

When the positive energy balance assessment moves from a **single building** to a **group of buildings** (**Building Portfolio**) at neighbourhood scale, new considerations are needed in terms of integrating urban and energy planning and evaluating the overall energy performance (according to different choice of assessment methods - e.g., measured versus calculated - defined in the modular and overarching framework of the ISO 52000). Among many assessment objectives, ISO 52000-1 assessment methods cover also the case where buildings (that are on a single site) are connected, while being located apart [13]. Thus, in that case of neighbourhood scale, the assessment boundaries are strictly related to the attributes of the assessed cluster of buildings, as also the mutual interactions between each other, regarding to the common technical building systems and the delivered energies carriers.

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[1] The EPBD and the EED have been amended by Directive (EU) 2018/844, which entered into force on 9 July 2018.

[2] From the amended (2018) text of EPBD Annex 1, point 1: "Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1, developed under mandate M/480 given to the European Committee for Standardisation (CEN)".

The building category is linked to typical uses satisfied by building services. Following the definition 4 of the recast EPBD, the EPB takes into account the following building services:

- *heating;*

- *cooling;*

- *ventilation;*

- *domestic hot water;*

- *lighting;*

- *humidification;*

- *dehumidification.*

Other energy services, for example "appliances", "transport" (e.g. lift, mechanical escalators) may be considered. If other appliances are considered, this should be indicated in the related table of the Input and method selection data sheet, according to Annex A of ISO 52000-1:2017.
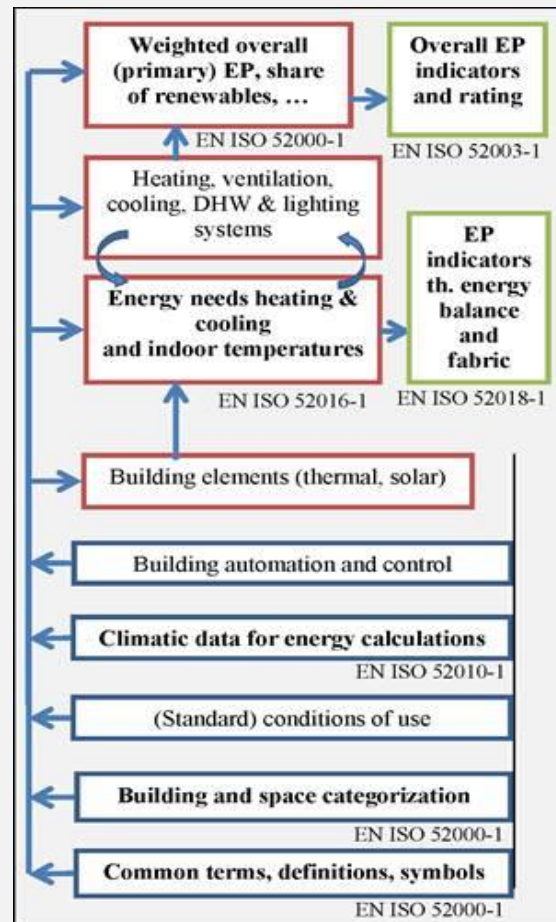
Figure 3. Flow chart of the set of EPB standards with position of the five "overarching" EPB standards (Source: REHVA_The new EN ISO 52000 family of standards to assess the energy performance of buildings put in practice) [15].

Furthermore, the manageable size of neighbourhoods includes other technological, spatial, regulatory, financial, legal, environmental, social and economic perspectives, but also barriers and challenges, which are not fully covered nor planned by the EPBD and EP standards at European level.

Despite these limitations, the **neighbourhood scale of Sustainable Positive Energy Neighbourhood (SPEN)** as defined in syn.ikia fits very well with the smartness imperative of exploiting all the potential from collaborative approaches (even if it means also new barriers and challenges beyond the single PEB). The SPEN concept includes also more profound integration and interoperability with the grid and infrastructures, but also with its governance. For instance, when focusing on a set of buildings, it is required to start considering a common technical building system whose energy performance means **aggregated performance,** since aggregation articulates synergies and discloses a significantly higher potential for smart and mutual interaction [15].

Therefore, the neighbourhood scale will foster **economic sustainability** (e.g. some economies of scale), **aggregation synergies (**e.g. efficiency deployment, flexibility, integration), at the same time **governance** in distributed resources and a considerable **involvement** of **stakeholders** and **communities**.

As consequence of the increased penetration of renewable energy sources (RES), flexible energy systems overcome the traditional centralized production, transport and distribution-oriented approach, by integrating distributed generation (DG), demand response (DR) and decentralized storage into the energy network. Consequently, the **distributed energy resources** (DER) - e.g. Electric Vehicles (EVs) charging stations, combined heat and power (CHP) units, electric water heaters and storage units - are potentially providers of this interaction and flexibility services at neighbourhood scale.

The syn.ikia definition of Sustainable Plus Energy Neighbourhood (SPEN)

The syn.ikia definition of a Sustainable Plus Energy Neighbourhood (SPEN) follows a similar procedure as described for Positive Energy Buildings, but the geographical boundary is physically or digitally expanded to the entire site of the neighbourhood development, including local storage and energy supply units (Figure 4). Users, buildings, and technical systems are all connected via syn.ikia Digital Cloud Hub (HUB) or common energy infrastructures. The SPEN framework includes also a strong focus on cost efficiency, indoor environmental quality, spatial qualities, sustainable behaviour, occupant satisfaction, social factors (co-use, shared services and infrastructure, community engagement), power performance (peak shaving, flexibility, self-consumption), and greenhouse gas emissions, similar to those defined for PEDs.
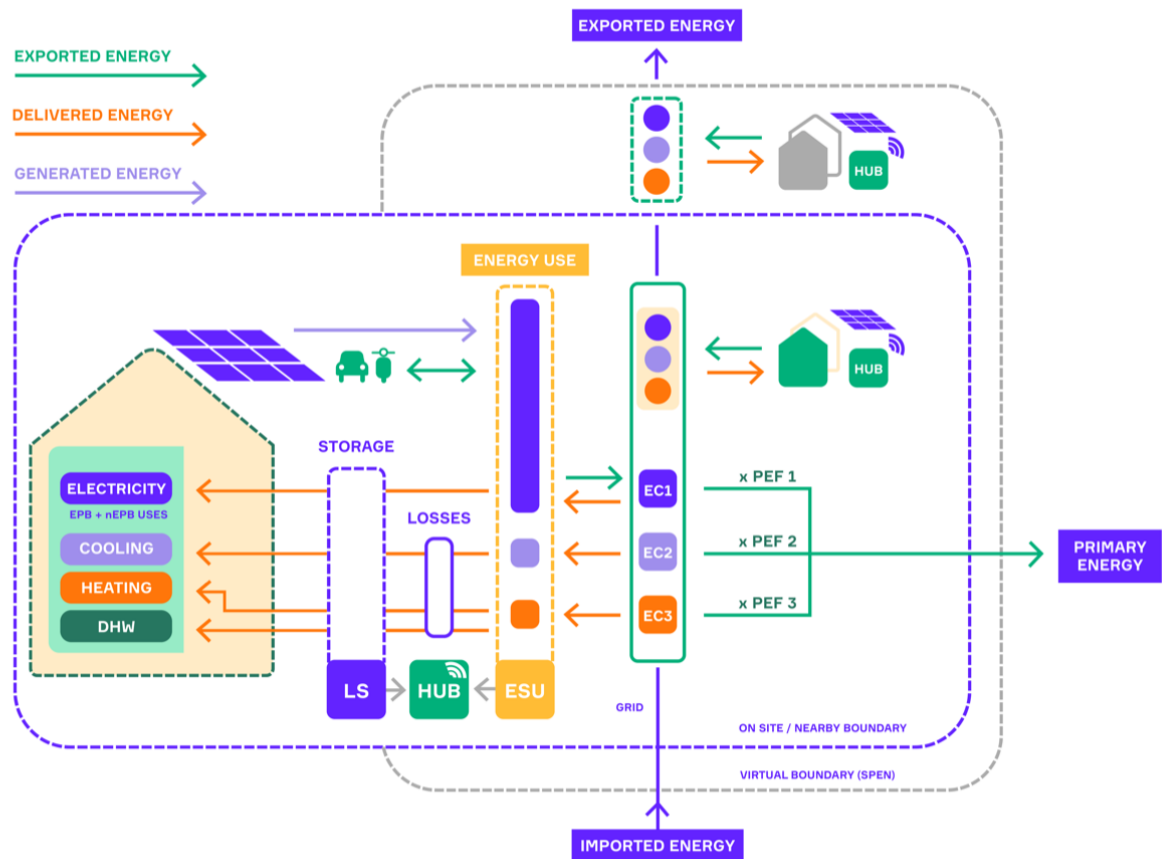
Figure 4. SPEN neighbourhood overview framework within syn.ikia project.

Syn.ikia Definition of Sustainable Positive Energy Neighbourhood - SPEN

The Sustainable Positive Energy Neighbourhood (SPEN) is defined as a group of interconnected buildings[1] with associated infrastructure[2], located within both a confined geographical area and a virtual boundary.

A SPEN aims to reduce its direct and indirect energy use towards zero over adopted complete year and an increased use and production of renewable energy according a normalization factor.

Moreover, the SPEN framework includes a strong focus on cost efficiency, indoor environmental quality, occupant satisfaction, social factors (co-use, shared services and infrastructure) and power performance (peak shaving, flexibility, self-consumption).

A Sustainable Positive Energy Neighbourhood i.e. highly energy efficient neighbourhoods with a surplus of energy from renewable sources, should focus on the following key-points:

- *A SPEN is embedded in an urban and regional energy system and is driven by renewable energy to provide optimized security and flexibility of supply.*

- *A SPEN is based on a high level of **energy efficiency**, in order to keep **annual local energy consumption lower** than the amount of locally **produced renewable energy**.*

- *A SPEN **enables** increased use of **renewable energy** within the local and regional energy system by offering optimized **flexibility** and by managing **consumption** and **storage** capacities **according to demand**.*

- *A SPEN couples the built environment with **sustainable energy production**, **consumption**, and **mobility** (e.g. EV charging) to create added value and incentives for the consumers and the society.*

- *A SPEN makes optimal use of advanced materials, local RES, and other low carbon solutions (i.e. local storage, smart energy grids, demand-response, cutting-edge energy management systems, user interaction, and ICT).*

- *A SPEN offers affordable living, improved indoor environment, and well-being for the inhabitants.*

Notes

[1]The neighbourhood concept in syn.ikia project refers but not limited to the Building Portfolio definition within the ISO52000 that considers a set of buildings and common technical Building systems whose Energy performance is determined taking into account their mutual interactions [SOURCE: ISO 52000-1:2017, 3.1.6]

The geographical boundary for calculating the import/export balance is the site boundary of the neighbourhood. The balance is calculated taking into account all building operational energy uses: space and domestic hot water heating, space cooling, ventilation, and fixed lighting, but excluding household appliances (plug loads).

[2] Infrastructure includes grids and technologies for exchange, generation and storage of electricity and heat. Infrastructure may also include grids and technologies for water, sewage, waste, mobility, ICT, and Energy Management System (EMS).

SPEN and different level of system boundaries

There is a continuous discussion of where to draw the system boundaries, i.e. what energy producing elements to include in the balance when developing and defining PEDs. From a technical point of view a SPEN is characterized by achieving a positive energy balance within a given system of boundaries according to an Energy Community scheme [16]. The SPEN energy concept and integration does not have to be exclusively on-site generation, as there are multiple ways to cover its RES generation requirement. Indeed, already moving from the single building boundary to the neighbourhood scale, on-site generation possibilities are significantly widened, exceeding some of the implicit inefficiencies linked to the PEB concepts. Thus, SPEN limits are not restricted to on-site boundaries, and when using the SPEN smartness attributes, it can also be expanded beyond the physical boundaries of the community. This will allow to unlock synergies with other communities and therefore reach significantly higher overall transition efficiency levels and potentials. Such boundaries refer to 3 different features:

- **Geographical boundary**: where the spatial-physical limits of the building portfolio, sites and infrastructures may be contiguous or in a configuration of detached patches.
- **Functional boundary**: where the limits regard to the energy grids (e.g. the electricity grid behind a substation that can be considered as an independent functional entity serving the neighbourhood; or a district heating system that can be considered as a functional part of the neighbourhood even if the former's service area is substantially larger than the heating sector of the building portfolio in question; or a gas network in the same sense).
- **Virtual boundary**: where the limits are in terms of contractual boundaries, e.g. including an energy production infrastructure owned by the occupants but situated outside the normal geographical boundaries (e.g. an offshore wind turbine owned through shares by the community).

According to these three boundaries descriptions, and aligned to the draft definition of PEDs from EERA JPSC working group and JP urban Europe [12], the net positive yearly energy balance of a SPEN will be assessed within the virtual and/or geographical boundaries. Thus, a SPEN is able to achieve a net positive yearly energy balance and dynamic exchanges within the geographical/functional boundaries, but in addition, it will provide a connection between buildings within the virtual boundaries of the neighbourhood. In a SPEN, buildings are digitally connected via digital cloud hub (HUB), common ICT infrastructure and Energy Management Systems. Dynamic exchanges with the hinterland may be provided to compensate for momentary surpluses and shortages according the assessment boundary methods.

4. Introduction to Multidimensionality aspects

Evaluating SPENs is not a straightforward task since neighbourhoods and neighbourhood scale energy systems are both complex just as sustainability itself [17], [18]. Therefore, most existing neighbourhood scale sustainability evaluation frameworks share the principle, that they could only be evaluated correctly considering the intertwined effects of multiple criteria. From another perspective, it is important for policies and interventions to react to the actual practice, otherwise there is a chance, that they will have limited effectiveness. Therefore, to adopt proper measures and mitigate the existing problems and barriers, a holistic perspective should be used for SPENs as well [19]. Decision making processes usually involve multiple and often different criteria, that differ by stakeholders. These can be present on different levels i.e. political interest, personal beliefs, market beliefs etc. [20]. Despite the differences in opinions when making decision, it is vital to take all drivers into consideration.

Thus there lies a need for a holistic, multidimensional assessment framework within the wider SPEN process that is able to recognize the technical capabilities of various district resources, accommodate various markets and enable the effect of commercial arrangements between the EPN and commercial partners to be appreciated. The need for balanced targets throughout different dimensions is also provided by the World Energy Council (WEC) as the 'energy trilemma' which describes healthy energy systems as a balanced structure between three equally important priorities: energy security, energy equity and environmental sustainability.

Ensuring multidimensionality in indicator selection:

As discussed by Valdes [20] it is really important to check the robustness of the initial indicators. To provide multidimensionality at the selection level the following design considerations related to the main project goals need to be ensured.

- **Avoidance of selection bias (Diversity analysis)**
  Selection bias can be present on multiple levels. To eliminate selection biases, first there is the need to describe the different levels that are important from the perspective of syn.ikia. Categorizing KPIs under different considerations results in a matrix like structure of tagged KPIs. To analyse the diversity, and make sure every relevant interest is represented, diversity analysis is applied. The more diverse the structure is, the more equally represented the evaluation framework will be. To ensure diversity, an index from ecological sciences is used.
- **Avoidance of anchoring bias (Multiple valid impact chains)**
  In many cases assumptions are made and conclusions are drawn by relying on initial information or simple judgement rules from a previous comparison that skew the cognitive processing of a specific information [21]. This is also called as the anchoring effect [21]. During the selection of fit-for-purpose indicators for the different project goals, one can also encounter such biases. To mitigate the risk of anchoring bias, there are two reliable methods (Consider the opposite method, and a Two-pronged approach) described in Adame et al [22]. Both methods aim at finding different informational paths to the same goal. To do this in the case of the evaluation framework, the causal structure of the framework is visualized, where the construction of multiple valid impact chains for the same goal (at least two for each goal) will result in the mitigation of the aforementioned bias.
- **Avoidance of overreliance on available and measurable data (Multiple valid impact chains)**
  It is important to note that for the evaluation of a SPEN, physical and social sciences both needs to be considered. While in the physical sciences we can reasonably assume, that every important factor can be measured relevant to a final goal, by the social sciences the same cannot necessarily be applied as their complexity described by Weaver [23] is different. Therefore, it is often the case, that conclusions in social sciences are drawn from factors that are measurable instead of the most important factors.

To mitigate this risk, constructing multiple valid impact chains towards the same goals, like mentioned before will be used.

- **Avoidance of multicollinearity (D-separation)**
Multicollinearity is present where at least two independent variables have linear relationship[24]. Determining which variables are independent is important to identify the measurable performance indices. D-separation as a procedure can be used to determine variable independences in directed acyclic graphs. This way variables can be identified which are crucial to measure or calculate to avoid double counting problems. D-separation (Dependence separation) can compute the conditional independence in directed graphs [25].

Therefore, to ensure all the above-mentioned design considerations, KPIs are tagged under a tag-based structure, and directed acyclic graphs or DAGs in short are created. Tag-based structure ensures diversity through diversity analysis, while DAGs ensure the other design considerations through D-separation and multiple valid impact chains.

Tag-based structure

Tagging KPIs is a commonly used approach, to ensure variability, and distribution of KPIs under different considerations. Alternatively, most sustainability based KPI development frameworks have used the so called 'three pillars of sustainability, 'namely environmental, social, and economic pillars [26]. There are also intersections used of these three pillars, creating three more dimensions; the intersection of environmental and social creates the livable dimension, the intersection of social and economic creates the equitable dimension, and the intersection of economic and environmental creates the viable dimension as presented in Figure 5.
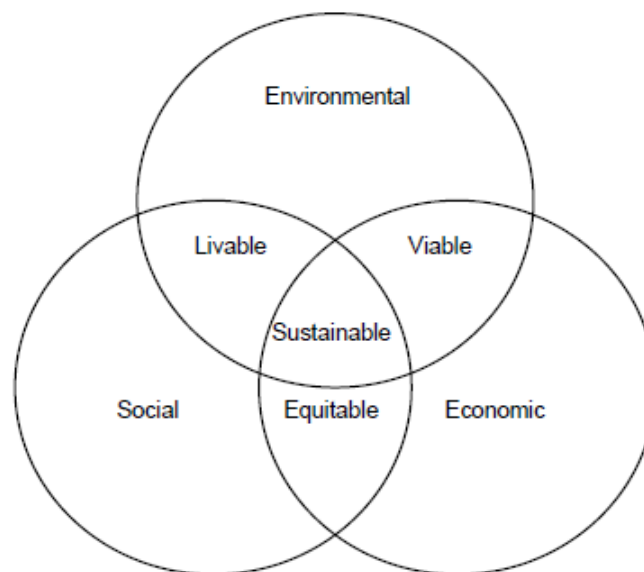
Figure 5. Pillars of sustainability and their intersections by Tanquay et.al.[26]

However, categorizing KPIs in these six dimensions can be confusing and may lead to misunderstandings. Also, it is not entirely clear where the boundaries are between these different dimensions. It is more appropriate thus to categorize KPIs separately in a logic structure which is more relevant for the project.

The following logic structures have been defined as relevant for the project syn.ikia:

- Domain of sustainability (Social, Economic, Environmental)
- Life cycle stage (Design, Operation)
- Scale (Household, Building, Neighbourhood)

- Functionality (Core, Sub)
- Type (Categorical, Numerical, Boolean, Index)
- Authority (Occupant, Facility manager, Grid operator, Policy developer, Building owner)
- Relation to the five main syn.ikia focus areas or the 5D (Design, Decentralization, Democracy, Decarbonization, Digitalization)
- Relation to five main syn.ikia strategies or the 5S (Save, Shave, Share, Shine, Scale)
- Relation to the goals in the SPEN framework (See Figure 4)
- Aspects of the syn.ikia's masterplan

Some logics are **inclusive**, meaning that multiple possible categorization can be relevant for one KPI (for example for Domain of sustainability, Life cycle stage, Scale, Authority, 5D, 5S, SPEN framework, syn.ikia masterplan), while some are **exclusive** (for example Functionality, Type) which means that for each KPI only one categorization is possible. Functionality notation here accounts for prioritization, which allows in cases where not all KPI can be measured, to choose the crucial ones.

Diversity index

To define whether the KPI set is diverse enough, diversity index is calculated for the different tags. This calculation is done with the Shannon diversity index, which is a broadly used diversity index in the field of ecology. It was first proposed by Claude Shannon[27], to quantify the entropy in strings of text. Here it will be used to define the diversity of different KPI groups (grouped by indicator sets). Shannon diversity index is calculated as follows:

$$H' = \cdot \sum_{i=1}^{N} p_{i \ ln \ pi}$$

(1)

where p_i is the proportion of indicators belonging to the i-th tag structure in the indicator set in question.

The individual indicator sets have the following diversity indices in Table 1.

Table 1. Shannon index of each indicator set

Indicator set	Shannon index
Energy and environment	2.18
Economical	2.03
Indoor Environmental Quality	2.27
Social	2.23
Flexibility /Smartness	2.23

The most evenly distributed diverse KPI variation has a Shannon index of 2.30, which is the maximum value we can get from this indicator set. Taking into account these numbers, it can be stated, that all of the indicator sets have roughly the same diversity, and also that all of the indicators sets are diverse enough. Therefore, looking at the tag based structure presented here (Appendix E – Tag based KPI structure) it is clear, that since there is no missing tag, the evaluation framework takes into account all the relevant project goals.

Causal DAG

DAGs are created to map the different indicators related to the drivers present for each performance measured in syn.ikia. To define cause and effect relations between indicators of different drivers, expert knowledge is used.

Related to the project goals, the following key performance categories were identified and are presented in Table 2.

Table 2. Different project goals categorized by the relevant key performance categories

Indicator set	Shannon index				
	Indicator set	Shannon index	syn.ikia masterplan	SPEN framework	DAG handle
Energy and Environmental	Design, Decarbonization, Decentralization	Save, Shave, Share	Climate neutral, Energy efficient, Surplus RES energy	Self-consumption, GHG emission	Decarbonization
Economic	Design	Save Scale	Economic sustainability, sustainable operation, Active management of energy flows	Cost efficiency, Self-consumption	Save
IEQ	Democracy, Design	Shine	Improved user comfort	IEQ, Occupant satisfaction	Design
Social	Decentralization, Democracy	Shine, Share, Save Scale	Good architectural and spatial qualities,	Social factors (co-use, shared services), Occupant satisfaction	Democracy
Smartness/ Flexibility	Digitalization, Decentralization	Shave, Share	Active management of energy flows	Self-consumption, GHG emission	Digitalization and Decentralization

Causal DAG is created for all of the project goals. For the sake of simplification these goals are presented by their DAG handles available in Table 2.

An overview of the DAG shows, that for every different goals there are at least two different impact chains or in other words, there is at least two arrows pointing towards the same goal from the outer circle in *Figure 6*. The five main goals are presented in the inside of the circle. The size of the nodes depends on the number of arrows pointing to the node. The more inbound arrows are, the bigger the nodes. Edge colours are inherited from the target nodes at the end of each causal chain.
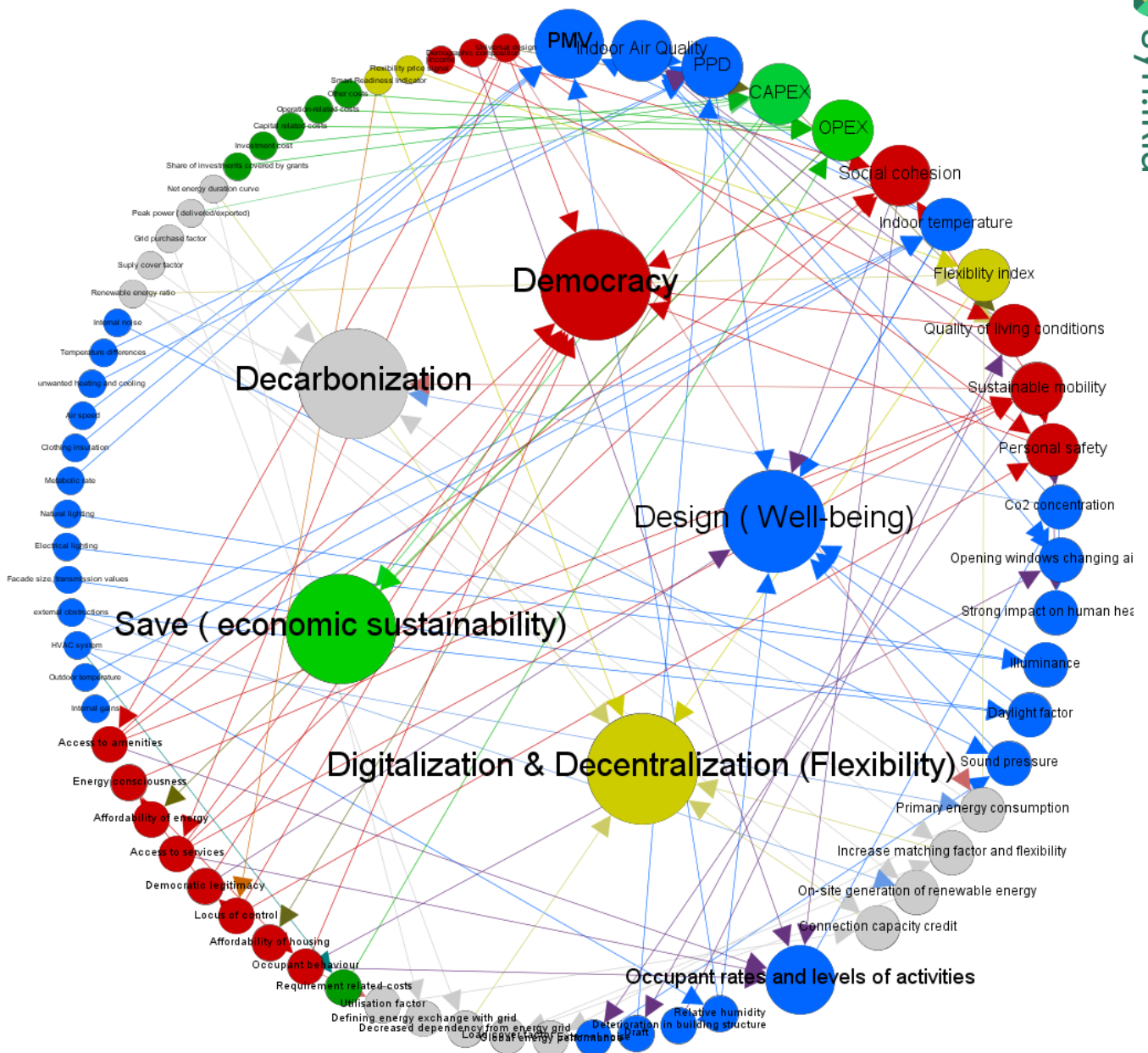
Figure 6. Complete causal DAG of the evaluation framework.

Since for every goal there are multiple ways and multiple considerations taken into account, it is ensured that the risk of anchoring biases and the overreliance of available data is mitigated.

To eliminate the risk of multicollinearity, confounding needs to be spotted between nodes. Confounding is a term broadly discussed in epidemiological research [28]. It is defined as follows in the dictionary of epidemiology:

"The distortion of a measure of the effect of an exposure on an outcome due to the association of the exposure with other factors that influence the occurrence of the outcome. Confounding occurs when all or part of the apparent association between the exposure and the outcome is in fact accounted for by other variables that affect the outcome and are themselves not affected by the exposure" [29].

Or in other simpler words, if a node A is a common cause of B and D, where B is cause of D then A is a confounding variable taking account the route from B to D since it creates an alternative route (backdoor path) [28]. Routes between the goals and their direct causes were examined further with the method of d-separation

[25] to spot confounding. Generally speaking, a backdoor path can be blocked in two ways. There is either a collider on the path meaning, that the collider node is not a common cause, rather a common effect of the source and target nodes. If there is a collider on the path, that path is blocked. If there is no collider on the backdoor path, there is a need to condition on the mediator node. Here in this case it means, that if a node should be conditioned on then the need will present itself to measure/model that effect directly. The term 'conditioning' in this context refers to restriction, stratification or regression adjustment.

In the following sections, the goals and the variables that are directly connected to them are presented.

Goal 1 Decarbonization

D-separation analysis shows, that there is no confounding present in the Decarbonization causal structure in Figure 7, therefore there is no need to condition on any of the variables and it does not present the risk of multicollinearity.
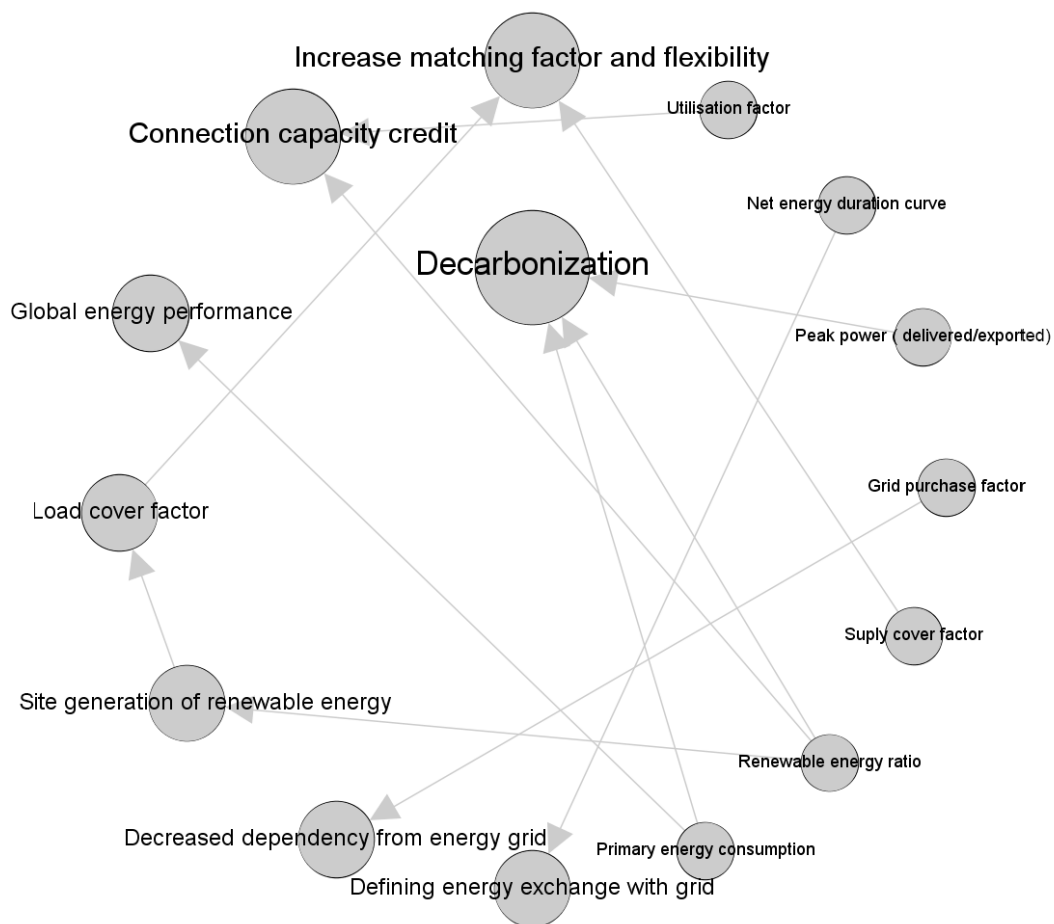
Figure 7. Causal DAG for the Decarbonization goal.

Goal 2 Save (Economic sustainability)

D-separation analysis shows, that there is no confounding in the Save (Economic sustainability) causal structure in Figure 8, there is no need to condition on any of the variables and it does not present the risk of multicollinearity.
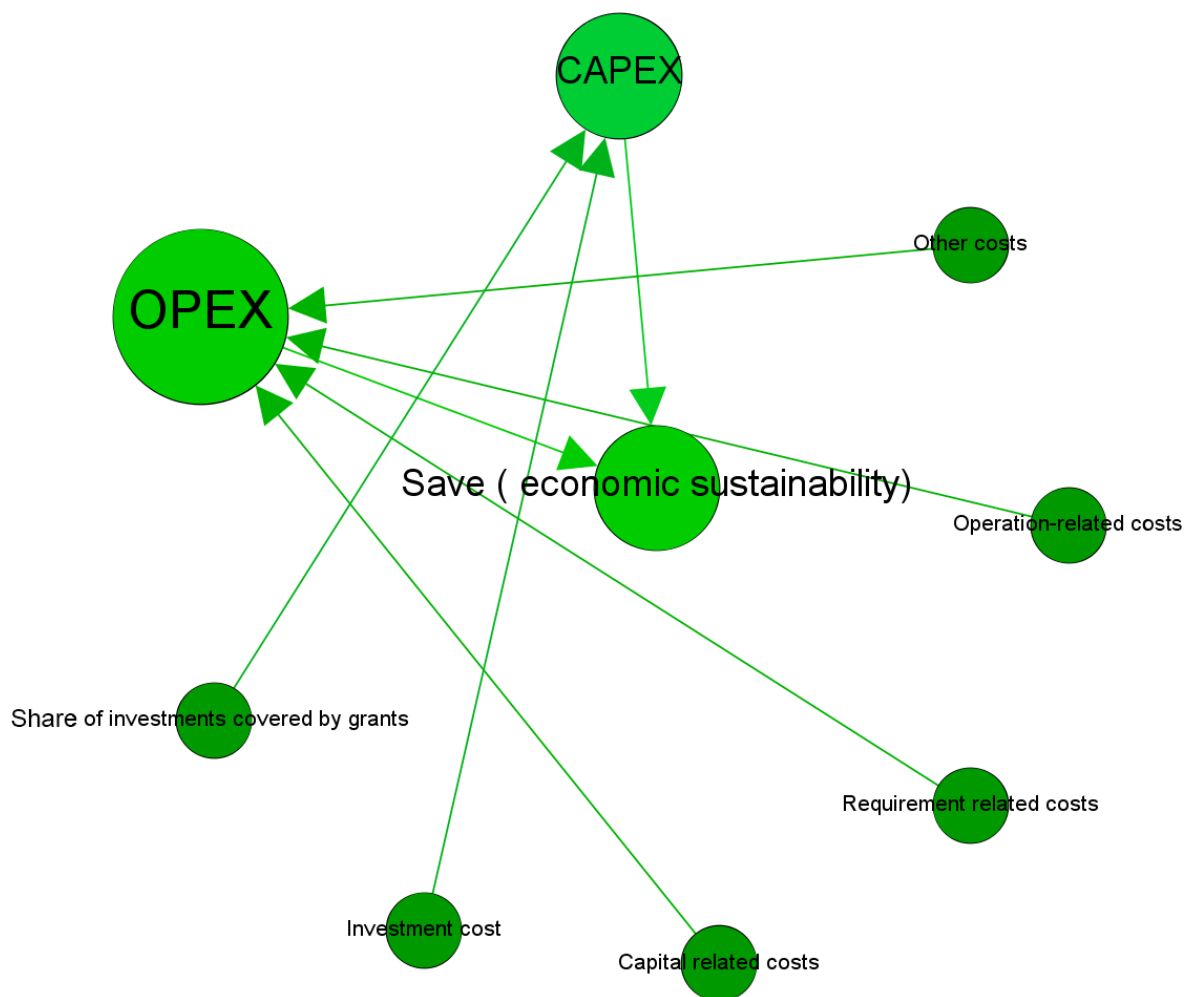
Figure 8. Causal DAG for the Save (economic sustainability) goal.

Goal 3 Design (Well-being)

According to the D-separation there is only one node to condition on when considering the causal structure of well-being in Figure 9 regarding the SPEN. There is a need to condition on relative humidity, when evaluating the indoor temperature regarding well-being. This means, that when evaluating the effects of indoor temperature on well-being should be conditioned on whether that room had high medium or low relative humidity.
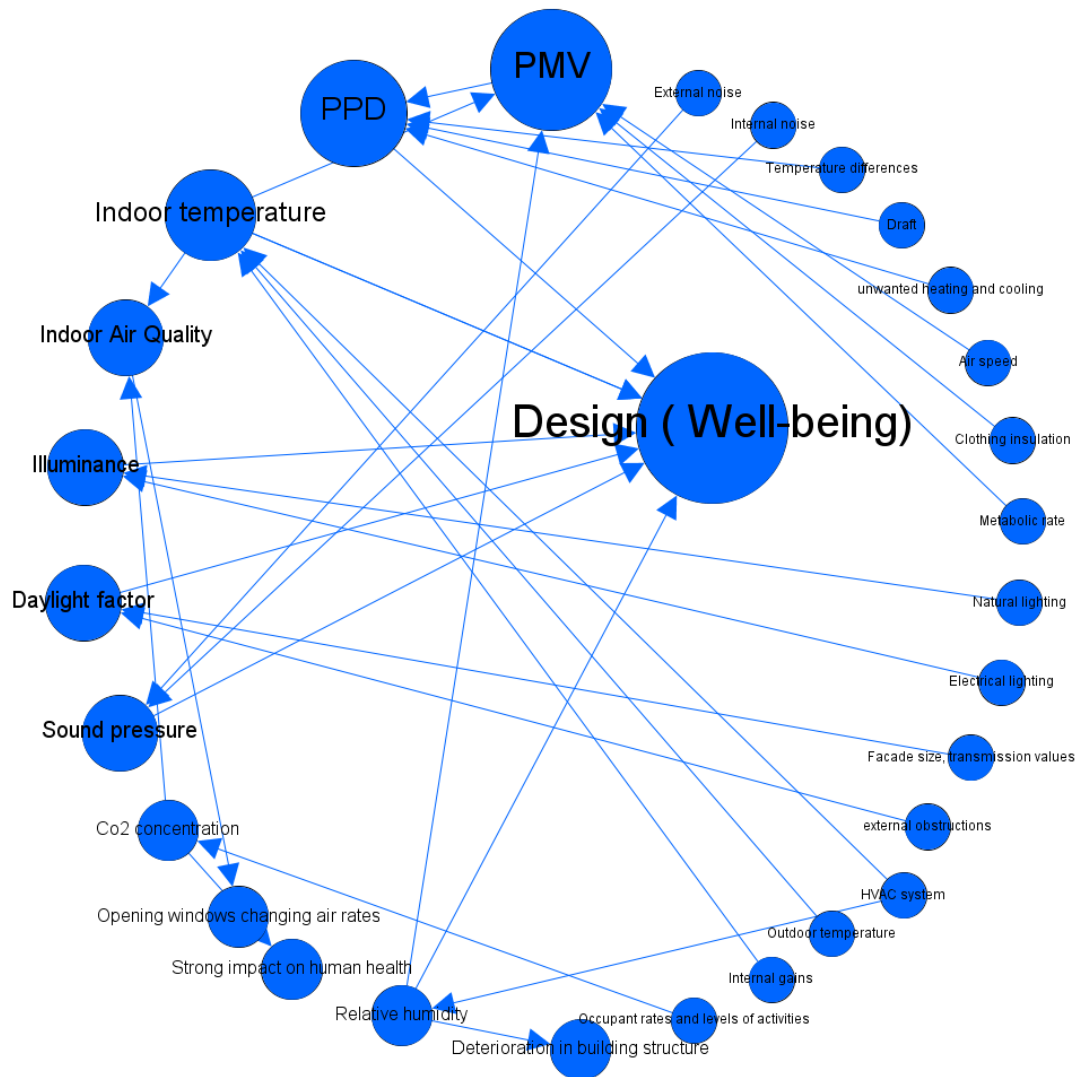
Figure 9. Causal DAG for the Design (Well-being) goal.

Goal 4 Democracy

The Democracy goal presented the most confounding variable in Figure 10. There is a need to condition on three different variables to block all backdoor paths and eliminate the risk of confounding or multicollinearity. It is needed to condition on Universal design, when looking at the effects of Access to services, Access to amenities, and Personal safety on Democracy. When examining the effect of occupant behaviour on Democracy, Energy consciousness should be conditioned on. And lastly the effect of Democratic legitimacy on the Democracy goal should be conditioned on the levels of Locus of control.
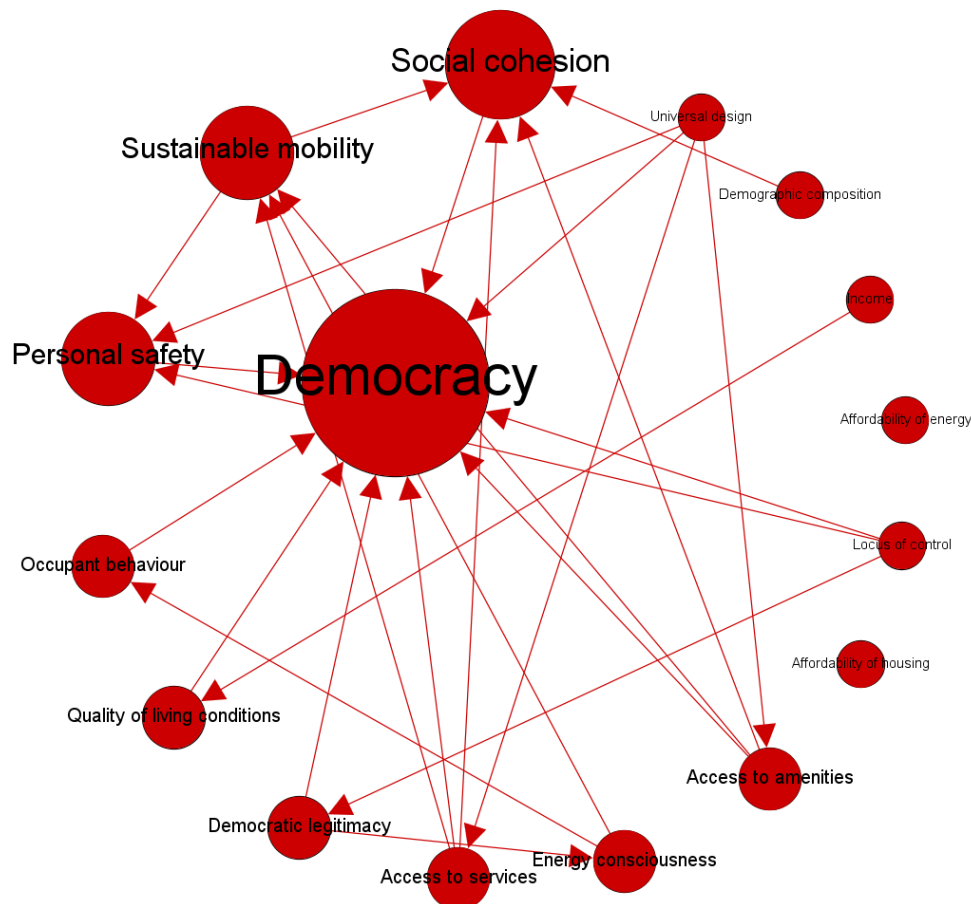
Figure 10. Causal DAG for the Democracy goal.

Finally, there is no confounding in the Digitalization causal structure in Figure 11, therefore, there is no need to condition on any of the variables and it does not present the risk of multicollinearity.
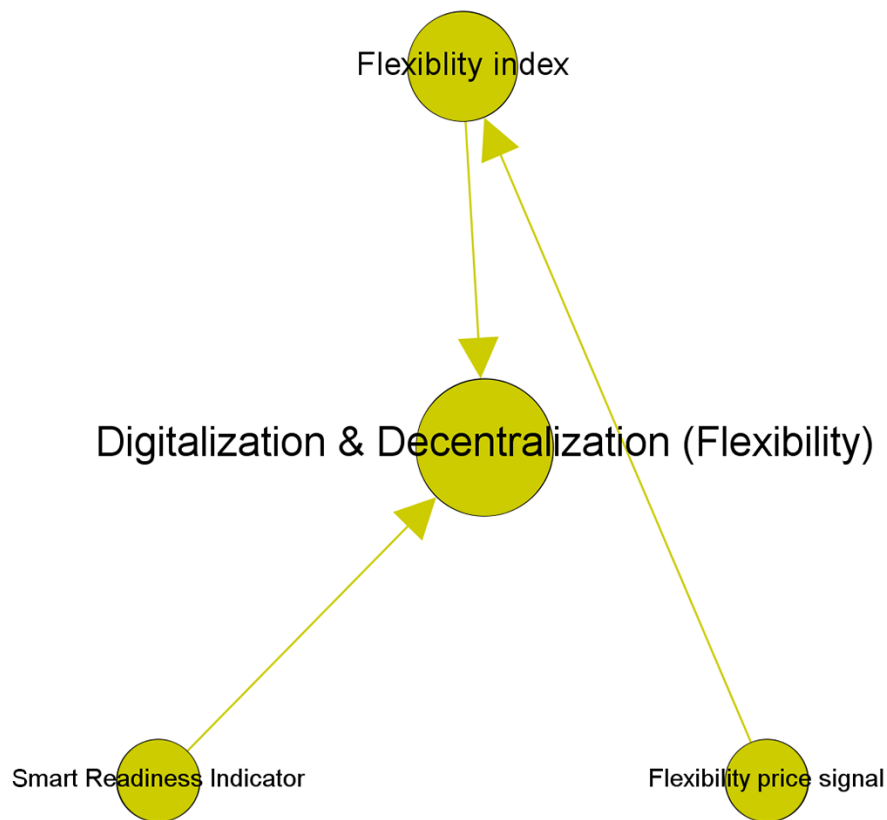
Figure 11. Causal DAG for the Digitalization & Decentralization (Flexibility) goal.

Presentation of the evaluation

Main purpose of the evaluation framework is twofold. The results should inform stakeholders, to easily compare performances with different spatiotemporal evaluations. Therefore, results should be presented with low complexity in an easily comprehensible, transparent, and comparable way. This can be done with combination of different approaches.

There is a yet unsettled debate regarding the use of composite indicators. Composite indicators are much easier to interpret than multiple indicators at once, but on the other hand valuable information could be hidden by the arbitrariness of a composite indicator [30].

The arbitrariness of the composite indicator building can come from the three main steps of constructing it and as Nardo et.al.[30] pointed out, ill constructed composite indicators can be misleading and lead to false conclusions. Therefore, to create a **composite indicator**, the usual approach is to conduct a multicriteria analysis (MCA).

MCA is generally good for comparing performances of different decision alternatives [31], [32] Opon and Henry[31] writes, that MCA is a cohort of four different analytical stages or steps:

1.   **Indicator selection**

Indicators should be selected carefully, and taken into account the multidimensionality aspects discussed beforehand.

2. Normalization

Since data are collected in different ways, and forms like e.g. different measurement units, different data types, dichotomy (positive outcome for one indicator might be increased value, and for other a decreased value)etc..[31]. Therefore, before aggregating, it is necessary to homogenize the data

3. Weighting

Different indicators do not always share the same level of contribution for reaching the end phenomenon. In addition, since there might be different number of indicators per dimension, it is important to balance indicators regarding their effect on the overall performance.

4. Aggregation

To summarize the indicators some aggregation method is necessary. The two main aggregation technologies are the linear, and geometrical aggregation of indicators. Most widely used is the linear aggregation, which entails the summation of normalised and weighted values of indicators.

With the right MCA, one can choose which sub-indicators to use, how those are divided into classes, which normalization, weighting and aggregation method to be used.

However, considering the drawbacks, for the present stage composite indicators from multiple different KPIs will not be constructed. The presentation of the evaluation framework results will be done by displaying them in a way that is easily comprehensible and helps the intuition of the stakeholders when making decision.

Visualization of data

In complex systems often performance-related dashboards do not contain enough information to understand the underlying metric structure. The different metrics containing different type of information need different visualization techniques. First there is a significant difference in visualizing qualitative and quantitative data. Then quantitative data can be further split into different subgroups according to the attributes of the numerical data i.e.: percentage data, categorical data (Boolean) and integer.

To visualize all of the dimensions of the evaluation framework, Schneiderman's Visual Information Seeking Mantra [33] needs to be kept in mind: "Overview first, zoom and filter, then on-details-on-demand". Thus, before figuring out how to visualize different data types, first a visualization technique is needed that provides clear overview. Overview should be available for every relevant scale of comparison in the project, to present the opportunity for relevant stakeholders to understand and compare the results. There should be an overview visualized for at least the following levels: EU level (comparing the different demos in different countries and country specific thresholds) and neighbourhood level (comparing the performance of different buildings). These two overview levels will be used for further discussion of the visualization.

EU level

The main question on EU level is to find the exact information sparseness. It should be detailed enough, to inform stakeholders and policy developers in an easily comprehensible manner, about the performances of SPENs in different regions, however it should be sparse enough to still keep its overview characteristics and stay easily perceivable. This level is best represented on a geographical map, where all of the projects can be indicated with their most characteristic performance metrics, and country or regional tresholds. An example from such a representation is presented from the SmartCEPS [34] project in Figure 12.
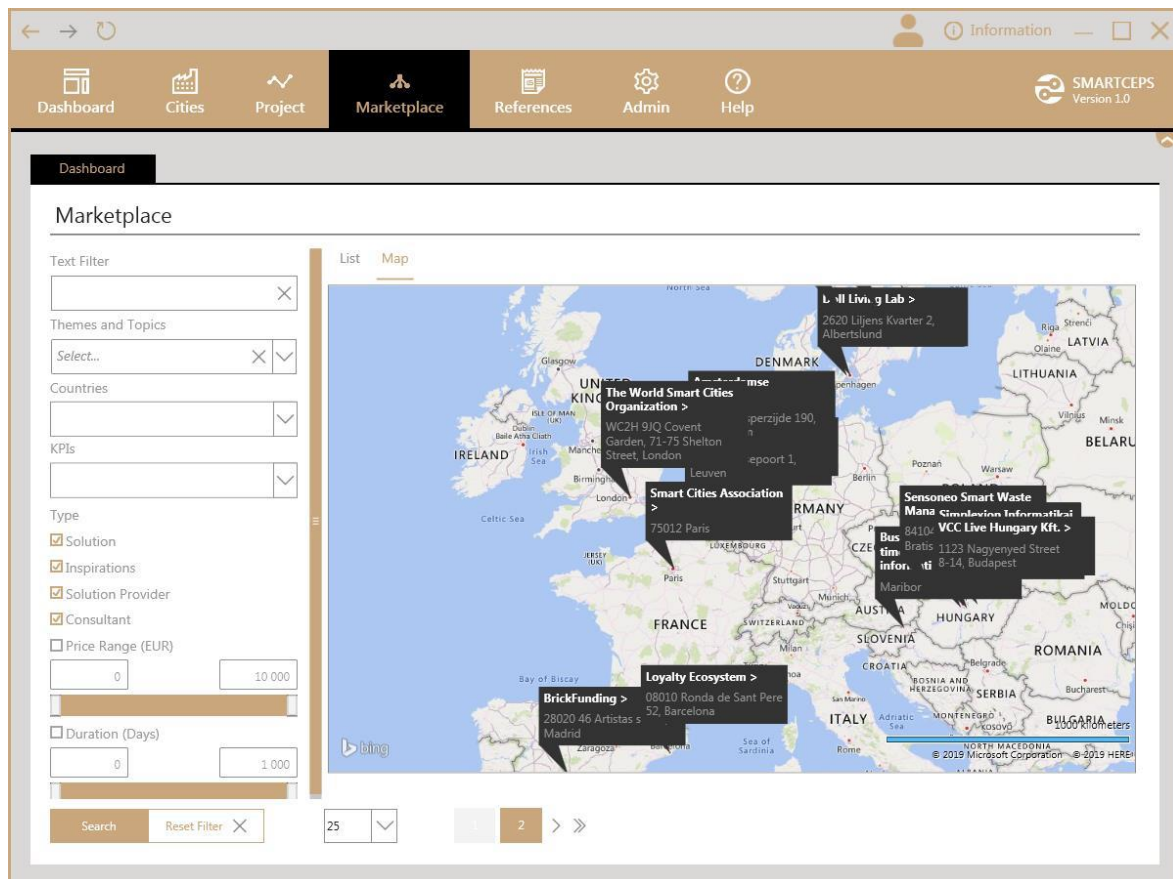
Figure 12. Virtual marketplace from the SmartCEPS project

Neighbourhood level

Scaling down from EU overview level to the Neighbourhood overview level, the information denseness increases. An important challenge here is, to solve the discrepancies between different KPI metrics i.e. Peak power will present itself in kW, while Sound pressure in db(A) and Access to amenities dimensionless. This may come across as a barrier, when trying to perform conditional "what-if" analysis, since it is not clear how the change in one metric is tied to the change in another metric [35]. Graph-based visualization can enhance transparency, and user's ability to discover the underlying metric structure. It is just a matter of information density, though graph-based visualizations work better when visualizing sparse networks. The advantage of this method as described by Brundage et. al. [35] is that it quickly shows the connections between different variables. It is also mentioned however, that graph-based visualization techniques are not the best for large number of KPIs, since occlusion issues might appear. To avoid overlapping and for compactness reasons, matrix-based representations can provide answers. For the sake of clarity and understanding, the best from both sides needs to be implemented. Therefore, providing both set of visual representations is proposed. An example is presented from Brundage et. al. where there is both a graph-based representation and a correlation matrix is provided in Figure 13.
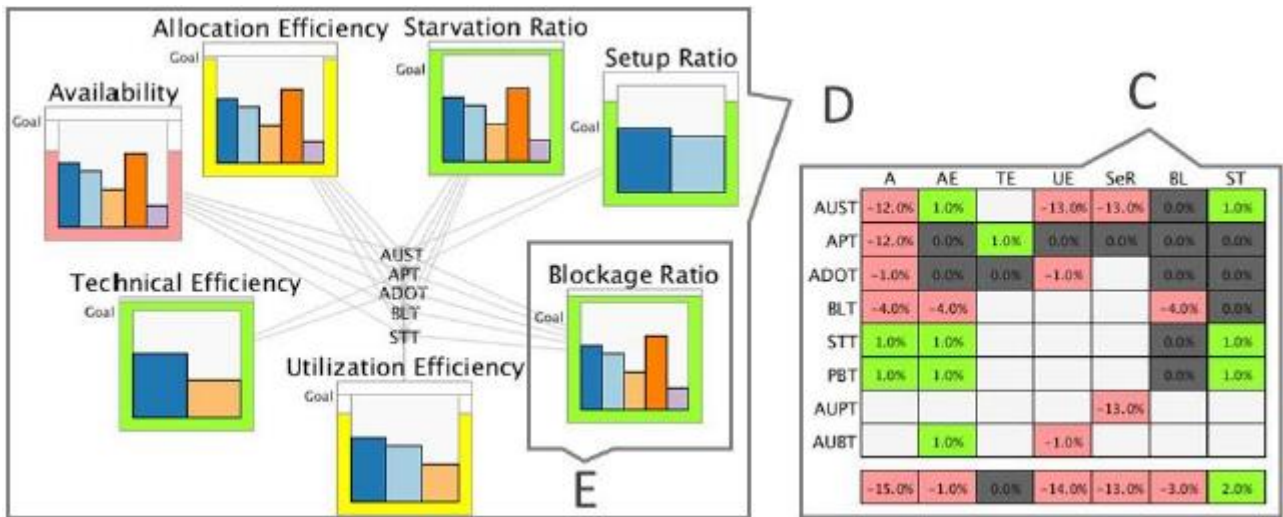
Figure 13. Graph based visualization complemented with correlation matrix from Brundage et al.
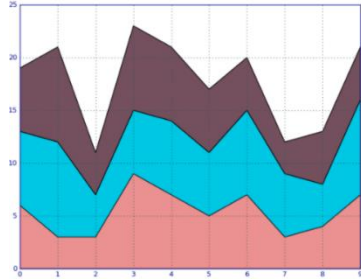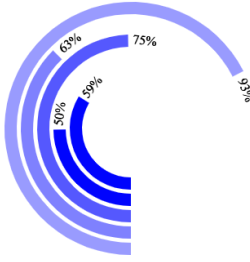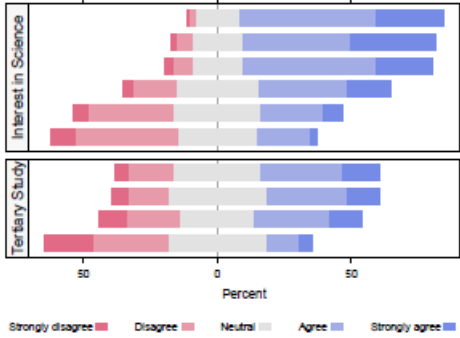
Since there are numerous KPIs and the connections in the graph might get confusing, an correlation matrix taking into account all KPIs and this graph based representation taking into account only the KPIs from one KPI set- as already presented in Figure 6-Figure 11 is recommended.

Detailed visualization of individual KPI level

Fit-for purpose visualization techniques also differ by the units of KPIs. Different plots can highlight different attributes of the data and therefore it is crucial to choose the best techniques for each data type. Furthermore, it is also crucial, to minimise the diversity of the plots, since if every KPI is presented with completely different methods, the user might get confused and valuable information gets lost. To define the best visualization technique KPIs were categorized by their metrics (percentage, integer, unitless, likert-scale was also categorized here); frequency of change (rare, constant), and relevance of scale (building, neighbourhood, both).

According to this categorization the following visualization techniques are proposed in Table 3:

Table 3. Showing the different visualization techniques proposed for each measurement type

Metrics	Frequency of changes	Scale	Proposed vizualisation
Integer	Constant	Both	Stacked line plot
Integer	Constant	Building	Line plot
Integer	Rare	Both	Stacked gauge chart
Percentage	Constant	Both	
Percentage	Rare	Both	
Unitless	Constant	Both	
Unitless	Rare	Both	
Unitless	Rare	Neighbourhood	
Likert-scale	Constant	Both	Diverging stacked bar chart

5. Energy and Environmental Performance KPIs

Introduction and general considerations

This section presents and describes the set of indicators selected to characterize the energy and environmental performance of each building/neighbourhood and their interaction with the connected energy networks through their system boundaries.

The proposed set of indicators, as presented in Table 4, follows the assessment methodology of the Energy Performance of new and existing Buildings (EPB) described in the ISO-52000 standards [13]. In general terms, the overall energy consumption of a building, by measurement or calculation, should be based on hourly or sub-hourly values of the different energy flows in the buildings and by the exchanged energy carriers (delivered and exported energy) with the energy networks (electricity, thermal energy with district heating and cooling networks, natural gas, etc.).

In order to calculate the overall energy balance or performance of a building or neighbourhood, the use of weighted metrics as primary energy has been established. For that, it is necessary to define the weighting factors, also known as conversion factors, used to convert the different final energies into a common magnitude, such as non-renewable primary energy or CO_2 emissions.

The imported and exported final energy should be multiplied by the appropriate site to-source conversion multipliers, based on the utility's source energy type. The source energy is the most equitable unit of evaluation. Source energy represents the total amount of raw fuel that is required to operate the building. It incorporates all transmission, delivery, and production losses. Special attention should be given in defining primary energy factors for energy carriers produced from on site, nearby or distant.

The quantification of proper conversion factors is not an easy task, especially for electricity and thermal networks, as it depends on several considerations, e.g. the mix of energy sources within certain geographical boundaries (international, national, regional or local), average or marginal production, present or expected future values and so on. In general, there are no correct conversion factors in absolute terms. Rather, different conversion factors are possible, depending on the scope and the assumptions of the analysis and the treatment of exported energy. Furthermore, 'strategic factors' may be used in order to include considerations not directly connected with the conversion of primary sources into energy carriers. Strategic factors can be used to promote or discourage the adoption of certain technologies and energy carriers, as it has been proven in [36] for the case of Net Zero energy Buildings. Weighting factors can be generally time dependent, as the share of renewables is depending on the season and the period of the day. However, usually mean annual national and regional factors are available for different regional or country approaches. In case of the absence of national/regional factors, European or global factors can be used as reference. The ISO-52000 proposes default values for primary energy weighting factors which can be used as reference.

Usually, energy and environmental performance are presented normalized to the building sizes. Reference size for the building is the useful floor area (m²) calculated according to national definitions and standards. For the neighbourhood, it is considered as reference size the sum of the reference areas for the buildings in the neighbourhood for the purpose of energy related performance calculations.

> *For the purpose of this section, the term system is used to name indistinctly either a building or a neighbourhood.*

Table 4. Energy and Environmental Performance key performance indicators.

Category	Sub category	KPI type Core or Sub (secondary/com plementary)	KPI	Unit (B/N/BN)[3]
Energy and Environmental Performance	Overall performance	Core KPI	Non-renewable primary energy balance	BN: kWh/(m² y)
		Core KPI	Renewable energy ratio	BN: -
	Matching factors	Core KPI	Grid purchase factor	BN: -
		Core KPI	Load cover factor / Self-generation	BN: -
		Core KPI	Supply cover factor / Self-consumption	BN: -
	Grid interaction factors	Core KPI	Net energy/ Net power	BN: kW
		Core KPI	Peak delivered/ peak exported power	BN: kW
		Core KPI	Connection capacity credit	BN: -
	Environmental balance	Core KPI	Total greenhouse gas emissions	BN: kg CO2eq/(m² y)
	Overall performance	Sub KPI	Energy produced on-site	BN: kW
		Sub KPI	Electrical vehicle energy consumption	BN: kWh

Overall Energy Performance

The overall energy performance of a system is based on the balance at the assessment boundary of the weighted delivered energy and weighted exported energy. The delivered energy is the one required to cover the energy demand of the considered building/neighbourhood, including the on-site produced energy which potentially can be exported.

To describe the overall performance of a building / neighbourhood, two main indicators are selected. The main one is the non-renewable primary energy balance which weights the delivered and exported energy. If this balance is lower than zero, it means that it is a positive energy system. The other main indicator is the Renewable Energy Ratio which represents the share of renewable energy in the system.

Non-renewable primary energy balance

Description:

This indicator takes into consideration all types of energy consumed and produced by the system, and the exchange with the energy networks. It is calculated using equation (2) which **sums up all delivered and exported energy for all energy carries into a single indicator with the corresponding non-renewable primary energy weighting factors**. Therefore, this indicator considers as well differences in the energetic effort within the supply chain of different energy carriers, e.g. domestic gas versus electricity [37].

---

[3] B and building, N as neighbourhood and BN as both building and neighbourhood level.

Unit:

- Building: kWh/(m² y)
- Neighbourhood: kWh/(m² y)

Calculation:

$$E_{P,nren} = \sum_i E_{p,nren,del,i} - \sum_i E_{p,nren,exp,i}$$

$$= \sum_i \int P_{del,i}(t) \cdot w_{del,nren,i}(t) \cdot dt - \sum_i \int P_{exp,i}(t) \cdot w_{exp,nren,i}(t) \cdot dt \qquad (2)$$

where

$E_{p,nren}$ - the non-renewable primary energy, [kWh/ m² y];

$E_{p,nren,del,i}$ - delivered non-renewable primary energy per energy carrier i, [kWh/ m² y];

$E_{p,nren,exp,i}$ - exported non-renewable primary energy per energy carrier i, [kWh/ m² y];

P_{del,i_i} - the delivered power on site or nearby for energy carrier i, [kW/ m²];

$w_{del,nren,i}$ - 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/m²];

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

Primary Energy consumption is used as one of the main indicators for the assessment of the energy balance in the EPBD directives and adopted in most of the countries in Europe. However, ISO 52000-1 which defines the overarching framework and procedures for the EPB assessment, distinguishes between non-EPB uses (appliances and lighting in some cases for residential) and **two different forms of the energy balance**. The different forms vary in the consideration of the resources avoided by the external grid due to the export of the energy carrier, and each EU country can choose what considerations to apply in the energy balance.

In the framework of syn.ikia, weighting factors for exported energy should be selected based on the resources avoided from the external grid, which is equivalent to "Step B" stated in ISO-52000. This means that for example the values of the delivered and exported weighting factors for electricity are considered to be equal.

> *In the framework of syn.ikia, assessed energy uses include HVAC, DHW and lighting needs.*
>
> *Plug loads, appliances and Electrical Vehicle consumption are not considered in the assessment of the energy balance.*

For the calculation of the amount of exported energy, it is necessary, for each energy carrier, to perform a balance between the energy needs and the produced energy inside the assessment boundary. Either using calculations or measured values, it is recommended that the interval period used to calculate the balance per energy carrier was one-hour resolution, as maximum. In some countries, as for example Spain [38], the targets established for nearly zero energy buildings are based on a monthly assessment, which means that, within a month, exported energy compensates for the delivered energy. Using an hourly or sub-hourly calculation gives a closer picture of the amount of exported energy available for sharing with other buildings in the reality.

Renewable energy ratio

Description:

The share of renewable energy is defined by the Renewable Energy Ratio (RER), 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 include solar thermal, solar electricity, wind and hydroelectricity, renewable energy captured from ambient heat sources by heat pumps and free cooling, and renewable fuels [39].

RER is the percentage of energy from renewable sources in the total energy consumption. The objective of efficient buildings is not using renewable sources as much as possible, but using as little energy as possible from non-renewable sources. A better renewable energy ratio should not lead to worse energy performance. The amount of primary energy from renewable source for RER calculation, E_{Pren} (in kWh). is calculated taking into account only delivered energy to the assessment boundary, in line with the renewable energy ratio (RER) in EPBD Article 2(2)"The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

RER is defined in the ISO 52000-1 and is dependent on the chosen perimeter. Usually two types of RER can be distinguished. The on-site RER which considers only the energy that is used in the building and the distant RER accounting for the benefit for the external world of exporting energy produced on-site. The latter one is the one used in syn.ikia. The renewable primary energy produced on-site have the total primary energy factor of 1.0 and the non-renewable primary energy factor of 0.

Unit:

Building: Dimensionless [-]

Neighbourhood: Dimensionless [-]

Calculation:

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

(3)

where:

E_{Pren} - renewable primary energy consumption kWh/(m² y)

E_{Ptot} - total primary energy consumption kWh/(m² y)

Matching factors

Load match factors intend to describe the degree of the utilization of on-site energy generation related to the energy use in the building and/or neighbourhood. These factors characterize the direct use of energy produced inside the assesment boundary over a period and time (e.g, a day, a month or a year). Their **calculation should be done on sub-hourly or hourly** basis to characterize correctly the simultaneous use of on-site produdedenergy and the energy exhanged with the grids [1].

The interpretation of the matching factors can be explained with reference to a graph showing the daily profiles of on-site produced electricity and electricity load in a single building with PV generation. The areas A and C represent the energy use in the building and the area B is the energy exported to the grid. The overlapping area, which is C, represents the power that is used directly within the building/neighbourhood. Although the matching factors have been mainly used to analyze mismatch between renewable electricity produced on-site and electricty load in the buildings, they can be extended to other energy uses and connections to other energy networks, e.g, district heating [40].
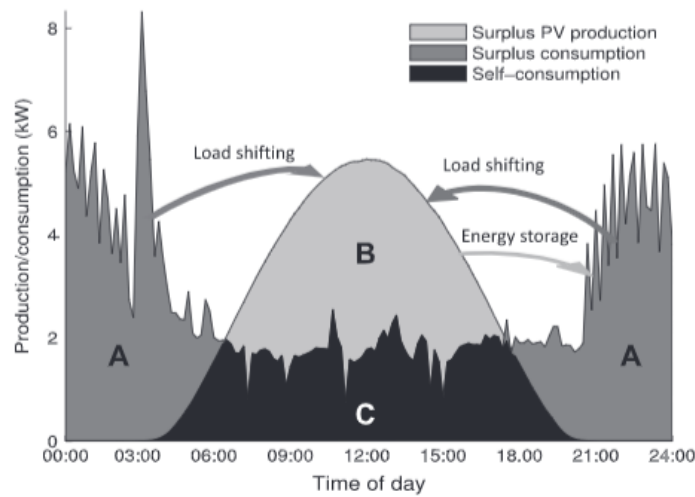
Figure 14. Schematic outline of daily net load (A + C), net generation (B + C) and absolute supply cover factor (C) in a building with on-site PV. It also indicates the function of the two main options (load shifting and energy storage) for increasing matching between on-site production and energy consumption [41].

In the literature, the same concept has received different names. Mainly two complementary indexes have been used: the **load cover factor** [1] or **self-generation** [42] and the **supply cover factor** [1],[39] or **self-consumption** [42]. This can also be complemented whith a third index which is the **grid delivered factor** or **grid purchase ratio** [43]. In case that energy use represents the useful energy demand grid purchase factor is a more reliable indicator and allows a fairer comparison of different systems, particularly if local electric and thermal storage are charged with renewables and/or efficiencies of the compared systems differs.

Load cover factor / Self-generation

Description:

The load cover factor is the relation between the energy produced on-site and directly used and the total electric energy use. In relation to Figure 14, it is the ratio between the self-consumed part (area C) and the total energy use (area A+C). In ISO-52000, this factor is named **use matching fraction**.

Unit:

Building: Dimensionless [-]

Neighbourhood: Dimensionless [-]

Calculation:

$$\gamma_{load} = \frac{E_{prod,used}}{E_{used,tot}} = \frac{\int min \left[P_{prod}(t), P_{used}(t) \right] dt}{\int P_{used}(t) \, dt} \qquad (4)$$

where:

$E_{prod,used}$ – self-consumed on-site production (kWh)

$E_{used,tot}$ - total consumption (kWh)

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

P_{used} – system consumed power (kW)

When presence of **energy storage** elements in the system, e.g. a battery in an electrical system, this needs to be considered in the definition of the on-site produced power, as the power produced when the storage is discharged is an on-site produced energy. For example, in case of a PV system and a battery, the load cover factor can be computed with the equation (5).

$$\gamma_{load} = \frac{\int min\,[P_{PV}(t) - P_{bat}(t), P_{used}(t)]\,dt}{\int P_{used}(t)\,dt} \tag{5}$$

where

P_{PV} – is the on-site (photovoltaic) production (kW)

P_{bat} - is the power sent to the battery (positive if charging) or incoming from the battery (negative if discharging) during the interval of time of evaluation (kW)

Supply cover factor / Self-consumption

Description:

The supply cover factor is the relation between the energy produced on-site and directly used and the total on-site produced energy. In relation to Figure 14, is the ratio between the self-consumed part (area C) and the total energy generation (area B+C). In ISO-52000, this factor is named **production matching fraction**.

Unit:

Building: Dimensionless [-]

Neighbourhood: Dimensionless [-]

Calculation:

$$\gamma_{supply} = \frac{E_{prod,used}}{E_{prod,tot}} = \frac{\int min\,[P_{prod}(t), P_{used}(t)]\,dt}{\int P_{prod}(t)\,dt} \tag{6}$$

where:

$E_{prod,used}$ – self-consumed on-site production (kWh)

$E_{prod,tot}$ - total electricity produced on-site (kWh)

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

P_{used} – on-site consumed power (kW)

When presence of energy storage elements in the system, e.g. a battery, this need to be considered in the definition of the used power, as the power used to charge the storage adds to power consumption in the building. For example, in case of a PV system and a battery, the supply factor can be computed with the Equation (7).

$$\gamma_{supply} = \frac{\int min\,[P_{PV}(t), P_{used}(t) + P_{bat}(t)]\,dt}{\int P_{PV}(t)\,dt} \tag{7}$$

where

P_{PV} – is the on-site (photovoltaic) production (kW)

P_{bat} - is the power sent to the battery (positive if charging) or incoming from the battery (negative if discharging) during the interval of time of evaluation (kW)

Grid delivered factor

Description:

The **grid delivered factor** is the relation between the energy delivered from the grid and the total energy used by the system over a time period. In relation to Figure 14, it is the ratio between the delivered energy from the grid (area A) and the total energy use (area A+C). It characterizes the dependency of the buildings/neighbourhood from the grid [43].

Unit:

Building: Dimensionless [-]

Neighbourhood: Dimensionless [-]

Calculation:

$$\gamma_{grid} = \frac{E_{del,grid}}{E_{used,tot}} = \frac{\int max\left[P_{used}(t) - P_{prod}(t), 0\right] dt}{\int P_{used}(t)\, dt} \tag{8}$$

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)

Grid interaction factors

Grid interaction indicators are based on the **net energy** which represents the electricity interaction between the building/neighbourhood and the grid, per energy carrier. Net energy should be computed with hourly or sub-hourly resolution making the balance between exported energy to the grid and delivered energy from the grid over the selected resolution period. For a proper analysis of grid interaction, sub hourly resolution data is required (recommended in the range of 1-5 minutes and 15 minutes maximum) as there is a relatively high impact due to time averaging effects [44].

Net energy / Net power

Description:

Net energy can be used to characterize the interaction of a system with the energy grids over a certain period: a day, a week, a month or a year. For doing that, it is useful to represent the net energy using a duration curve, coloured carpet plots and/or using box plots [1]. This kind of visual representations allows for an immediate understanding of distribution of power and differences between alternative solutions.

For each energy carrier, the net energy indicator can be represented by a "curve of duration", where the values of the power obtained during a period are ranked from the highest value to the lower one. The convection shown here is that negative values represent power/energy **exported to the grid** and positive values represent that the power/energy is **delivered from the grid** to the system.

The Figure 15 represents schematically the net energy duration curve. It should be noted that the red area of the net load duration curve represents the net delivered energy. That means that in case of a yearly duration curve, the red area of the duration curve is equal to annual delivered energy, while the green area is equal to annual exported energy. Figure 16 shows three examples of net energy duration curves for a three different weeks of the year based on measured data.

Unit:

Building: Power - kW; Energy - kWh

Neighbourhood: Power - kW; Energy - kWh

Calculation:

$$E_{net,i} = \int P_{net,i}(t) \cdot dt = \int \left[P_{del,i}(t) - P_{exp,i}(t) \right] dt \tag{9}$$
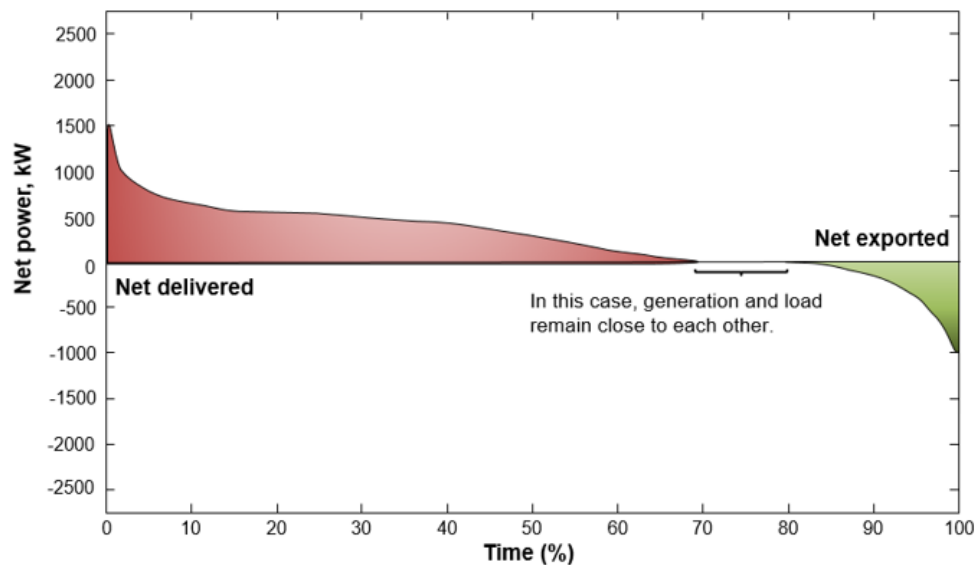
Figure 15. Net energy duration curve: conceptual scheme.
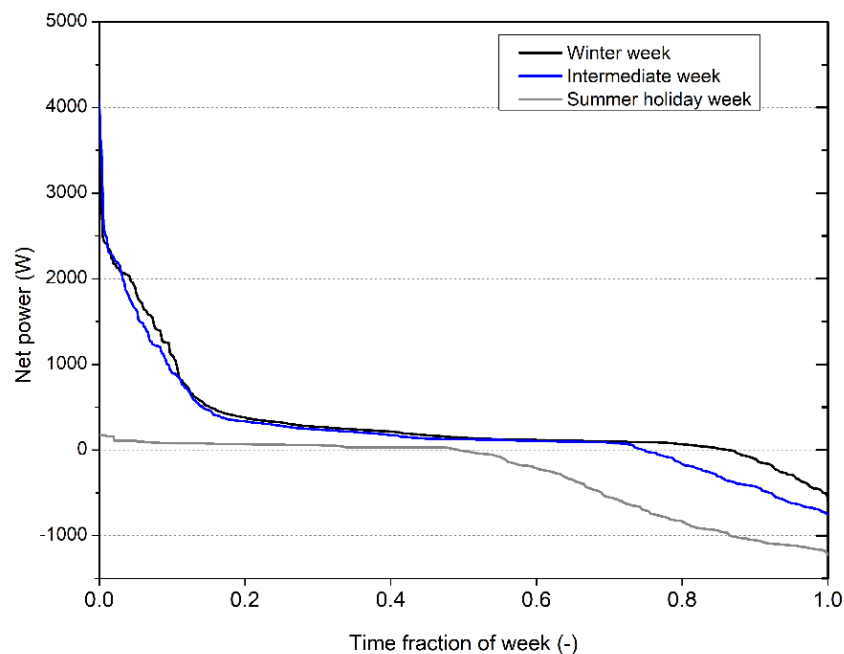
Figure 16. Net energy duration curve: examples for three different weeks in a building from measurements

From this kind of representation, interesting information can be easily visualized, such as:

- Amount of energy delivered to the building/neighbourhood
- Amount of energy exported to the grid
- Percentage of the time when the building/neighbourhood is importing energy from the grid
- Percentage of the time when the building is exporting energy to the grid
- Percentage of time in which the balance between generation and load is close to zero, therefore, there are not energy exchanges with the grid.

In coherence with the definition of SPEN and ISO52000 set of standards, we refer to net energy exchange as a result of an energy balance considering on-site/nearby produced energy and energy consumption to cover the EPD energy use. As part of the energy consumption of the building and neighbourhood is discarded for the

energy assessment, actual metered grid interaction will differ of the calculated one, as it is represented schematically in Figure 17.

Similar to Figure 17, Figure 18 represents the net energy duration curve, but provides a comparison between different system boundaries. The red area represents net delivered energy, when only EPB uses are counted inside the system boundary, when yellow and red area together represent the net delivered energy in case when all consumption (EPB and non-EPB uses) is taken into account. Net exported energy duration curve follows the same logic: blue area in case of only EPB uses, green and blue together in case of all consumption in accounted.
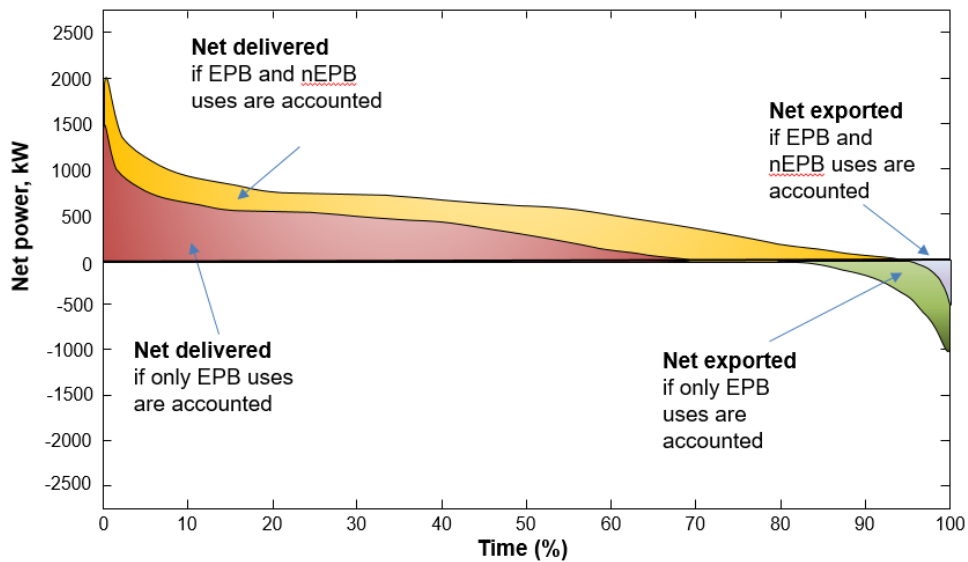
Figure 17. Net energy duration curve considering EPB energy use and all energy uses in a system: conceptual scheme

Peak delivered / Peak exported power

Description:

The peak delivered and the peak exported power KPIs are extreme values of the net duration curve. The maximum positive value is the peak delivered, while the maximum negative value is the peak export. If there is no net export, then the peak export is equal to zero.
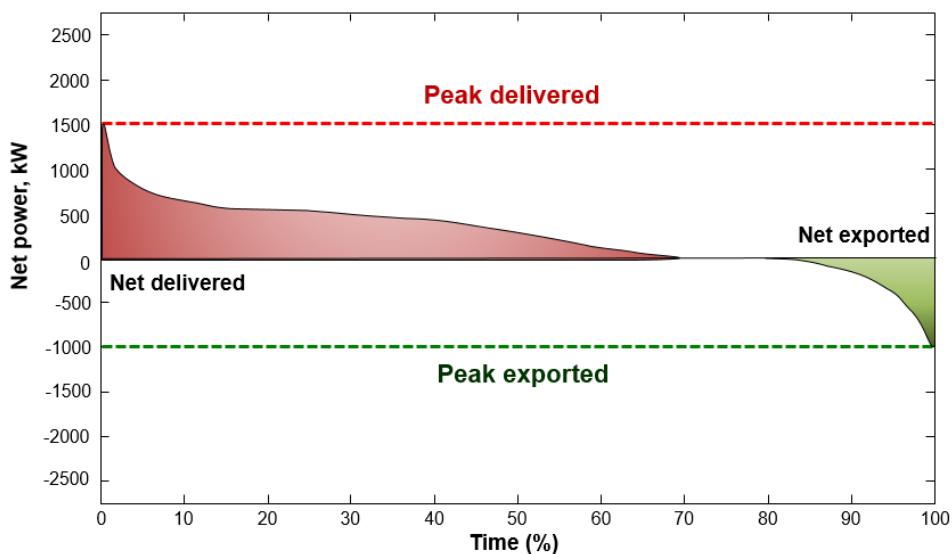
Figure 18. Net energy duration curve. Schematic representation of peak delivered and peak export power.

Building: kW or kW/m²

Neighbourhood: kW or kW/m²

Calculation:

$$P_{max,del,i} = \max[P_{net,i}(t)] \tag{10}$$

$$P_{max,exp,i} = -\min[P_{net,i}(t)] \tag{11}$$

Where:

$P_{max,del,i}$ – Peak delivered power: peak power of energy delivered to the grid by the energy carrier i

$P_{max,exp,i}$ – Peak exported power: peak power of energy exported to the grid by the energy carrier i

$P_{net,i}$ – net power by energy carrier i

Connection capacity credit

Description:

The **connection capacity credit**, or **power reduction potential** [45], is defined as the percentage of grid connection capacity that could be saved compared to a reference case.

This indicator can be used for several purposes, depending of what is used as reference value.

- If the reference value is the grid connection capacity, the indicator gives information about the degree of utilization of the connection capacity or the room for adding additional loads that can be installed in the building or the neighbourhood [46].
- If the reference value is the value in a BAU scenario, the indicator informs about the increased hosting capacity for RES, electrical vehicles and other new loads [47].

Unit:

Building: Dimensionless [-]

Neighbourhood: Dimensionless [-]

Calculation:

$$CC = 1 - \frac{\max|P_{net,i}(t)|}{P_{max,ref}} \tag{12}$$

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

Overall Environmental balance

Greenhouse gases (GHGs) are gases in the atmosphere that absorb infrared radiation that would otherwise escape to space; thereby contributing to rising surface temperatures. There are six major GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) [12]. The warming potential for these gases varies from several years to decades to centuries. The greenhouse emissions shall be expressed in kg of CO_2 equivalent per kWh and can be quantified per energy carrier.

Total greenhouse gas emissions

Description:

The greenhouse gas assessment is calculated in a similar way that the primary energy balance and takes into consideration all types of energy consumed and produced by the system, and its exchange with the energy networks. It is calculated using equation (13) which sums up all delivered and exported energy for all energy carries into a single indicator with the emissions weighting factors.

Unit:

Building: kg CO2eq/(m² y)

Neighbourhood: kg CO2eq/(m² y)

Calculation:

$$E_{CO_2} = \sum_i E_{CO_2,del,i} - \sum_i E_{CO_2,exp,i}$$

$$= \sum_i \int P_{del,i}(t) \cdot w_{CO_2,del,i}(t) \cdot dt - \sum_i \int P_{exp,i}(t) \cdot w_{CO_2,exp,i}(t) \cdot dt$$

(13)

where:

$P_{del,i}$ - Delivered energy for energy carrier i into object of assessment (kWh/year)

$w_{CO_2,del,i}$ - CO2eq emission coefficient for delivered energy carrier i

$P_{exp,i}$ - Exported energy for energy carrier i out of object of assessment (kWh/year)

$w_{CO_2,exp,i}$ - CO2eq emission coefficient for exported energy carrier i,

The values for the CO2eq emissions weighthing factors are country specific although generic values can be found in ISO-52000 and are represented also in Appendix B – Primary energy weighting factors and non-renewable CO2 emission coefficients .

Guidelines for measurement and calculation

During the design phase, energy and environmental assessment should be based on calculations. It is highly recommended that a building energy software is used to drive the Integrated Energy Design (IED) process and to extract the energy and environmental metrics, as well of other indicators related with Indoor Environmental Quality. Using detailed simulation software allows to calculate the delivered and exported energy per energy carrier starting from the energy needs for the different building energy uses. The general recommendations for calculations within the **design phase**:

- Use a simulation software allowing to perform dynamic calculations
- Time step resolution should be at least hourly, but 5 minutes or 15 minutes time resolution is preferred.
- Matching factors should be calculated with sub-hourly or hourly resolution.
- In case of multifamily buildings, diversity in the occupants of the different apartments should be considered by using stochastic user behaviour profiles and/or other methods like profiles from measurements
- For the case of energy uses not considered in the assessment, use-time energy profiles may be used to estimate the expected energy exported to the grid. Otherwise, exported energy will include energy consumed in the building for non-EPB uses and the expected available energy to be exchanged with other buildings in the neighbourhood will be incorrectly calculated.

During the **operational phase**, overall energy performance of the building/neighbourhood can be assessed by means of measured energy flows. The basic flows to be measured at building level are the delivered and exported energy, although sub-metering is desirable to have a better knowledge of the flows in the building. The general recommendations for measurement are:

- Measurement values should be done or integrated with a 5-minutes or 15-minutes time resolution.
- To distinguish between energy flows used to cover EPB needs and non-EPB needs (e.g. plug-loads) submetering is needed.
- The renewable energy ratio cannot be determined if the contribution of the renewable energy sources cannot be measured. Then, energy contribution of non-renewable energy systems installed on-site should be measured.

Results of calculations or measurements can be presented with monthly and yearly figures, in addition to hourly representation. For doing that, a created Excel calculation form may be used in the framework of syn.ikia to report the energy needs and the energy consumption for different building uses and the delivered / exported energy per energy carrier, as it shown in Table 5 and Table 6. They are considered Sub KPIs, and are further explained in Appendix C – Energy and environmental performance sub KPIs.

Table 5. Example of template to report thermal energy needs and energy consumption for different building services.

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
On-site energy production														
Energy produced on-site		kWh/m²												
Manual matching factor														
Technical systems														
Heating needs (el+env heat)		kWh/m²												
DHW needs (el+env heat)		kWh/m²												
Cooling needs (el+env heat)		kWh/m²												
System performance factor	Heating													
System performance factor	DHW													
System performance factor	Cooling													
EPB uses.														
Heating	EPB	kWh/m²												
DHW	EPB	kWh/m²												
Cooling	EPB	kWh/m²												
Ventilation	EPB	kWh/m²												
Lighting	EPB	kWh/m²												
Humidification	EPB	kWh/m²												
Dehumidification	EPB	kWh/m²												
Other	EPB	kWh/m²												
non EPB uses.														
Cooking	nEPB	kWh/m²												
Appliances	nEPB	kWh/m²												
EV consumption	nEPB	kWh/m²												
Other	nEPB	kWh/m²												

Table 6. Example of template to report delivered/exported energy per energy carrier.

	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB used electricity													
Exported electricity													
Exported for non EPB uses													
Grid exported													
Grid delivered, (EPB uses)													

6. Economic KPIs

Introduction and general considerations for demonstrating economic performance

To become mainstream developments, SPENs must be demonstrated to be competitive also on economic performance. According to the EPBD, all new buildings are required to be nearly zero-energy (nZEB) by the end of 2020, which makes the nZEB guidelines a good comparison for alternative developments. Economic performance for SPEN is relevant on many levels and for an array of factors, from the individual building owner to the society. Here, we will foreground the economic performance for the building owners and investors, such that the economic priorities in the macro level and from the end user perspective will be in the background for now. Nonetheless, it should not be ignored that SPENs also affect the macroeconomic level as they have the potential to produce a significant amount of energy. Given that it is feasible technically and legally, SPENs could trade energy within the neighbourhood boundaries, and thereby reduce the peaks in load demand. This can result in significant savings in grid investments as well as other positive macroeconomic effects. At the same time, it should also not be disregarded that in the long run, the market demand by end user occupants of SPENs will to a large extent determine the success in the replication and scale-up of SPENs. The community engagement among end user occupants, along with digital platforms, will trigger more efficient use of energy in the neighbourhood. While these two background aspects are important, this chapter will focus on the economic performance of SPENs from the perspective of building owners and investors.

To the potential building owner that is considering whether to invest in a SPEN, the following aspects of economic performance is primarily considered:

- Capital costs compared to alternative investments (can be reflected by extra cost per unit as well as total extra costs per m^2)
- Costs of operating and maintaining the building over a period of time
- Overall performance such as Internal Rate of Return, or comparing measures such as Net Present Value, Economic Value Added or Payback Period)

These aspects are inter-connected. For example, higher capital costs may be warranted given that the operational costs are lower; lower capital costs may be realised by exploiting synergies between different systems. In the same vein, SPENs can take advantage of systems with double or triple functions (e.g. PV panels that function as cladding or shading elements) and cost savings may be achieved by designing systems that encourage energy efficient user behaviour.

This chapter outlines three categories of economic KPIs, as presented in Table 7, as part of the evaluation framework for syn.ikia demonstration sites. The economic KPIs consider the whole process of building, operation and maintenance [48] of the SPENs. Firstly, syn.ikia economic KPIs consider Capital costs. In the development of SPENs, besides the complete building construction cost, the construction of interconnected new buildings and the retrofitting of existing buildings entails various types of costs to purchase or implement assets or items with the aim of improving the energy efficient aspects of the system. Such assets or items can include but are not limited to multi-functional façade elements with integrating photovoltaic and solar panels, geothermal heat pumps, heat flexible thermal storages and batteries. Secondly, in the operation and maintenance of SPENS, respective Operational costs are envisaged, from the maintenance to repairs and replacements. On their own, these costs as well as the uncertainty in divestment present a major barrier for investment in energy efficiency of buildings from the perspective of building owners and investors. However, as economic KPIs, they facilitate the collection of important data to evaluate sources of costs[4] in order to

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[4] Please note that the demo site in Norway will convert costs in NOK to € at the prevailing rate to be agreed upon.

develop the third category of KPIs, termed "Overall performance", which represent important factors in the decision-making in residential real estate markets (new built and renovation) from the perspective of building owners and investors.

Table 7. Economic Performance key performance indicators.

Category	Core KPI	Sub KPI	Unit (B/N/BN)[5]
Economic Performance	Capital costs	Investment costs	BN: €/m^2
		Share of investments covered by grants	BN: €/m^2
	Operational costs	Maintenance-related costs	BN: €/m^2/yr
		Requirement-related costs	BN: €/m^2/yr
		Operation- related costs	BN: €/m^2/yr
		Other costs	BN: €/m^2/yr
	Overall Performance	Net Present Value	BN: €
		Internal Rate of Return	BN:-
		Economic Value Added	BN: €
		Payback Period	yr
		nZEB Cost Comparison	BN: %

Capital costs

Description:

Capital costs in the evaluation framework refers to complete building construction cost and the cost of assets or items that are purchased or implemented with the aim of improving the energy efficient aspects of the system [47]. As stated earlier, such assets or items can include but are not limited to multi-functional façade elements with integrating photovoltaic and solar panels, geothermal heat pumps, heat flexible thermal storages and batteries.

- The capital costs of the building, assets or items involved in a newly constructed system is defined as cumulated payments until the initial operation of the system. The capital costs of the building, assets or items involved in the refurbishment of an existing system is defined as cumulated payments until the initial operation of the system after the refurbishment.
- Should the building, assets or items related to the energy efficient aspects of the system be subsidised or covered by grants in any of the demonstration sites, they should be singled out. Grants are non-repayable funds that a grant maker, such as the government, provides to a recipient for projects to provide public services and stimulate the development of PEDs, for example. To reflect a truly market-based approach in evaluating the cost efficiency of SPENs, such grants and subsidies should be accounted for rather than ignored.

Unit:

Building: CapEx €/m^2

Neighbourhood: CapEx €/m^2

---

[5] B and building, N as neighbourhood and BN as both building and neighbourhood level.

Calculation:

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

(14)

where

$CapEx$ Capital cost per conditioned area (€/m2)

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 (m2)

Operational costs

Description:

Operational costs in the evaluation framework refers to capital-related annual costs (e.g. interests and repairs caused by the investment), requirement-related costs (e.g. power costs), and operation-related costs (e.g. costs of using the installation, i.e. maintenance) and other costs (e.g. insurance). These costs (can) vary for each year [47].

- Capital-related costs encompass depreciation, interests, repairs and replacements of those assets or items purchased or implemented for improving the energy efficiency aspects of the system.
- Requirement-related costs include power costs, auxiliary power costs, fuel costs, and costs for operating resources and in some cases external costs.
- Operation-related costs include the costs of using the installation and costs of servicing and inspection.
- Maintenance costs
- Other costs include costs of insurance.

Unit:

Building: OpEx €/ m^2/yr

Neighbourhood: OpEx €/ m^2/yr

Calculation:

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

(15)

where

$OpEx$ Operational cost per conditioned area per year (€/m2/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 (m2)

Overall performance indicators

Overall performance indicators provide an evaluation of the relative benefits of a particular choice of investment. They summarize both the capital costs and the operational costs, together with possible sources of income in a single indicator. Within this category of KPIs, the Net Present Value is the one that is considered the most reliable [49]. Nevertheless, in some cases, especially when liquidity is a limiting factor, other KPIs, such as the Payback Period, might assume importance.

The Net Present Value (NPV) is computed as the difference between the investment and the discounted cash flows related to an investment.

The Internal Rate of Return (IRR) is strictly connected to the concept of NPV and is defined as the discount rate that makes the current value of savings equal to the initial investment.

The Economic Value Added is a quick evaluation measure that can be used when there are no projections for the future cash flow savings and the investors need to resort in using the data for one year only. It is the difference between the actual savings of a given year and the minimum required savings computed multiplying the investment by the required rate of return of the investment.

The Payback Period is the number of years needed to recover the initial investment through the savings.

In addition, given the objectives of syn.ikia project, we also introduce an additional KPI - the nZEB Cost Comparison. This compares the total annualized cost of the SPEN investment with an alternative investment in line with the nZEB guidelines. The nZEB comparison will be specific to the investment and pilot and should refer to investments that are in line with nZEB guidelines.

Net Present Value

Description:

The Net Present Value (NPV) is computed as the difference between the investment and the discounted cash flows related to an investment. In the context of syn.ikia the cash flows can be represented by the yearly savings obtained by entering the project. These savings can be discounted using a risk-adjusted rate of return to provide an estimate of the value of these savings as if the investors would obtain them at the same moment when the investment occurs. The discount rate needs to be defined using available ones employed in similar projects or recovered from the stock market.

Unit:

- Building: €
- Neighbourhood: €

Calculation:

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

(16)

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

Description:

The Internal Rate of Return is defined as the rate δ that makes the Net Present Value equal to zero. It is a dimensionless measure of the investment value and does not require the estimation of a required rate of return. There is no closed formula for finding its value and numerical methods are normally applied.

Unit:

- Building: €
- Neighbourhood: €

Calculation:

Find δ *such that*

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

(17)

INV	Investment
Sav_t	Savings in year t
T	Total expected life of the building

Economic Value Added

Description:

The Economic Value Added can be computed as the difference between the yearly savings and the minimum required savings.

Unit:

- Building: €
- Neighbourhood: €

Calculation:

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

(18)

EVA_t	Economic Value Added for year *t*.
INV	Investment
Sav_t	Savings in year t
r	Required rate of return

Payback Period

Description:

The payback period is found 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:

Building: yr

Neighbourhood: yr

Calculation:

$$\text{find T such that } \sum_{t \geq T} \text{Sav}_t \geq \text{INV } and \sum_{t < T} \text{Sav}_t < \text{INV}$$

(19)

    INV   Investment

    Sav_t Savings in year t

nZEB Cost Comparison

Description:

The nZEB Cost Comparison is computed as the ratio between the total cost of the respective investment and its nZEB alternative. The calculation period should cover the expected lifetime of the SPEN and the reference, e.g. 60 years.

Unit:

- Building: %
- Neighbourhood: %

Calculation:

$$CC_{nZEB} = 1 - \frac{TotCost(SPEN)}{TotCost(nZEB)} \text{ ,}$$

(20)

$$\text{where} \quad TotCost(X) = \frac{r}{1-(1+r)^{-T}} \cdot CapEx(X) + OpEx(X), \quad X \in \{SPEN, nZEB\}$$

(21)

CC_{nZEB} nZEB Cost Comparison (%)

$TotCost(SPEN)$ Total annual cost for the SPEN investment (€/m²-yr)

$TotCost(nZEB)$ Total annual cost for the nZEB alternative investment (€/m²-yr)

r Annual discount rate (%)

T Calculation period (NB! Should be equal for the SPEN and the reference) (yr)

Guidelines for measurement and calculation

In order to track and reflect the savings from a building level to a neighbourhood scale, the three categories from capital costs, operational costs to overall performance need to be accounted for on a building level and on a neighbourhood level (see Table 7) based on the agreed approach to defining the boundaries per demo site (see section on SPEN limits and boundaries in Chapter 3).

At the building level, it may be relevant to reflect the building level cost using nZEB reference costs when performing the nZEB Cost Comparison, and if that is not available, the building common code costs in the respective demo sites in that country. It will be preferred that the reference cost in either case is estimated per m² and year in line with the guidelines in this document for the calculation of $CapEx$ and $OpEx$. In that way, the comparison between the SPEN and the reference can be performed following the CC calculation presented in this document.

At the neighbourhood level, there is potentially several buildings that require several cost calculations. Additionally, there could be aggregation cost savings achieved when scaling up to the neighbourhood level, e.g. economies of scale, multi-purpose use of assets, and saving related to flexibility optimization. To estimate

the costs on the neighbourhood level, the different costs should be combined through a weighted sum based on m² adjusted by the aggregation cost savings as follows:

$$Cost_N = \sum_{b \in N} \frac{A_b}{A_N} \cdot Cost_b - AggSav, \tag{22}$$

where N represents the neighbourhood, b represents a building type in the neighbourhood, and A_b and A_N represents the area of the building type and the neighbourhood, respectively.

For example, a neighbourhood could consist of two types of buildings, type A and type B. Assume $A_A = 1\,000$ m², while $A_B = 2\,000$ m². Then, $A_N = A_A + A_B = 3\,000$ m². Further, assume $Cost_A = 200$ €/ m²-yr, $Cost_B = 150$ €/ m²-yr, and $AggSav = 20$ €/ m²-yr. The neighbourhood total cost is then estimated as:

$$Cost_N = \frac{A_A}{A_N} Cost_A + \frac{A_B}{A_N} Cost_B - AggSav = \frac{1000}{3000} 200 + \frac{2000}{3000} 150 - 20 \approx 147 \text{ €/m²-yr} \tag{23}$$

In this example, the neighborhood cost is smaller than the costs estimated for both building type A and type B because of two reasons: (1) the cheaper building type B occupies more neighbourhood area than A and (2) the aggregation savings from scaling to the neighbourhood level are sufficiently large. This approach can be used for all economic KPIs in the category 'Capital costs' and 'Operational costs', as well as for the nZEB Cost Comparison.

This chapter has focused on the economic performance of SPENs from the perspective of building owners and investors. Scalability of Plus Energy Buildings (PEBs) and SPENS needs be complemented by an attractive business model that ensures the reliability of the cost effectiveness of the proposed solutions in interaction with the environmental and social performances. Better access to clear information can help sensitise the different actors in the building sector and in the financing sector to increase their confidence in energy-efficient measures inherent in SPENs. Economic KPIs are therefore imperative in the longer-term planning for the scale-up and uptake of SPENs by facilitating the collection of important data to evaluate sources of costs and to assess the progress towards achieving environmentally sustainable and economically viable neighbourhoods.

7. Indoor Environmental Quality KPIs

Scope

People spend approximately 90% of their time in indoor environments [50]. Over the last decades, an abundant number of studies has shown that the indoor environmental quality (IEQ) has a significant impact on human health [51]. IEQ refers to the quality of a building's environment with respect to wellbeing and health of the building occupants and is determined by many factors such as indoor thermal environment, air quality and lighting [52]. Energy efficiency and plus energy buildings and neighbourhoods can bring multiple benefits such as improvements in air quality and health and it is crucial to ensure that the IEQ positively contributes to health, comfort, well-being and productivity of the building occupants. Multiple benefits of energy efficiency and plus energy buildings, will be thoroughly explored and quantified at a later stage of this project (WP5, Task 5.3, D5.3, D5.4). The main determinants of the IEQ are indoor air quality (IAQ), thermal comfort, lighting and visual comfort and acoustics [53].

According to the Annex 68[6], for buildings to achieve a net zero energy use, they will need to be more efficient and optimised. This in turn leads to more insulated buildings and the attentions goes to reducing the space heating and energy consumption by reducing the demand for ventilation. The reduction of ventilation rates can save energy even though it can have negative impacts on the indoor air quality (IAQ). It is consequently critical to ensure a balance between energy efficiency and maintaining appropriate levels of all the components of the IEQ.

This section aims at developing an approach to assess the IEQ of plus energy buildings by focusing on the main factors that determine the indoor environment. This will result in highlighting potential areas for improvement and will further provide useful feedback to designers, construction managers but also and operators, facilities managers, and property agents.

Methodology for the assessment of the indoor environmental quality

In order to create a robust and comprehensive evaluation framework of the indoor environmental quality that can be easily and widely applied, three main aspects of user friendliness, quality and reliability and economic feasibility are taken into account throughout its development. User friendliness refers to any support material (e.g. questionnaire survey, visual representation of the IEQ outputs etc.) that will be available to the end-users (building occupants). Quality and reliability refer to the compliance with standards of the methodology and to the competency of the experts executing the campaign (either on site or on desk through simulations). Economic feasibility is related to the costs of the monitoring equipment, the time and effort required to execute the campaign and analyze the results.

There are several building rating and assessment systems around the world that link IEQ with health, comfort and wellbeing of building occupants. The development of the evaluation framework of the IEQ has been inspired from already developed methodologies, frameworks, indexes and certification schemes such as

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[6] IEA-EBC Annex 68 Indoor Air Quality Design and Control in Low Energy Residential Buildings

Level(s) [7], CBE Survey[8], TAIL[9], DEQI[10], WELL[11] , IEQ-Compass[12] and CBE Survey while it complies with the EN Standard 16798-1 and CEN/TR 16798-2 (2019) [48] [54] [55] [56] [57] [58].

The evaluation framework can be used at several stages of the life cycle of a building. The predicted IEQ characteristics of the plus energy buildings will be explored at the design phase through calculations and simulations while the actual IEQ will be investigated during the operational phase through on-site measurements, checklists, and questionnaire surveys. This will allow to investigate whether the plus energy buildings meet their design objectives but also make a link between design and occupied performance.

Definition of KPIs

The definition of key performance indicators will allow a more systematic assessment of the indoor environment. As also mentioned in the introduction of this chapter, the main determinants of the IEQ which will be referred to as evaluation areas, are indoor air quality, thermal comfort, lighting and visual comfort, and acoustics (Figure 19, Table 8). Each of these evaluation areas is comprised by characterising elements which will be the KPIs of this chapter. For example, Carbon Dioxide (CO_2) concentrations are of the most important contaminants of the indoor air and will be the KPI of the IAQ.

This section will include brief descriptions of the evaluation areas of the IEQ and their KPIs required to determine them. Their main calculation methodologies are also explored, while country specific IEQ requirements are presented.
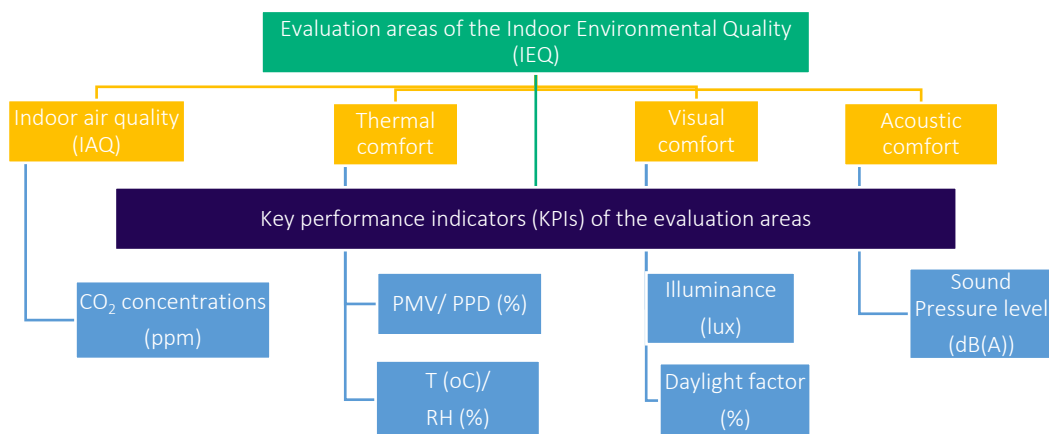
Figure 19. Evaluation areas and KPIs of the IEQ.

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[7] Level(s)-A common EU framework of core sustainability indicators for office and residential buildings, JRC Technical reports

[8] Center for the Built Environment (CBE), Occupant Indoor Environmental Quality Survey, https://cbe.berkeley.edu/research/occupant-survey-and-building-benchmarking/

[9] TAIL index, D2.4 ALDREN Methodology note on addressing health and wellbeing

[10] A methodology for the determination of the indoor environmental quality in residential buildings through the monitoring of fundamental environmental parameters: A proposed Dwelling Environmental Quality Index, Indoor and Built Environment, Laskari et al. 2017

[11] The WELL Building standard

[12] IEQ-Compass-A tool for holistic evaluation of potential indoor environmental quality, Larsen et al., 2020, Building and Environment

Table 8. KPIs of the Indoor Environmental Quality.

Category	Evaluation area	KPI type Core or Sub (secondary/complementary)	KPI	Unit (B/N/BN) 13
Indoor Environmental Quality	Indoor Air Quality	Core KPI	Carbon Dioxide (CO2)	BN: ppm
	Thermal Comfort	Core KPI	Predicted Mean Vote (PMV)	BN: -
		Core KPI	Predicted Percentage Dissatisfied (PPD)	BN: %
		Sub-Core KPI	Temperature (T)	BN: oC
		Sub-Core KPI	Relative Humidity (RH)	BN: %
	Lighting and visual comfort	Core KPI	Illuminance	B: Lux
		Core KPI	Daylight factor	B: %
	Acoustics comfort	Core KPI	Sound Pressure Level	B: dB(A)

The European Standard EN15251:2007, recently revised to the EN16798-1-2019, defines four categories of the indoor environmental quality, related to the level of expectations of the building occupants (Table 9) [59] [60]. Category 'Medium' represents a normal level, a high lever can be selected by people with special needs such as people with disabilities, children, elderly. A lower level may decrease comfort but will not cause health risks [60].

Table 9. Categories of indoor environmental quality (Source: EN ISO 16798-1-2019).

Category	Level of expectations
IEQ$_I$	High
IEQ$_{II}$	Medium
IEQ$_{III}$	Moderate
IEQ$_{IV}$	Low

Indoor Air Quality (IAQ)

Good indoor air quality is the air without harmful concentrations of contaminants with which the great majority of tenants are satisfied [61]. The most well-known contaminants are carbon dioxide, carbon monoxide, particulate matter and volatile organic compounds (VOCs) [62]. Sources of contaminants in residences are emissions from indoor combustion sources, activities such as cooking or smoking, emissions from furnishings, cleaning products, construction material, or even occupants themselves (e.g. through human respiration CO_2 concentrations released) [59]. Apart from the indoor sources, indoor air quality is also affected by the outdoor air pollution from combustion sources, construction and agricultural activity or traffic entering the building through the windows, infiltration or mechanical ventilation systems.

A great number of studies have linked bad indoor air quality with adverse health effects such as asthma, eczema and allergic diseases. Eye, nose, skin and throat irritations, upper respiratory symptoms, fatigue and headaches are of the most frequently appeared building related health symptoms[63]. These symptoms are usually not linked to specific illnesses, disappear when the person leaves the building and are described as

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13 B and building, N as neighbourhood and BN as both building and neighbourhood level.

'Sick Building Syndrome' (SBS) symptoms [64]. These symptoms usually disappear when the affected person leaves the 'mal-functioning' building.

Role of ventilation and carbon dioxide

A critical method of removing indoor air contaminants is via proper ventilation. Ventilation is also essential to ensure thermal comfort and provide pre-cooling of the building's structure during the night in summer months, but also to extract moisture, odours and air pollutants [62]. However, introducing adequate ventilation rates without removing internal sources of air pollutants this can result in partial and limited improvement of the indoor air quality. Overall, the indoor air quality is affected by the outdoor air quality, the levels of ventilation, the installed building materials, the household activities and the occupant's level to control these [58].

Through ventilation, fresh air is supplied in buildings that plays a critical role in removing harmful pollutants from a space. Higher ventilation rates are generally associated to improved health. Ventilation is also used to passively cool a space [65]. Ventilation is further needed for extracting contaminants at source (e.g. extract systems for kitchens and bathrooms), distributing of conditioned air (heating and cooling) or precooling building' structure (e.g. night ventilation). The amount of required ventilation depends on the occupant density, the occupant activities and the amount of pollutants emitted in a space. Natural ventilation is intended to provide adequate outside air to maintain appropriate standards of air quality and provide cooling when needed. It is one of the most fundamental ways of reducing energy use of buildings and is a process of introducing air to the indoor space (supply) or remove contaminated air (extract), driven by temperature (stack effect) and wind (wind effect). Natural ventilation can support a mixed-mode strategy where mechanical ventilation or cooling is coupled with the natural systems. There are also cases where mechanical ventilation is exclusively used to cover ventilation requirements [65].

According to the EN 13779 and based on the categorisation of IEQ presented in the Table 9, the recommended minimum outdoor air rates per person[14] and indoor air quality classifications are given on the table below (Table 10). Based, on EN 13779, the design outdoor air rate may take into account emissions f other sources like building and furnishing materials.

Table 10. Rates of outdoor air per person and indoor air quality classifications.

Indoor air quality standard	Ventilation range (l/s/person)
High	>15
Medium	10-15
Moderate	6-10
Low	<6

Considering that carbon dioxide (CO_2) is emitted through metabolic processes, the increase of indoor CO_2 concentrations above the outdoor values are often used to estimate the sufficiency of ventilation. Carbon dioxide is a good proxy of the indoor air quality as it can provide an indication of the ventilation rate in a space (Table 11). Typically, for a sedentary occupied zone, a concentration of 800-1000 ppm represents a ventilation rate of 10 l/s/p [64].

Description:

CO_2 (in units of ppm) will be the KPI of the IAQ, it will be measured in all of the dwellings, and its concentration ranges will be used to evaluate the indoor air quality according to the four quality categories specified in Table 11. The percentage of time that the CO_2 concentrations fall within these ranges should be calculated. In line

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[14] National legislation requirements are applied where available

with the methodology followed by the TAIL index of the Aldren project, to be able to classify the measurements in the four quality categories, the measurements should not exceed the defined range by more than 5% of the occupied time (assuming continuous measurements). The technical specifications of the monitoring instrument to measure CO_2 concentrations along with the monitoring protocol, is presented in the following chapter.

Table 11. CO_2 concentrations per category assuming a standard CO_2 emission of 20L/h per person (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:

Building: ppm

Neighbourhood: ppm

Calculation:

Based on assumptions related to building occupancy (number of occupants, age, activity level etc.) and operation (e.g. window opening, HVAC operation), CO_2 concentrations may be predicted using the mass balance equation seen below, giving an indication on the overall indoor air quality.

$$C(t) = C_v + (C_o - C_v)exp\left(-\frac{Q_v t}{V}\right) + \left(\frac{G}{Q_v}\right)\left[1 - exp\left(-\frac{Q_v t}{V}\right)\right] x 10^6 \qquad (24)$$

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 CO_2 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.

Thermal Comfort

According to the EN ISO 7730, 'thermal comfort is that condition of mind which expresses satisfaction with the thermal environment'. Extreme temperatures (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 [66] [67].

The thermal environment is defined by environmental parameters, such as temperature (air, radiant), relative humidity and air velocity, and by personal parameters such as clothing, level of activity, gender and age, which affect a person's metabolic rate (Figure 20) [68]. Operative temperature is a combination of air temperature and mean radiant temperature in a single value, and it used to express their joint effect [65]. Operative temperature is often used to determine the impact of the thermal environment to building occupants,

however it is difficult to measure. Recent studies of CBE show that in low-energy buildings where radiant heating is used, air temperature is a good approximation of the operative temperature [69].
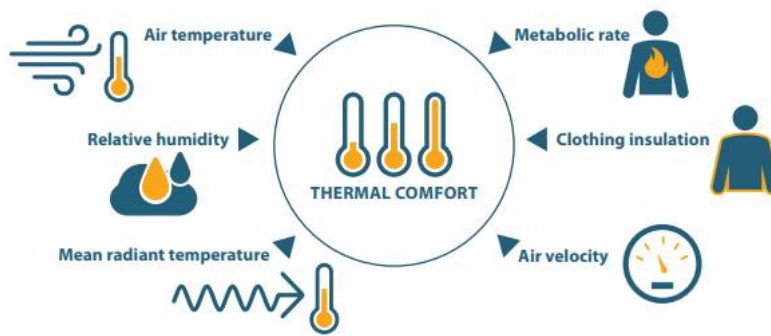
Figure 20. Factors primarily affecting thermal comfort based on EN ISO 7730 [1]

PMV and PPD indexes

Description:

The level of occupant thermal comfort is often expressed in percentage of the number of people who are satisfied or dissatisfied with the thermal conditions. The most commonly used indexes are the **predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD), these will be KPIs of the thermal environment.** The calculation formulas for the PMV and PPD indexes according to ISO 7730 and ASHRAE Standard 55 are developed below.

The first model of thermal comfort was developed by Fanger in 1967 (Fanger's comfort model) and based on the heat-balance equation, it can calculate the PMV and PPD indexes using a 7-point thermal sensation scale: : +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral), -1 (slightly cool), -2 (cool) and -3 (cold) [2].

Recommended criteria for mechanically heated and cooled buildings

For mechanically heated and cooled buildings, different categories of the indoor environment are established for different criteria of PMV and PPD indexes. According to the EN 16798-2019, the recommended PPD ranges are given in Table 12.

Table 12. Default categories for the design of mechanical heated and cooled buildings (Source EN ISO 16798-1-2019).

Category	Predicted Percentage of Dissatisfied (PPD) (%)	Predicted Mean Vote (PMV)
IEQ$_I$	<6	-0.2 < PMV < +0.2
IEQ$_{II}$	<10	-0.5 < PMV < +0.5
IEQ$_{III}$	<15	-0.7 < PMV < +0.7
IEQ$_{IV}$	<25	-1.0 < PMV < +1.0

Unit:

Building: PMV: -, PPD: %

Neighbourhood: PMV: -, PPD: %

Calculations:

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

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

$$\left\{ \begin{aligned} &(M-W) - 3{,}05 \cdot 10^{-3} \cdot \left[5\,733 - 6{,}99 \cdot (M-W) - p_a\right] - 0{,}42 \cdot \left[(M-W) - 58{,}15\right] \\ &-1{,}7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_a) - 0{,}0014 \cdot M \cdot (34 - t_a) \\ &-3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{aligned} \right\} \tag{1}$$

$$t_{cl} = 35{,}7 - 0{,}028 \cdot (M-W) - I_{cl} \cdot \left\{ 3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4\right] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \right\} \tag{2}$$

$$h_c = \begin{cases} 2{,}38 \cdot \left|t_{cl} - t_a\right|^{0{,}25} & \text{for} \quad 2{,}38 \cdot \left|t_{cl} - t_a\right|^{0{,}25} > 12{,}1 \cdot \sqrt{v_{ar}} \\ 12{,}1 \cdot \sqrt{v_{ar}} & \text{for} \quad 2{,}38 \cdot \left|t_{cl} - t_a\right|^{0{,}25} < 12{,}1 \cdot \sqrt{v_{ar}} \end{cases} \tag{3}$$

$$f_{cl} = \begin{cases} 1{,}00 + 1{,}290 I_{cl} & \text{for } I_{cl} \leqslant 0{,}078 \text{ m}^2 \cdot \text{K/W} \\ 1{,}05 + 0{,}645 I_{cl} & \text{for } I_{cl} > 0{,}078 \text{ m}^2 \cdot \text{K/W} \end{cases} \tag{4}$$

Where

M is the metabolic rate (W/m²);

W is the active mechanical power (W/m²);

I_{cl} is the clothing insulation (m²·K/W);

f_{cl} is the clothing surface factor; t_a is the air temperature (ºC);

t_r is the radiant mean temperature (ºC);

v_{ar} is the relative air velocity (m/s);

p_a is the vapor pressure of air (Pa);

h_c is the convective heat transfer coefficient (W/m²·K); and

t_{cl} is the clothing surface temperature (ºC).

The PMV index is used for values that range between -2 and +2, when the six main parameters are within the intervals of:

M 46 W/m² to 232 W/m² (0,8 met to 4 met);

I_{cl} 0 m² · K/W to 0,310 m² · K/W (0 clo to 2 clo);

t_a 10 °C to 30 °C;

$\bar{t}_r$ 10 °C to 40 °C;

v_{ar} 0 m/s to 1 m/s;

p_a 0 Pa to 2 700 Pa.

Once the PMV value is estimated the PPD can be estimated using the following equation

$$PPD = 100 - 95 \cdot \exp(-0{,}033\,53 \cdot PMV^4 - 0{,}217\,9 \cdot PMV^2) \tag{5}$$

Due to complexity, the nature of the monitoring campaign but also aspects related to the economic feasibility, it will not be possible to monitor specific parameters such as mean radiant temperature and air velocity. For these parameters which are required for the calculation of the PMV index, specific assumptions are made following the methodology used for the GrowSmarter project[15]. Unless detailed data is available, mean radiant temperature is approximated to air temperature (t_r approximated to be equal to t_a), while the air velocity is assumed to be constantly equal to 0.1m/s. PMV and PPD indexes can be theoretically estimated during the design stage.

To determine the metabolic rate and clothing insulation specific information is required related to the activity that occupants perform and level or clothing that they wear. During the design stage this information can be assumed depending on the season, while at the operational phase this information can be acquired from the post occupancy evaluation survey.

Acceptable indoor temperatures for buildings without mechanical cooling systems: Adaptive comfort

Whilst the heat balance model described above applies to air-conditioned buildings, for naturally ventilated spaces, the adaptive model is applicable. The adaptive model allows the building occupants to adapt to the thermal environment through behavioural, psychological and physiological means. The adaptive comfort applies for buildings used for human occupancy with sedentary activities (e.g. residences, offices) where people have access to openable windows and can freely adapt their clothing depending on the thermal conditions. In this case the adaptive criteria can be applied for summer and mid-seasons (Figure 21, upper and lower limits for cat. I, II and III) [60].
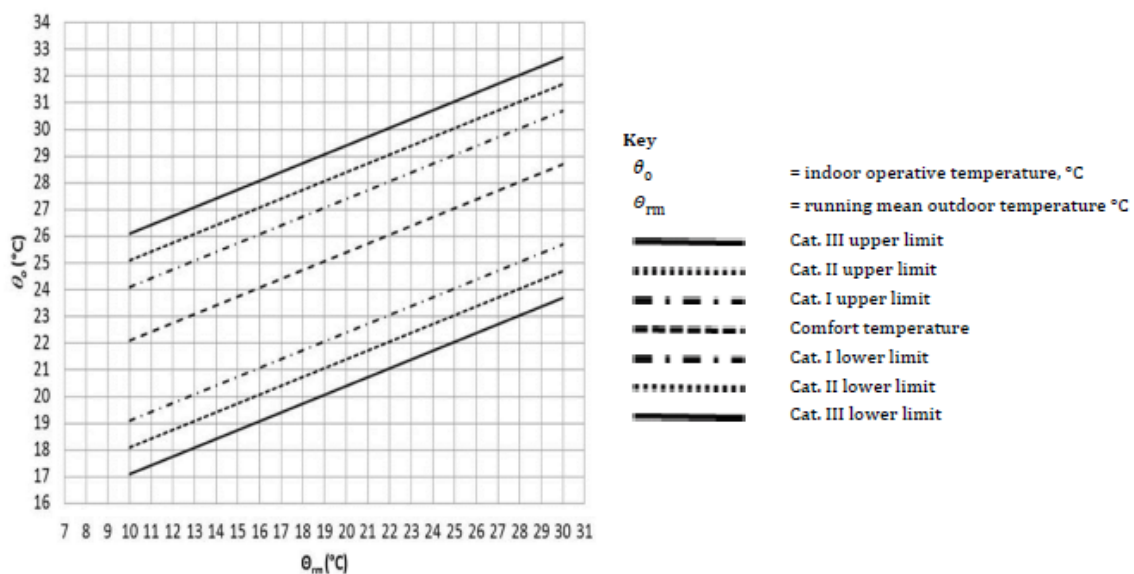
Figure 21. Design values for operative temperature in buildings without mechanical cooling systems (Source: EN 16798-1-2019).

Air temperature

Description:

Air temperature (ºC) and relative humidity (%) will be further KPI of the thermal environment for buildings without mechanical cooling. To evaluate the thermal environment, the percentage of time that temperatures are out of the ranges specified in the categories of EN 167989-1-2019, should be estimated for buildings with

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[15] GrowSmarter Project, https://grow-smarter.eu/home/

and without cooling systems for the heating and cooling seasons (Table 13). Considering the aforementioned findings of the CBE study, it should be highlighted that in this study, operative temperature is assumed equal to the air temperature. The temperatures can exceed the recommended range by 1 °C by not more than 5% and by 2°C by not more than 1% of the annual occupied time, so as to be classified in the different categories, based on an approach similar to Level(s) and the TAIL index of Aldren project. It should be noted that this evaluation concerns the living rooms where the monitoring equipment will be installed and during times that the dwellings are occupied. Information about typical occupancy patterns can be acquired from the questionnaire surveys filled in by the building occupants. This methodology is also proposed in Level(s) and in the TAIL index of the Aldren project.

Unit:

Building: °C

Neighbourhood: °C

Calculation:

Table 13. Operative temperature ranges for summer and winter in buildings with and without mechanical cooling systems classified in the 4 categories (Source: EN 16798-1-2019).

Category	Operative temperature (oC)			
	Buildings with mechanical cooling systems		Buildings without mechanical cooling systems	
	Minimum for heating season, (Winter) ~ 1,0 clo	Maximum for cooling season (Summer) ~ 0.5 clo	Minimum for heating season (Winter) ~ 1,0 clo	Maximum for cooling season (Summer) ~ 0.5 clo
IEQ$_I$	21	25.5	21	upper limit: $\Theta_o = 0{,}33\,\Theta_{rm} + 18{,}8 + 2$ lower limit: $\Theta_o = 0{,}33\,\Theta_{rm} + 18{,}8 - 3$
IEQ$_{II}$	20	26	20	upper limit: $\Theta_o = 0{,}33\,\Theta_{rm} + 18{,}8 + 3$ lower limit: $\Theta_o = 0{,}33\,\Theta_{rm} + 18{,}8 - 4$
IEQ$_{III}$	18	27	18	upper limit: $\Theta_o = 0{,}33\,\Theta_{rm} + 18{,}8 + 4$ lower limit: $\Theta_o = 0{,}33\,\Theta_{rm} + 18{,}8 - 5$
IEQ$_{IV}$	16	28	16	

Where:

Θrm= Outdoor Running mean temperature for the considered day (°C) which can be calculated by:

$\Theta rm = (1-\alpha) \{ \Theta_{ed-1} + \alpha\, \Theta_{ed-2} + \alpha^2\, \Theta_{ed-3} \}$

$\Theta ed - 1$= daily mean outdoor air temperature for previous day

α = constant between 0 and 1 (recommended value is 0,8)

$\Theta ed - i$ = daily mean outdoor air temperature for the i-th previous day

In case that daily running mean outdoor temperatures are not available, the following formula can be used:

$Qm = (Q_{ed-1} + 0.8\, Q_{ed-2} + 0.6\, Q_{ed-3} + 0.5\, Q_{ed-4} + 0.4\, Q_{ed-5} + 0.3\, Q_{ed-6} + 0.2\, Q_{ed-7})/3.8$

The dotted line in the middle of Figure 21 is the optimal operative temperature represented by:

$\Theta c = 0{,}33\Theta_{rm} + 18{,}8$

Where:

Θo = indoor operative temperature, °C

θrm= running mean outdoor temperature, $^{\circ}C$

θc=Optimal operative temperature, $^{\circ}C$

Where the limits apply when $10<\theta_{rm}<30^{\circ}C$

The results can be then visualised in a chart similar to Figure 22.

Quality of indoor environment in % of time in four categories				
Percentage	5	7	68	20
Thermal Environment	IV	III	II	I

Figure 22. Visualisation of the evaluation of the thermal environment in the four categories.

Overheating risk and criteria

Naturally ventilated homes should assess overheating by using the adaptive method. For living rooms, bedrooms and kitchens, the number of hours during which the temperature difference ΔT between the indoor and outdoor environment is greater to or equal to $1^{\circ}C$ during May to September (inclusive) should not be more than 3% of the occupied hours. To ensure comfort during sleeping hours, in bedrooms only, the operative temperature between 10pm and 7am should not exceed $26^{\circ}C$ for more than 1% of the annual hours (1% of the annual hours is 32 hours, therefore if 33 hours or more are above $26^{\circ}C$, then are recorded as a fail) [70][71]. The thermal performance of buildings during summertime is usually measured against a benchmark temperature that should not be exceeded for a certain number of hours during an annual occupied period. When the benchmark temperature is exceeded then the building is 'overheated' and when this occurs for more than a specified amount of time it is then said that the building suffers from 'overheating'[65].

In locations of high humidity, the heat index (HI) can be used as a basis of overheating conditions. Heat index is an index that combines air temperature and relative humidity in a single value that shows how hot the weather will feel. The higher the index, the hotter the weather will feel [72]. The result is also known as the "felt air temperature", "apparent temperature", "real feel" or "feels like". For example, when the temperature is 32°C with 70% relative humidity, the heat index is 41°C. Caution is needed when the heat index is between 26°C and 32°C as fatigue is possible with prolonged exposure and activity. Heat cramps and heat exhaustion are likely to appear when the index is above 32°C.

Lighting and visual comfort

According to the EN12665 visual comfort is defined as "a subjective condition of visual well-being induced by the visual environment". Lighting in buildings should create a pleasant appearance of the space and allow building occupants move safely and conduct their working tasks productively. Excessive brightness or glare from either solar or electric sources can be disruptive therefore appropriate lighting levels can be ensured by natural or/and artificial lighting.

Recent studies have shown a negative impact on human health from inadequate illumination. Specifically the lack of appropriate lighting levels is connected to potential harmful effects such as circadian disruptions leading to lack of sleep, depressive symptoms and reduced alertness and cognitive performance [73]. A good visual environment (e.g. adequate levels of natural and artificial lighting, reduced glare etc.) can add to the well-being and productivity of the building occupants [74]. Daylight exposure through windows has a significant positive effect on sleep quality as well. However, increased use of glazing can increase the heat losses of a building, therefore a correct balance between thermal losses and daylight levels is needed.

Illuminance and daylight factor

Description:

Lighting design criteria are given in terms of maintained illuminance for different building types. Illuminance it the total amount of light delivered on a surface by either natural daylight or electrical fitting. In this project, the **illuminance and the daylight factor** will be measured and simulated to evaluate the visual environment and will be the **KPIs of the lighting and visual comfort**. The recommended lighting design criteria for dwellings are summarized below.

Table 14. Recommended lighting design criteria.

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

Daylight factor is a metric expressing as a percentage the amount of daylight that is available in a room in comparison to the amount of daylight available outside under overcast sky conditions [74]. The daylight factor depends on the size, the transmission properties of the façade, the size and shape of the space and well as the extent to which external structures obscure the view of the sky.

Unit:

Building: Illuminance: Lux, Daylight factor: %

Neighbourhood: N/A

Calculation:

$$DF = \frac{E_I}{E_O} \times 100\% \qquad (25)$$

where:

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

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

Eo 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:

$$Average\ DF = \frac{W}{A} \frac{T\theta}{(1-R^2)} \qquad (26)$$

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

For the purpose of this particular project, daylight factors can be estimated through calculations on a horizontal surface at 0.85m above the floor, following the methodology of the TAIL index of the Aldren project.

Rooms that have daylight factor of 2% or more are considered as daylit, however electric lighting may still be needed for specific visual tasks. Rooms with daylight factor of 5% or more, it's likely that electric lighting will not be used during the day. BS 8206[16] recommends average daylight factors of at least 1.5% in living rooms, 1% in bedrooms and 2% in kitchens even when predominantly daylit appearance is not necessary.

Acoustics comfort

Acoustic comfort includes the capacity to protect building occupants from noise and provide a suitable acoustic environment to fulfil the purposes that the building is designed for [75] (BPIE policy paper). Depending on the levels of noise, it can cause annoyance, hearing damage or interference to speech intelligibility [65]. Building users are affected by both internal and external noise. Road traffic, aircrafts, construction sites can generate increased levels of external noise, while background noise from HVAC systems or even noise from the neighbours can be disruptive. The acoustic environment must be designed to avoid these harmful effects and the criteria used to specify an acceptable acoustic environment are expressed in sound levels decibels (dB), noise rating (NR) or noise criteria (NC) [76].The World Health Organization (WHO) recommends a background noise level lower than 45 dB(A).

Sound pressure level

Description:

To determine the quality levels of acoustic comfort in the living room, the percentage of hours that the level of acoustics exceed the different categories shown in Table 15 shall be estimated. For the classification in each category, the indicated sound pressure level can be exceeded by max 3dB(A) for not more than 5% of the time and by more than 3 dB(A) by no more than 1% of the time. **The sound pressure level (dB(A)) will be the KPI of the acoustic comfort.**

Table 15. Noise levels per category (EN 16798-1: 2019, p.58).

Category	Noise level (from installed equipment)	Design equivalent continuous sound level
IEQ$_I$	≤25 dB(A)	≤30 dB(A)
IEQ$_{II}$	≤30 dB(A)	≤35 dB(A)
IEQ$_{III}$	≤35 dB(A)	≤40 dB(A)

Unit:

Building: dB(A)

Neighbourhood: N/A

Calculation:

Sound Pressure Level Formula:

$$SPL\ (dB) = 10\log_{10}\left(\frac{p^2}{p_o^2}\right) \tag{27}$$

Where:

SLP (dB): sound pressure level in dB

p: sound pressure level in Pa unit area in meters

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[16] BS 8206-2: 1992: Lighting for buildings. Code of practice for daylight

p$_o$: reference sound pressure level in Pa

Assessment methods

In order to ensure the best possible collection of information that will facilitate the evaluation of the IEQ holistically, both at the design and operational phase, the framework will be based on a four pillar approach including modeling and simulations, on-site measurements, checklists, and questionnaire surveys. The following table summarizes the activities related to the different project stages (Table 16).

Table 16. Activities related to the different stages of the project (Source: Level(s)).

Project stage	Related activities
Design phase (based on calculations/simulations)	Design of the building structure and HVAC systems to meet ventilation rate (CO$_2$ 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 CO$_2$ concentrations
	Prediction of daylight factor
	Prediction of sound pressure levels
Operational phase (based on measurements, surveys and checklists)	On-site measurement of T, RH, CO$_2$, illuminance, sound pressure level
	Post-Occupancy evaluation surveys
	Checklists to evaluate parameters that cannot be measured

Design stage modelling and calculation

Building simulations constitute an effective way to analyse the expected performance of buildings[77]. Thermal simulations will be performed to calculate the profile of the thermal environment at the design stage in compliance with the EN 16798-2019, EN 13790 and EN 15603. All assumptions must be clearly defined, while all inputs should be specified ensuring high levels of accuracy, preciseness, and representativeness. Annual thermal simulation using weather files of the respective pilot city will run by taking into account construction details and materials, and theoretical usage and occupancy of the dwellings.

- Overheating can be predicted before occupation through thermal dynamic simulations. It is essential that: simulations predict operative temperature of occupied buildings, sources of heat gains (such as electrical appliances) and solar radiation through windows are realistically taken into account and
- for free-running buildings simulations include realistically the use of window opening [70].

The design criteria for the thermal environment of heated and/or mechanically cooled buildings should be based on the indices of PMV and PPD described in the previous sub-section. For these indices, typical levels of activity and thermal insulation for clothing should be assumed. The operative temperature will be established based on the selected criteria. The upper values of comfort range during the summer (cooling season) shall be used for dimensioning the cooling systems and the lower values of the comfort range shall be used for dimensioning the heating system [60]. In case that cooling systems are not installed, calculations should demonstrate that the mechanical and/or natural ventilation strategies prevent overheating according the IEQ established limits.

CO$_2$ concentrations for the evaluation of the IAQ and daylight factor for the evaluation of the lighting comfort, can be simulated by using building dynamic software such as TRNSYS, Energy Plus or ESP-r following criteria specified in the previous chapter of KPIs.

Operational phase on-site measurements

Monitoring objectives

The main objective of the on-site measurements of syn.ikia is to characterise the IEQ of the plus energy buildings. Aiming to examine how the buildings perform in real life, spot illuminance levels but also accurate monitoring of three of the most important parameters of the IEQ, those of air temperature, relative humidity (RH) and carbon dioxide (CO_2) will take place in selected apartments of each of the pilot projects. Air temperature is the main indicator of thermal comfort and key determinant for the use of heating and cooling. Relative humidity is of great importance as it is associated to health effects to building occupants due to condensation and mould at long-term exposures. CO_2 concentrations in residential buildings, where the occupants are the main source of pollution, are considered as a major indicator of the ventilation and air quality [56]. Monitoring will last for a year aiming to investigate seasonal patterns.

Selection of case studies

The criteria on selecting the locations of the samplers are based on aspects related to the representativeness of the indoor environment, technical (and accessibility), economic but also human-related aspects, aiming to avoid interference with building occupants.

To be able to get a representative whilst realistic sample per demo case, 10 to 15 apartments per pilot will be monitored. In order to have a good representation of orientations, at least one apartment per orientation and floor should be chosen to investigate the degree to which solar penetration and hight from the ground affects the overall IEQ. For comparability purposes the apartments selected should be of the same floor area (and volume), occupied by the same number and similar age group of people and have similar physical condition and occupancy patterns, if possible.

Stakeholder engagement

All stakeholders involved in the on-site measurements such as tenants, owners and building managers should be well informed about the installation of the equipment and execution of the monitoring campaign to ensure their support. Building occupants are the main stakeholders and in order for them to engage and agree with the monitoring campaign it is recommended to organise raise awareness communication campaigns (e.g. workshops including information sheets and consent forms) to ensure their consent. It is also important that all monitoring equipment are installed in such way that are not disturbing the building occupants. Amongst other, data privacy should be also ensured and communicated to the building occupants. Risk assessment and health and safety considerations (e.g. during the installation of the equipment) should be taken into account.

Sampling site description

All four sampling sites should be briefly described. This description should include information ranging from a larger to a smaller scale covering description of the climate, the microclimate of the neighbourhood, the construction characteristics of the building, orientation and size of the apartment as well as theoretical occupancy patterns which can be confirmed through the surveys.

Monitoring period, data collection

In order to examine the seasonal variation of the parameters of the indoor environment, measurement will last for at least a year in each of the pilots. T, RH, CO_2 should be measured at a short enough sampling interval to ensure important fluctuations will not be missed, but at the same time not too short that will require a very large computational and storage capacity (e.g. 15min for T and RH based on ASRHAE's 55 recommendations and 5min EN12599 for CO2 concentrations) [78] [56]. It is recommended that for a testing period of approximately a month the minimum sampling interval is tested to identify the optimum frequency so as not to lose important information and once this is done to then modify it to the ideal logging interval.

Measurements should take place in representative zones and orientations of the building. The representative space of the houses has been agreed to be the living room, although measurements could be extended in other rooms such as the bedrooms for some monitoring campaigns. Following the EN 16789-1-2019 samplers should be ideally installed in the center of the room, at a breathing level height (e.g. living room people are assumed to be seated therefore, ideal height at 1.10m), not closer than 1m from the wall nor next to an air supply/extract point or direct exposure to the sun. At the same time as previously mentioned it should be ensured that the monitoring equipment are not disturbing the building occupants, therefore an appropriate balance between the ideal measurement location and the least possible disturbance should be considered.

Type of samplers

The minimum requirements of detection range, accuracy and resolution for the temperature, relative humidity, CO_2 , and illuminance samplers are presented in Table 17. It is further recommended that all monitoring devices of the same pilot should be calibrated and tested before their installation for accuracy and comparability purposes.

Table 17. Minimum required technical specifications of sensors.

	Detection range	Accuracy	Resolution
Temperature (ºC)	0 to 50°C	±0.4°C	0.1°C
Relative Humidity (%)	0-100% RH	±4% RH	0.1%
Carbon Dioxide (ppm)	0-5000ppm	±50ppm	3%
Illuminance		±3lux	1Lux
Sound Pressure Level		± 1dB(A)	

Neighbourhood level measurements

Weather stations will be installed in each of the pilots. It is recommended that they are installed at a representative point (10m above the ground - ideally on the roof of a representative building of the neighbourhood without surrounding obstructions e.g. high trees or buildings blocking wind) of each of the neighbourhoods.

Operational phase surveys

A great number of scientific studies examine how building users perceive the indoor environment and which are the conditions that they find as comfortable. Several physical and chemical parameters of the indoor environment can influence the comfort of building occupants. The acceptable ranges of these parameters are addressed in standards however even when these are met, building occupants are not necessarily satisfied due to personal preferences and characteristics or building-related factors [79]. Therefore, building occupants are an important source of information about the IEQ and its effect on comfort and well-being. Surveys can be used to evaluate the performance of individual buildings but also to systematically compare the performance of groups of buildings. Surveys can also inform the design community on the effectiveness of specific strategies and technologies but also provide useful information to facilities managers that are involved in operating and improving their building portfolio [80].

The survey that is developed for syn.ikia is based on standardised questionnaires (CBE, ASHRAE) and is aiming at identifying the perception, level of satisfaction and acceptance of building occupants of plus energy houses in relation to IEQ. The survey can be found in the Appendix G – Post occupancy Indoor Environmental Quality survey.

Operational phase checklists and visual inspection

Considering that great amount of information is not captured during the on-site measurements and post occupancy evaluation surveys, it is important to include a checklist for assessing additional risks of the indoor environment. This will ensure a reliable, of good quality and holistic evaluation framework of the IEQ [63]. The checklist can be found in Appendix G – Post occupancy Indoor Environmental Quality survey and checklist.

8. Social performance

Introduction

The social dimension of sustainability is a contested term with inconsistent approaches for measurement [81]. Therefore, a monitoring and evaluation (M&E) framework requires a bespoke indicator development process and an internal definition of what is meant by social performance in the context of SPENs. Based on the principles of SPENs outlined in chapter 3, the definition of Polese and Stren is directly applicable to the syn.ikia context [82]:

> *"Development (and/or growth) that is compatible with harmonious evolution of civil society, fostering an environment conducive to the compatible cohabitation of culturally and socially diverse groups while at the same time encouraging social integration, with improvements in the quality of life for all segments of the population"*

This definition is broken down into three broad areas of social performance:

1. **Equity**: assessment of the fair, just, legitimate functioning of the community.
2. **Community**: assessment of the ability of the community to maintain itself and thrive.
3. **People**: assessment of human experiences, behaviour, and outcomes.

There are other considerations unique to the M&E of social performance. First, social KPIs can focus either on the individual or emergent properties of people, the properties of the protocols among people, or the properties of the conditions where people are present – i.e. the built environment, which is why occupant surveying is as integral part of M&E as measurements. Second, the outputs of social performance measurements are not always normative, and even when they are, they can be contested, which is why target values must almost always be uniquely set [81], [83]. Third, the subjective experience of performance is in many cases as important to measure as the performance itself, which is especially true for social performance, which is why certain indicators couple objective and subjective methods of evaluation simultaneously.

The remainder of this chapter outlines each social performance indicator (with an overview in Table 18), followed by a step-by-step guideline for general M&E with practical recommendations. The full methodology of indicator development can be tracked through Appendix D – Social performance KPIs methodology and metadata.

Definition of KPIs

Overview

Table 18. Overview of social performance indicators.

Category	Sub category	KPI type **Core or Sub** (secondary/complementary)	KPI	Unit (B/N/BN)[17]
Social performance	Equity	Sub	Access to amenities	N: -
		Core	Access to services	N: -

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[17] B as building, N as neighbourhood and BN as both building and neighbourhood level.

		Core	Affordability of energy	BN: % of pop
		Core	Affordability of housing	BN: % of pop
		Core	Democratic legitimacy	BN: % of pop
		Core	Living conditions	BN: % of pop
		Sub	Sustainable mobility	BN: % of passenger kms, qty of enablers
		Sub	Accessible or universal design	B: 10-pt-scale, BN: % of barrier-free units
	Community	Sub	Demographic composition	BN: pop, % of pop, pop/ha
		Sub	Diverse community	BN: pop, % of pop
		Core	Social cohesion	BN: 6-pt-scale, qty of enablers
	People	Core	Personal safety	BN: 6-pt-scale, qty of enablers
		Core	Energy consciousness	BN: 5-pt-scale
		Sub	Healthy community	BN: % of population

Access to amenities

Description:

Access to amenities is the first of the two spatial justice indicators representing "the fair and equitable distribution in space of socially valued resources and opportunities to use them" [84]. Location and accessibility of key resources in space were represented in 6 of the 12 examined references have been emphasised as crucial social determinants of health [85] and as a measure of neighbourhood attractiveness [42], especially when they are in reasonable walking and/or cycling distance [86].

Amenities refer to a range of functions beyond what is considered essential for a good quality of life. They describe added values and unique selling points of a certain neighbourhood over others. As such, what constitutes an amenity can be defined, indirectly, as every non-residential function a neighbourhood offers that is not a service. (for a specification of services, please refer to the sister indicator, "access to services")

Assessment:

Access to amenities measures the distance of households to a set of locally relevant amenities. The first step of the assessment is the selection of amenities to be assessed. It is recommended that during data collection, an amenity pool is created in consultation with community members, and that a channel is provided for members to update this pool. Then, sub indicators are specified by classifying amenities according to a consistent rationale. In practice, this is done by tagging, as certain amenities might fit into multiple categories.[18] A reference labelling system with amenity metadata with possible specifications and tags are provided in Table 19, which also serves as a convention for specifying amenities in syn.ikia SPENs. Nonetheless, a locally relevant list of amenities is recommended to be defined case by case.

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[18] For digital applications providing monitoring interfaces, the affordance to produce custom sub indicators by assigning custom tags to the amenity pool is recommended.

Table 19. Amenity reference table[19]

Amenity label	Specification	Tags
Sports facility	Playing fields/pitches, outdoor-indoor gyms, pools, jogging tracks, extreme sports parks, etc.	leisure, health, green
Waterfront	Creeks, publicly accessible riverbanks, beaches, lakes, ponds for recreational purposes.	leisure, green
Spectator entertainment	Cinemas, stadiums, theatres, circus, concert halls, etc.	leisure, culture
Thematic parks	Zoos, amusement parks, museums, galleries, etc.	leisure, culture
Hospitality	Cafés, restaurants, bars, hotels, hostels, etc.	leisure
Library	Libraries and archives	culture
Nature	Any open area with some form of conservation measure, and restriction of human activities, such as wildlife parks, forests.	green
Agriculture	Sites of active agricultural production, such as wheat fields, vegetable plantations, farms, etc.	health

Once the tagging process is completed, the amenity pool in and around the neighbourhood must be mapped, and an amenity database stored with the following minimal data structure:

- Instance ID, data type: string;
- Amenity label, data type: string;
- Location, stored as x-y coordinates, data type: (float, float).

The instance label is the unique identifier of the specific amenity, while the amenity label is to be matched with a label from Table 19. Optionally, additional attributes, such as instance description may be added. The area for mapping is enlarged to the neighbourhood by the area accessible from the boundaries (to specify this, see *characteristic distance* below).

For further steps it is assumed that a similar database of households exists with a minimal data structure of:

- Household ID, data type: string;
- Population, data type: integer;
- Location, stored as x-y coordinates, data type: (float, float).

Then, for each household, two reasonably accessible areas are computed and added to the database:

- **access_close** is defined as a 500 m radius circle from the household location, or centre of mass, if the household is stored as a polygon. Alternatively, if the database is linked to a mature GIS, including traffic networks, and average traffic information, access_close is defined as a polygon, in which all points can be reached within 5 minutes of walk (5 km/h), 90% of the time.

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[19] Please note that table should only be taken as a reference so that the auditor/community is free to further disaggregate amenities to highly granular units when necessary. This may be needed when the objectives of the community can only be measured with tags that connect conventionally different amenities. For instance, all sports facilities may be specified as a single amenity in most cases, but a community may wish to generate a sub indicator for all free, publicly accessible amenities. In this case, a golf pitch would be excluded, while an outdoor gym and a public library may be included under the tag.

- **access_far** is defined either as a 1km radius circle, or a 10-minute walk polygon, respectively. The latter metric is the designated characteristic distance of the assessment. The auditor may choose to suggest other distances and thus other accessible areas, such as areas accessible by bike in "n" minutes. Each access area is given a weight equal to household Population.

The assessment concludes with calculating the indicator outputs based on the amenities and the accessible areas using formulae N (28) and N (29).

Units:

Two outputs are calculated from this data: **density** (AA_D), and **accessibility** (AA_A). The first favourably weights more amenities of the same type, while the second measures whether there is any amenity of the type within reach.

Building: not applicable

Neighbourhood: dimensionless (AA_D), % of people (AA_A).

Calculation:

To calculate the **density score**, each instance of amenity is given a reach score based on the weighted sum of access areas it falls into (chosen by the auditor to fit local pedestrian culture). The reach scores for the instances are then summed to get an individual amenity-density score. This amenity score is normalized to a 100point scale, where 100 points equals to the total number of access areas (also the total number of housing units). Sub indicator and total indicator scores are generated by averaging all normalised amenity-density scores from the filtered, and unfiltered amenity pool.

$$AA_D = \left(\frac{1}{N}\right) \cdot \sum_{z=1}^{N} min \begin{cases} \frac{\sum_{i=1}^{n} amr_i}{N_{area}} \cdot 100 \\ 100 \end{cases}$$

(28)

Where:

AA_D: density score for amenities

N: number of amenity types

n: number of amenities within type

amr: the amenity reach score, meaning the number of accessible areas (e.g. access_far zones) containing the amenity

N_{area}: total number of access areas in neighbourhood (total number of housing units)

The **accessibility score** on the other hand, is the proportion of people within distance of an amenity. To calculate the accessibility score, each access area is tested whether it contains an amenity instance. The weighted sum (by population) of amenity-equipped access areas divided by the community population yields the accessibility score for an individual amenity. Sub indicator and indicator scores are aggregated the same way as density scores – by averaging.

$$Am_A = \left(\frac{1}{N}\right) \cdot \sum_{z=1}^{N} \frac{\sum_{i=1}^{n} P_{ser,i}}{P_{tot}}$$

(29)

Where:

Am_A: accessibility score for amenities

N: number of amenity types

n: number of amenities within type

$P_{ser,i}$: serviced population, the population in access_far zones containing at least one instance of amenity in type

P_{tot}: total neighbourhood population

Interpretation:

Table 20. General interpretation of indicator outputs.

Output name	KPI	Interpretation
Output_01	Density score	An indication of the richness of amenities in the neighbourhood.
Output_02	Accessibility score	An indication of the equitable access to amenities in the neighbourhood.

Once the underlying data is set, the interpretation of this indicator consists of filtering for appropriate amenities, setting the characteristic distance for the access zone, and processing density and accessibility scores. When choosing access zones, it is important to pick one for the amenity type: for amenities more frequently accessed, the closer zone is more appropriate and vice versa.

Higher density indicates more choices, alternatives for a given amenity type in the neighbourhood, while lower scores indicate fewer amenity alternatives. A maximum score would indicate that each individual household could choose a different amenity. There is no normative target to hit with this output, the community may choose to invest in higher density of amenities and set a target autonomously, or the auditor may benchmark relevant syn.ikia sites and other model neighbourhoods for comparison.

Higher accessibility indicates that the population have more equitable access to valued amenities in the neighbourhood compared to others, while lower scores indicate more people would have to spend a disproportionate amount of time or a different mode of transport to reach certain amenities. A maximum score indicates that everyone in the neighbourhood can reach at least one instance of the amenity in reasonable time, which is the normative target to strive for, for each amenity type that is important for the community.

The former output is a better representation of attractiveness, while the latter is a better representation of justice. Optionally, the auditor may choose to modify the accessibility algorithm, to count only access areas with at least two, three or "n" instances of the amenity.

Access to services

Description:

Access to services is the second of the two spatial justice indicators, representing "the fair and equitable distribution in space of socially valued resources and opportunities to use them" [84]. Location and accessibility of key resources in space were emphasised as crucial social determinants of health [85], and as a measure of neighbourhood attractiveness [42], especially when they are in reasonable walking and/or cycling distance [86].

Services refer to essential local functionalities a neighbourhood must provide to sustain to be compact and well-integrated. In the context of this indicator, services are considered as "services of general interest" (SGI)[20]. It refers to assets that are required by most people, providing the means to lead dignified human lives, and ensure fundamental citizens' rights. For example, SGIs include utilities, waste, sewage, public transport, education, healthcare, social services, communication, banking, postal services, and green spaces. However, the full scope of SGIs is split between this indicator and living conditions, where the accessibility indicator

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[20] as discussed in EC COM (2011) 900

refs to urban services with a reach of multiple households, and the living conditions is an indicator hosting SGIs distributed for households directly. Due to this split, the access to services indicator is calculated almost identically to the access to amenities indicator.

Assessment:

Access to services measures the distance of households to a set of locally relevant basic services. Like its sister indicator (access to amenities), it considers a set of points of interest, and assesses the population it reaches. However, unlike the list of amenities, the list of services, and its corresponding measures of appropriate distance (characteristic distance), is predefined in the services reference table (Table 21).

Characteristic distance can be substituted by a time-based metric, which converts 500-1000 m distances into 5-10-minute walking distances (1-minute / 100 m) and larger distances into 15-minute bike or public transport distances. This step becomes necessary if the underlying database contains traffic network and traffic load data. Sub indicators can be specified by classifying certain services according to consistent rationale. In practice, this is done by tagging, as certain amenities might fit into multiple categories.[21] The services reference table (Table 21) lists some predefined tags.

Table 21. Services reference table

Services	Characteristic distances (m)	Tags (optional)
Primary School	1300	children
Playground	500	children
Kindergarten	1000	children
Supermarket, grocery store	1300	errands
General Practitioner	700	children, health
Bank, ATM	700	errands
Public parks/gardens (also serve as open space)	1000	children, health, gathering
Other public, open space	500	gathering
Local public transport node (bus, tram, underground, etc.)	300	errands, mobility
Transfer station (intercity bus, train, intermodal stations, etc.)	1000	mobility
Community centre	1000	gathering
Post office	500	errands
Commercial centre (mall, high street, etc.)	2000	errands

Once the tagging process is completed, services in and around the neighbourhood must be mapped, and a service database stored with the following minimal data structure:

- Instance label, data type: string;
- Service label, data type: string;

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[21] For digital applications providing monitoring interfaces, the functionality to produce custom sub indicators by assigning custom tags to the amenity pool is recommended

- Location, stored as x-y coordinates, data type: (float, float).

The instance label is the unique identifier of the specific service, while the service label is a lookup attribute to link the SPEN service database to the services metadata. Optionally, additional attributes, such as instance description may be added. The area for mapping is enlarged from to the neighbourhood by the characteristic distance of each service type. For further steps it is assumed that a similar database of households exists with a minimal data structure of:

- Household ID, dtype: str;
- Population, dtype: int;
- Location, stored as LONG-LAT tuples, dtype: (float, float).

The assessment is concluded by calculating the indicator output using formula N (30).

Units:

The indicator is measured through a single **accessibility** (AS_A) output.

Building: not applicable

Neighbourhood: % of population (AS_A)

Calculation:

To measure accessibility, the proportion of population within characteristic distance of the services is calculated. Each household is tested on the distance to the instance of the service. The weighted sum (by population) of households properly served is then divided by the total population to return individual service scores. Sub indicator, and total indicator scores are generated by averaging all service scores from any filtered, and unfiltered service pool.

$$AS_A = \left(\frac{1}{N}\right) \cdot \sum_{z=1}^{N} \frac{\sum_{i=1}^{n} P_{ser,i}}{P_{tot}} \tag{30}$$

Where:

AS_A: accessibility score for services

N: number of service types

n: number of services within type

$P_{ser,i}$: serviced population, the population in access_far zones containing at least one instance of service in type

P_{tot}: total neighbourhood population

Interpretation:

Once the underlying data is set, the interpretation consists of filtering for appropriate tags while calculating various service type accessibilities. The accessibility score signals equitable access to services, where the normative target is 100 %. Lower values indicate that more people would have to spend a disproportionate amount of time, or a different mode of transport to access certain services.

Affordability of energy

Description:

In the 7th UN Sustainable Development Goal (SDG), universal access to clean, sustainable, reliable, and affordable energy is stressed [87]. As the EU-wide sustainable transition of energy systems will affect citizens in different social/geographic contexts differently [88], it is crucial to monitor if and to whom the SDG is reached. Both can be monitored by operationalising the concept of energy poverty: the inability of households

to secure adequate, sustainable, affordable, and reliable energy [89]. At European level, standardised metrics developed by the European Energy Poverty Observatory (EPOV) provide a comparable monitoring framework for national scales, that can be adapted to the SPEN context [89].

Assessment:

To assess affordability of energy two primary EPOV metrics are used that are relevant on building/neighbourhood scales: assessment of energy costs in household expenditure versus income; and assessment of people reporting arrears on utility bills (late payments).[22] Data is collected in annual household surveys of a statistically representative subset of households on both building and neighbourhood scales, comprising of two questions with a Yes/No answer:

1. **Have you spent a higher share of your equivalised* disposable** income on energy in the last year than the threshold energy expenditure***?**
2. **Has your household been in arrears for the last year (being unable to pay utility bills due to financial difficulties)?**

Adherence for precise questioning is recommended for this indicator to avoid collecting sensitive information. The auditor or the digital interface must streamline this process, and clarify definitions for the phrases in asterisks as follows:

*equivalised meaning distributed to household members (i.e. divide income by number of people living in the household). This step must be omitted when using proxy data.

**disposable meaning after taxes and deductions.

****threshold expenditure* must be given by the auditor/UI.

To provide threshold expenditures, prior the survey, energy expenditure and equivalised disposable income for the country must be retrieved from the EUR_HE045 and EUR_HH099 microdata sets [89]. If microdata is not feasibly obtainable, the national median share of electricity, gas and other fuels in consumption expenditure are an acceptable proxy. This is published under hbs_str_t211 dataset under CP045 feature code[23]. A threshold expenditure is generated from this data (see equations N (31) and N (32)).

The assessment is concluded by calculating the indicator outputs with equations N (33) and N (34).

Units:

The indicator is assessed by two metrics: **expenditure** (AE_E) and **arrears** (AE_A). Both are reported as share of population falling below a benchmark.

Building: % of population (AE_E), % of population (AE_A)

Neighbourhood: % of population (AE_E), % of population (AE_A)

Calculation:

For both metrics, the calculation can be separated into the formulation of thresholds prior to the surveys and the share of "True" responses resulting from the surveys. In case of arrears, the threshold value is always $T_A = 1$ (occurred at least once in the last year). For expenditure, it is (optimally) the national median of the share of electricity, gas and other fuel cost in the household disposable income.

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[22] This is done so to eliminate false positives (which can occur when assessing only expenditures) and false negatives (which can occur when assessing only arrears).

[23] Dataset link: https://ec.europa.eu/eurostat/web/products-datasets/product?code=HBS_STR_T211

$$T_E = \text{med}_{i=1}^{n} \left\{ \frac{HE045_i}{HH099_i} \right\}$$

<div align="right">(31)</div>

Where:

T_E: threshold value for share of expenditure for given country

HE045_i: Household expenditure for electricity, gas, and other fuels for household "i" in given country, encoded as EUR_HE045 in the HBS microdata.

HH099_i: Net income (total income from all sources including nonmonetary components minus income taxes) for household "i" in given country, encoded as EUR_HH099 in the HBS microdata.

When the proxy data is used, it is taken directly from the source, and converted to percentage points:

$$T'_E = CP045/10$$

<div align="right">(32)</div>

Where:

T'_E: proxy threshold value for share of expenditure for given country

CP045: share of individual expenditure for electricity, gas and other fuels in given country in per mile.

Finally, Boolean responses are counted and divided by number of respondents to retrieve the final indicator:

$$AE_E = \frac{P_{True,E}}{P_{tot}} \cdot 100$$

<div align="right">(33)</div>

$$AE_A = \frac{P_{True,A}}{P_{tot}} \cdot 100$$

<div align="right">(34)</div>

Where:

Ae_E: affordability of energy as indicated by composition of household expenditure

Ae_A: affordability of energy as indicated by arrears in utility bills

P_{True,i}: number of respondents responding with "Yes" for question i.

P_{tot}: total number of respondents

Affordability of housing

Description:

The right to adequate housing has been enshrined as a human right into international law since 1948 [90]. More recently, SDG 11 targets "adequate, safe, and affordable" housing for all [85]. Both in European statistics, and in reports of housing observatories operating at European scale, the "affordability" component of this goal is usually represented as the presence/absence of cost overburden in access to housing [91], [92]. This is both relatable from a household perspective and is a relevant target to minimize if aggregated, making this indicator applicable to both building and neighbourhood scales.

Assessment:

In both national and city-level accounts, affordability is expressed by relating housing costs to income [85], [91], [93], [94]. The condition of housing poverty is used to describe households with a cost overburden, measured by comparing the share of income spent on housing (including rent, utilities) with a benchmark. The specific benchmark varies for different countries, but in Eurostat, 40% is used, which will be retained for this indicator [91], [93]. Housing market prices, and residential real estate development trends are also considered relevant contextual factors influencing housing affordability [85]. However, these are only actionable at city scale and have been omitted from this assessment. Finally, affordability must be assessed for neighbourhood

residents and the larger population separately, otherwise a risk of gentrification would not be adequately measured.

More specifically, in addition to assessing the cost overburden of local residents (internal affordability of housing), the indicator also measures the proportion of a target population that can afford to live in the SPEN without overburden (external affordability of housing). This target population is up to the policy of the community, it can include the city, a culturally/economically well-defined region, or the country. The default target population is the population of the country.

To proceed, the following input data must be obtained. The benchmark housing poverty expenditure rate is always $B_{housing} = 40\%$. The income of the target population is to be retrieved as the bin endpoints for disposable, equivalised income deciles, which is retrieved from Eurostat $D_{i=1}^{10}$= {dataset id: ilc_di01, indic_il: TC, quantile: D$_i$}[24]. The housing costs include: rent, maintenance, security, utilities, and dwelling related services, as specified in the Classification of Individual Consumption by Purpose [95]. A statistically representative subset of households is to be surveyed annually if their own equivalised disposable income is below 40 % of these costs, leading to a single question with Yes/No answers:

> **1.A Have you spent a higher share of your equivalized* disposable** income on housing in the last year than 40%?**
>
> **2.A How much have you spent on rent, mortgage interest, maintenance, utilities, security, and dwelling related services in the last year, a) altogether, b) altogether plus payment of mortgage principal?**
>
> **3.A Would you consider that due to housing costs, your household has: a) no financial burden, b) financial burden, c) heavy financial burden?**

Adherence for precise questioning is recommended for this indicator to avoid collecting sensitive information. To be able to answer the first question, the respondent must recollect gross household income for the last year and the number of people living in the household for each month (unless gross income has not changed at all) of the last year. They will then have to use this information to calculate their own equivalised disposable income using the following specifications:

> *equivalised meaning distributed to household members. This means dividing income by weighted number of people living in the household, with a weight of 1.0 to the first person aged 14 or more, a weight of 0.5 to other persons aged 14 or more and a weight of 0.3 to persons aged 0-13. This step must be omitted when using proxy data.
>
> **disposable meaning a net household income must be calculated from the gross, meaning direct taxation and social transfers must be deduced from it.

It is advised that the auditor or the digital tool collecting the data supports this process by providing an interface/additional survey questions for calculating income and cost and explaining the answering process step-by-step:

> **1.B What was the total gross income of the household in the last 12 months?**
>
> **2.B How much of the gross income is deduced as taxes and social transfers?**
>
> **3.B How many and how old people (including children) live in the household?**

However, in neither case must this information be stored after question 1.A is fully answered. The only data that is not deleted immediately after answering the question, is a True/False answer. For question 2.A, the cost (as an integer value) must be deleted from the system after the assessment is finished and all outputs are produced. The assessment concludes by plugging the data into equations N (35), N (36) and N (37). When

---

[24] https://data.europa.eu/euodp/data/dataset/V6gke8FztkDfOQKBLoZwA

plugging 2.A response in equations and when considering housing costs in question 1.A, both 2.A.a and 2.a.b must be calculated/considered separately. Indicator outputs for monitoring are to be based on 2.A.b, while 2.A.a-based outputs must be retained as back-end data for Eurostat comparability.

Unit:

Two outputs are calculated: **internal affordability** of housing (AH_{in}) to track residents, subjective affordability () and **external affordability** of housing (AH_{ex}) to monitor danger of gentrification.

Building: % of population (AH_{in}), % of population (AH_s), integer in range (1;10) (AH_{ex}).

Neighbourhood: % of population (AH_{in}), % of population (AH_s), integer in range (1;10) (AH_{ex}).

Calculation:

Internal affordability of housing is calculated by counting the share "Yes" responses, dividing them by the number of respondents:

$$AH_{in} = \frac{P_{True}}{P_{tot}} \cdot 100 \qquad (35)$$

Where:

AH_{in}: internal affordability of housing

P_{True}: number of respondents responding with "Yes" for question 1.A.

P_{tot}: total number of respondents

Subjective affordability is calculated by listing the percentages of population who responded either answer for equation 3.A. All three percentage values together are the complete output for this indicator.

$$AH_s = \frac{P_{True,i}}{P_{tot}} \cdot 100 \qquad (36)$$

Where:

AH_s: subjective affordability of housing

$P_{True,i}$: number of respondents responding with "Yes" for category "i" question 3.A.

P_{tot}: total number of respondents

External affordability of housing is calculated by mapping the minimum income that can afford a median household cost in the SPEN to the income decile bin endpoints. The minimum income is calculated from the median of household costs as reported in question 2. Then, the index of the first income decile that is smaller than this minimum income is returned as the output. Formally:

$$AH_{ex} = min_{k=1}^{10} \left\{ D_{k,key} | D_{k,val} < \frac{med_{i=1}^{n}\{HE04_i\}}{40} \cdot 100 \right\} \qquad (37)$$

Where:

AH_{ex}: external affordability of housing

D_k: key-value pairs of target population income deciles, where the key is the index of the decile and the value is the endpoint income of the bin.

$HE04$: the total cost of housing for household i, reported in question 2.

Democratic legitimacy

Description:

Following the principle of subsidiarity, decision making processes on the development and investment of the neighbourhood should involve citizens as much as possible [96]. To ensure the legitimacy of these decisions, the range of stakeholders must be identified, and their interests and influence should be analysed and proportionally considered [42]. This entails both collective decisions (e.g. refurbishment of housing estate) and public sector decisions (e.g. redesigning public spaces).

Assessment:

Democratic legitimacy is assessed by auditing whether an adequate and proportionate (to the scope of the decision) consultation has been carried out prior to the decision-making process. The adequacy of consultation is measured by a set of criteria related to the content of the consultation [97], and the ex-post evaluation of the consultation process by the stakeholders [94]. For each decision on the development of public spaces and assets, shared spaces, and assets (including constructions, such as building shell), and infrastructural elements, a consultation process is expected.

The indicator itself produced annually through two different surveys that help reviewing all consultation processes of the year according to both content criteria and process evaluation

For the content criteria, the auditor must use the checklist in Table 22 to evaluate the consultation plan and report for each consultation process exhaustively for all criteria. The evaluation results should then be plugged in to formula N (38).

Table 22. Democratic legitimacy criteria for consultation content

Content criterion	Evaluation format
A core stakeholder group is identified and fully mapped. From the community influenced by the development, at least the following actors are accounted for: • occupants in developed asset • users of developed asset, facility, or public space • inhabitants disrupted by the development	True/False
An external stakeholder group is considered, and the exclusion/inclusion of its members well-reasoned. This includes mainly, but not exclusively: • local authority representative • local business groups • local cultural, ecological conservation groups	True/False
General instruments for consultation are programmed, including: • Channels and adequate timeframe to provide inputs freely • Accessible information on development progress • Transparency on the way contributions are accounted for, and reasoning behind dismissal • Responsibility assigned to consultation-managing personnel • Special provisions to consult silenced, minority, vulnerable groups	True/False
Crucial topics are discussed during the consultation, including: • development impacts, and impact specificity	True/False

• design quality		
• operation of the new/changed assets		
• use of the new/changed assets		

For the process evaluation, a statistically representative subset of the stakeholder group identified in the consultation plan must be surveyed using the criteria in Table 23 [94]. However, if the stakeholder group was not adequately recognised (fail for criterion 1 in the content checklist), the auditor must repeat the stakeholder mapping, otherwise the process evaluation will not be valid. When analysing the survey result, the % of true responses for each question determines whether the criterion is met (see these benchmarks in column 2 of Table 23). The evaluation results should then be plugged in to formula N (39).

Table 23. Democratic legitimacy criteria for consultation process

Process criterion	Benchmark (% of True responses)	Evaluation format
Understanding of decision	90	True/False
Agreeing with decision	51	True/False
Understanding reasons for decision	90	True/False
Being informed on decision in timely manner	90 (of those wanting to be informed)	True/False
Wanting to be informed in decision	descriptive, no benchmark	True/False
Satisfaction with available choices	51	True/False
Choice awareness	90	True/False
Decision execution satisfaction	51	True/False
Degree of involvement	90	True/False
Satisfaction with degree of involvement	90	True/False

Units:

The indicator is assessed through two outputs: an objective **content score** (DL_{cont}), and a subjective **process score** (DL_{proc}).

Building: 100-point scale (DL_{cont}), 100-point scale (DL_{proc}).

Neighbourhood: 100-point scale (DL_{cont}), 100-point scale (DL_{proc}).

Calculation:

Both the content criteria checklist and the survey on process yield several True/False responses. The score for a single consultation is the percentage ratio of True responses of the total number of items (4 criteria for the checklist and 10 survey questions). Each consultation in the given year are assessed individually and averaged to get an annual score.

$$DL_{cont} = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{Resp_{i,crit,true}}{4} \cdot 100 \qquad (38)$$

$$DL_{proc} = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{Resp_{i,subj,true}}{10} \cdot 100 \qquad (39)$$

Where:

DL_{cont}: democratic legitimacy scoring of the consultation content

DL_{proc}: democratic legitimacy scoring of the consultation process

$Resp_{i,crit,true}$: number of true responses on the criteria checklist for consultation "i"

$Resp_{i,subj,true}$: number of true responses on the survey evaluation checklist for consultation "i"

n: number of consultations in the current year

Demographic composition

Description:

Demographic composition is a descriptive metric for the community living in the SPEN or building. It entails a current snapshot, and a longer-term trend of the gender, age, and income composition of inhabitants [85], [91]. While as a standalone metric demographic composition is not indicative of social performance, it can become an important factor to interpret normative indicators (e.g. a higher proportion of elderly people increases the importance of universal design).

Assessment:

Demographic composition is assessed through a quinquennial household survey.[25] Both building and neighbourhood scale data are to be collected. For the purposes of interpreting social performance on core KPIs, Table 24 summarises the specific data to be retrieved with an indication of the output where it will be used. Auditors must compose questions fitting to local language and culture to return these variables.

Table 24. Survey question variables for demographic composition

Variables	Output
Number and share of building occupants or neighbourhood inhabitants aged [0-17; 18-64; 65+]	Age distribution, age trends, age segregation
Number and share of building occupants or neighbourhood inhabitants identified as [male; female; non-binary]	Gender distribution, gender trends, gender segregation
Number and share of building occupants or neighbourhood inhabitants below 60 % median equivalized[26] income for the country [at risk; not at risk]	Income distribution, income segregation

Additionally, to be able to calculate how these cohorts vary spatially, a map of the neighbourhood must also be sectioned into a grid of n-sized squares (1 km <= n), where n is chosen according to urban structure case by case as the smallest area where social segregation is still meaningful.

In case the data is collected for an automated assessment system, the data retrieved for each respondent is to be stored as the following data structure:

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[25] surveys should mirror the census timing of the country, and the availability of micro census data should be checked in local government statistics before surveying.

[26] equivalized meaning distributed to household members (i.e. divided income by number of people living in the household). The reference income medians per country can be retrieved from Eurostat {dataset id: ilc_di01, indic_il: TC}

- Building label, data type: string;
- Building location, stored as x-y coordinates, data type: (float, float);
- Building grid label, data type: string;
- Age cohort, data type: category (str), in ['0-17', '18-64', '65+']
- At risk of poverty status, data type: bool
- Gender cohort, data type: category (str), in ['male', 'female', 'non-binary']

Units:

Three types of assessment outputs are specified: **distribution** (DC_{dist}) of occupants/inhabitants in different cohorts, **trends** (DC_{trend}) in different cohorts over time, and **segregation** (DC_{seg}) of cohorts spatially.

Building: % of population (DC_{dist}), % rate of change (DC_{trend})

Neighbourhood: % of population (DC_{dist}), % rate of change (DC_{trend}), 100-point scale (DC_{seg})

Calculation:

Of the demographic composition assessments, distribution is not calculated, the measurements of population in each cohort is taken as is. For trend calculations the cohort measurements of current year are divided by the last available measurement and returned as a percentage.

$$DC_{trend,cohort} = \frac{N_{cohort,n}}{N_{cohort,n-5}} \cdot 100 \qquad (40)$$

Where:

$DC_{trend,cohort}$: short-term trends in demographic composition in any variable, any cohort

$N_{cohort,n}$: population measured in any cohort of any variable, in year n

For segregation calculations, an index of similarity is calculated, using the neighbourhood grid to subset population, and taking the cohort populations in each subset to compare similarity between grid cells. The aggregation of dissimilarities between cells is the final index for segregation. Formally:

$$DC_{seg} = \frac{1}{n} \cdot \sum_{i=1}^{n} \left| \frac{a_i}{A} - \frac{b_i}{B} \right| \cdot 100 \qquad (41)$$

Where:

DC_{seg}: segregation index for any variable in the neighbourhood

a_i: population of cohort "a" in cell "i", where "a" is a cohort of interest

b_i: population of cohort "b" in cell "i", where "a" is a control cohort

A: total population in cohort "a"

B: total population in cohort "b"

n: number of grid cells

Living conditions

Description:

The living conditions in dwellings are closely linked to health outcomes, social status, carbon footprint, and overall quality of life [86], [89], [91], [94]. To better approximate what living conditions mean, the issue is addressed through two main failure scenarios: (1) overcrowding or (2) a lack of facilities enabling dignified human habitation [86], [89], [91], [94]. Standards for both "what is considered an overcrowded dwelling" and

"which are the minimum facilities required for a dignified human life" while exist globally [90], these standards will vary by culture and economic development. The indicator is designed for the EU context and are based on standards already used by Eurostat [91].

Assessment:

Living conditions are assessed through a quinquennial household survey, mirroring the census timing of the country. In case micro census data is available from the local government statistics, a separate survey can be avoided. Also, the data needs for the indicator may be fully or partially covered by a database of technical specifications and performance if it exists (see data specification in column 2 of Table 25).[27] The data is collected on building scale and aggregated on neighbourhood scale. The specific variables for this indicator are generated from information describing overcrowding, and poor living condition scenarios, as defined in Table 25. Auditors must compose questions fitting to local language and culture to identify these scenarios.

Table 25. Survey variables for living conditions

Scenario	Definition
Overcrowding	The share of building occupants/neighbourhood inhabitants living in an overcrowded household: if the house does not have at least one room for the entire household as well as a room for a couple, for each single person above 18, for a pair of teenagers (12 to 17 years of age) of the same sex, for each teenager of different sex and for a pair of children (under 12 years of age)[28]. Simultaneously, the whole dwelling unit is overcrowded if its area is: less than 30 m² for 1 bedspace units, 45 m² for 2 bedspace units, 57 m² for 3 bedspace units, 67 m² for 4 bedspace units [86].
Poor living conditions	The share of the building occupants/neighbourhood inhabitants experiencing at least one of the following basic deficits in their housing condition: a leaking roof, damp walls, floors or foundation, or rot in window frames or floor[29]; not being connected to waste water treatment systems with at least secondary treatment[30].

The assessment is concluded by plugging in the number of occupants where the scenario is true into formula N (42) (separately, for both scenarios).

Units:

The indicator is measured in two separate outputs corresponding to the two scenarios: overcrowding (LC_{oc}), and poor living conditions (LC_{plc}).

Building: % of population (LC_{oc}), % of population (LC_{plc}).

Neighbourhood: % of population (LC_{oc}), % of population (LC_{plc}).

Calculation:

Both outputs are calculated by returning the percentage share of occupants/inhabitants where the investigated scenario is true:

---

[27] If the data is to be retrieved through neighbourhood digital databases, overcrowding data and some of the wastewater treatment system connection can be read from design documentation. Basic deficits can only be read if the digital database is mature to support building operation (e.g. a digital twin or 7D BIM system is running), and/or an interface to report deficits is available for occupants (e.g. a simple mobile app for surveys).

[28] https://ec.europa.eu/eurostat/cache/metadata/en/sdg_11_10_esmsip2.htm

[29] https://ec.europa.eu/eurostat/cache/metadata/en/sdg_01_60_esmsip2.htm

[30] https://ec.europa.eu/eurostat/cache/metadata/en/sdg_06_20_esmsip2.htm

$$LC_{var} = \frac{N_{var}}{N_{tot}} \cdot 100 \qquad (42)$$

Where:

LC_{var}: living condition score for any of the two variables (overcrowding, poor living condition)

N_{var}: the number of occupants/inhabitants where the variable is True

N_{tot}: the total number of occupants/inhabitants

Interpretation:

The indicator is normative, where the target value for both outputs are 0. Higher values indicate inadequate living spaces and/or people in living conditions not meeting basic human needs. In general, the living condition criteria set are the bare minimum that needs to be provided by any new housing development, which is why this indicator becomes more relevant when assessing existing neighbourhoods, to diagnose the need for retrofit. If the target value is not met, an intermediate target can be set to the city average if data is available. In this case, a simplified list of conditions applies for overcrowding rate, not considering its area – to be able to set the intermediate target from Eurostat data alone. Finally, if the primary target is not met, it is also advised to cross-check with demographic composition indicator for any potential segregation and run a performance distribution audit to rule out spatial injustice.

Sustainable mobility

Description:

Choosing sustainable modes of transport is crucial in mitigating climate change, as the transportation sector is the second largest emitters of greenhouse gases [98]. While much of this is attributed to logistics, aviation, and the transportation of goods, which is not addressable through isolated, neighbourhood-scale actions, 44% of transportation-related emissions are still linked to cars [99]. It is therefore crucial for neighbourhood developments to incentivise low-carbon modes, through urban design, infrastructure, and building-scale supporting interventions [86], [100]. At the same time, the actual modal split of mobility must be monitored to continuously gauge the way such interventions influence mobile behaviour [85].

Assessment:

Sustainable mobility is assessed by simultaneously monitoring a normative mobile performance and all descriptive mobility design and soft features that are (1) actionable on building/neighbourhood scales, and (2) influence the mobile behaviour.

Specifically, the normative component is the modal split, the share of journeys by mode of transport [private motorised, public, non-motorised]. The data must be collected at least annually, however, a separate winter and summer data collection is recommended to gauge the impact of weather. In case data needs can be met through microscale statistical data, a separate survey can be avoided. In case no such data is available, a statistically significant sample of the neighbourhood/building population must be surveyed for self-reported mobile behaviour. Also, it must be noted that surveying modal share in the EU has different methodologies, and the indicators used in Eurostat are greatly simplified[31]. Table 26 summarizes the data needs to calculate modal share, with corresponding Urban Audit data sources referenced accordingly.

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[31] https://ec.europa.eu/eurostat/documents/3433488/5298257/KS-SF-07-087-EN.PDF/bf69235f-f285-4dc0-ac55-55a2d0c69c11

https://ec.europa.eu/eurostat/cache/metadata/en/tran_hv_psmod_esms.htm

Table 26. Modal share specification

Mode	Definition	Eurostat approximation
Motorised private transport	Share of all journeys by car or motorcycle as a % of passenger km-s	Share of journeys to work by car or motorcycle as a % of journeys {dataset: urb_ctran, indic_ur: TT1012V}
Public transport	Share of all journeys by rail, metro, bus, tram as a % of passenger km-s	Share of journeys to work by rail, metro, bus, tram as a % of journeys {dataset: urb_ctran, indic_ur: TT1010V}
Non-motorised transport	Share of all journeys by bicycle or on foot as a % of passenger km-s	Share of journeys to work by bicycle or on foot as a % of journeys {dataset: urb_ctran, indic_ur: TT1007V; TT1008V}

To be able to retrieve this data through surveying, respondents must be asked to recollect all journeys of a characteristic weekday, both weekend days, and all non-routine long-distance (50 km<) trips in a 6-month timeframe. For each journey, the following data is to be collected (where each record is a journey):

- Respondent ID, data type: string
- Purpose of travel, data type: categorical, [work, education, shopping, business, leisure, other]
- Distance in km, data type: integer
- Mode, data type: categorical, [car, motorcycle, rail, metro, bus, tram, bicycle, foot]

Regarding the descriptive component of the indicator, the assessment consists of evaluating building/neighbourhood through a checklist of enabling/hindering factors of sustainable mobility (Table 27). The data source for this is the technical documentation of the building and urban design documentation of the neighbourhood for new projects and site visits for existing projects.

Table 27. Enabling factors of sustainable mobility

Enabler	Scale of application	Evaluation format
EV-charging stations	BN	True/False
Sheltered bicycle parking (BN), changing/shower facilities (B)	BN	True/False
Adequate bicycle infrastructural coverage on roads where car traffic does not allow mixed-use	N	True/False
Share of population within characteristic distance of public transportation stop (see "access to services")	N	True/False
Vehicle-calming traffic measures on lighter roads	N	True/False
Pedestrian-friendly design of junctions, signified by surface levels, fit-for-volume traffic-management facilities, surface materials	BN	True/False
Well-lit, well-connected, easy-to-traverse, well-maintained pedestrian infrastructure leading to all building access points.	BN	True/False
Car-sharing facilities	B	True/False
Home-office space and facilities at residential buildings	B	True/False
Any additional enabler of sustainable transportation modes can be added to the checklist if the auditor deems necessary	BN	True/False

The assessment is concluded by listing the available enablers and plugging the survey results into equation N (43) for each mode.

Units:

The indicator is assessed through two outputs: modal share (SM_{mode}) and list of sustainable mobility enablers (SM_{ena}).

Building: % of passenger kms (or work journeys) (SM_{mode}), qty of available enablers (SM_{ena}).

Neighbourhood: % of passenger kms (or work journeys) (SM_{mode}), qty of available enablers (SM_{ena}).

Calculation:

The descriptive output of the indicator is simply the list of enablers present/absent from the evaluated building/neighbourhood. The modal share is conventionally represented as a distribution between the three modes of transport. A numerical score is generated by summing the shares of all motorised private mode results. The individual shares of mode are calculated by dividing the sum of passenger kilometres in the given mode by the total sum of passenger kilometres. In case of an approximated dataset, the Eurostat data is taken directly without any further calculations.

$$SM_{mode} = \frac{\sum_{i=1}^{n} d_{mode,i}}{d_{tot}} \cdot 100 \qquad (43)$$

Where:

SM_{mode}: share of transportation in mode of interest

$d_{mode,i}$: the distance travelled with mode of interest in journey "i"

d_{tot}: the sum of all distances travelled in km

Interpretation:

The results of the indicator must be evaluated together to gain a full picture of mobility. Modal share and especially the share of motorised private transportation are normative outputs, however, there is no clear, universal target for any of them. Local, city-scale targets must be consulted to set a benchmark. Alternatively, a modal share that enables a positive neighbourhood/building scale energy balance and carbon-neutrality can be set as a target, where transportation emissions/energy consumption are considered. In case of underperformance, the list of enablers, the "universal design", and the "environmental consciousness" indicators can be consulted to diagnose probable causes that are actionable on the neighbourhood scale.

Accessible or universal design

Description:

Universal design broadly refers to providing equal opportunities in terms of accessibility. In the EU context, this practically means providing barrier-free access to those with impaired motor, perceptive, and cognitive capabilities both inside buildings and sites, and within the neighbourhood [86]. Physical design interventions are usually necessary especially for people using wheelchairs (or impaired in their mobility any other way), that are visually impaired, deaf, elderly people, children, or people with unusual physical characteristics [100].

Assessment:

A complete assessment of universal design for buildings and outdoor spaces is a complex, multifaceted task for a single (or more) specialist auditor(s) who would screen through design documentation and the actual sites against a wide range of criteria regarding wayfinding, ease-of-movement, environmental information, ergonomics, and user experience, following ISO 21542:2011 [101]. This indicator is a feasible, simplified alternative, gathering some of the more common, and urgent barriers for universal access, which in no way substitutes a thorough universal design audit (which is not in the scope of syn.ikia).

The indicator is assessed on both building and neighbourhood scales, with data being collected for three types of units: facilities, road segments, and junctions. Facilities refer to any building, together with its site, and outdoor public destinations, such as parks and squares. Road segments refer to any pedestrian paths on streets, between two junctions. When assessing at building scale, the functionality of the building determines the range of units that needs to be assessed, while at neighbourhood scale, all units must be assessed. For residential buildings, every road segment, junction, and facility within 500 metres must be assessed. For each assessment, the checklist criteria are shown in Table 28. For a unit to pass the assessment, all criteria must be met. The assessment is concluded by plugging in the assessment results to equation N (44).

Table 28. Universal design criteria checklist

Criterion	Applied to	Evaluation format
Combined audio-visual information regulating pedestrian flow	Facilities, junctions	True/False/NA
Passenger lift, capable of accommodating wheelchair, or stairway wheelchair lift in multi-storey building	Facilities	True/False/NA
At least 1 housing unit or 50% workspaces meeting wheelchair design standards in residential building	Facilities	True/False/NA
Publicly accessible areas meeting local wheelchair design standards	Facilities, road segments, junctions	True/False
On-site movement is provided for by wheelchair-compliant ramps, or by motorised means (where height difference is larger than a storey)	Facilities	True/False
Illuminated, covered entrances with level access over the threshold	Facilities	True/False
Doorways and hallways width accommodate wheelchair, opportunities to turn are provided within eyesight	Facilities	True/False
Wheelchairs able to turn in dining, waiting, living areas	Facilities	True/False
Wheelchair accessible bathrooms available on all floors in commercial, industrial, and public buildings	Facilities	True/False/NA
Windows, fixtures, and fittings at accessible height	Facilities, junctions	True/False

Units:

At building scale, two scores are calculated from the same data: **barrier-free location** (UD_{loc}), and **barrier-free area** (UD_{area}). At neighbourhood scale, only **barrier-free area** (UD_{area}) is calculated.

Building: 10-point-scale (UD_{loc}), % of barrier-free units (UD_{area}).

Neighbourhood: % of barrier-free units (UD_{area}).

Calculation:

For the location score, a 10-point scale is returned counting the number criteria passed (of Table 28). For the area score, the share of passed units in all units within characteristic distance is calculated. Formally:

$$UD_{area} = \frac{U_{pass}}{U_{tot}} \cdot 100 \qquad (44)$$

Where:

UD_{area}: barrier-free area score

U_{pass}: the number of barrier-free accessible units (max points on all relevant criteria) in area of investigation

U_{tot}: the total number of units within area of investigation

Interpretation:

Universal design scores on the building scale may not be meaningful for new construction in many countries, where the requirements are baked into the building code. However, when assessing existing buildings and neighbourhoods, both scores can signal whether the basic requirements of most movement/visually impaired people are met. Any score lower than 10 on barrier-free location indicate a significant flaw in universal design that must addressed. Barrier-free area scores show how much of the local services and amenities serviceable for disabled people. Lower scores mean that for disabled people, both access to amenities and access to services are smaller proportionally (to the score).

There are some caveats to this interpretation. On a neighbourhood scale, it is important to look at "sustainable mobility" and universal design concurrently, as more car-hostile neighbourhoods inadvertently punish those impaired who rely on cars to get by. In extreme cases, a more thorough assessment of universal design is warranted. Also, if "demographic composition" highlights a significant elderly population, universal design criteria become more important. Finally, as noted before, the criteria listed here cover only the most common barriers for the most common disabilities, there is a wide spectrum of perceptual, cognitive, and motor disabilities, and unconventional body shapes that encounter different barriers. It is the responsibility of the neighbourhood community, or the building owner to recognize when these special needs arise, and offer one-off, or more permanent solutions, bespoke for the situation.

Diverse community

Description:

Diverse community is a descriptive metric for the community living in the SPEN or building. It describes how much the community is exposed to new members from different cultural and ethnical backgrounds. It entails a current snapshot, and a longer-term trend migration, cultural, and ethnic plurality [85], [93]. While as a standalone metric diverse community is not indicative of social performance, it can become an important factor to interpret normative indicators (e.g. higher migration levels increase the importance of social cohesion to support better perceived personal safety).

Assessment:

The indicator is assessed through two approaches: by recording the stability of inhabitants through migration metrics and by assessing the diversity of inhabitants. Data is collected through a quinquennial household survey, mirroring the census timing of the country. In case micro census data is available from the local government statistics, a separate this survey should be avoided. For both building, and neighbourhood scale assessments, data is to be disaggregated for households. Table 29 summarizes the specific data to be retrieved with an indication of the output where it will be used. Auditors must compose questions fitting to local language and culture to return these variables.

Table 29. Survey variables for diverse community.

Variables	Output
Share of building occupants or neighbourhood inhabitants who moved in in the last five years by origin categories: [city, country, foreign EU, foreign non-EU]	Migration distribution, migration trends, migrant segregation
Share of building occupants or neighbourhood inhabitants in visible minorities by minority categories[32]	Minority distribution, trends, and segregation
Share of building occupants or neighbourhood inhabitants occupied in industry categories: [top level NACE classes [102]]	Occupational distribution, trends, and segregation
Share of building occupants or neighbourhood inhabitants where language used at home is not the official language of the country	Foreign language-user distribution, trends, and segregation

Additionally, to be able to calculate how these cohorts vary spatially, a map of the neighbourhood must also be sectioned into a grid of n-sized squares (1 km <= n), where n is chosen according to urban structure case by case as the smallest area where social segregation is still meaningful.

The data retrieved for each respondent is to be stored as the following data structure:

- Building label, dtype: str;
- Building location, stored as LONG-LAT tuples, dtype: (float, float);
- Building grid label, dtype: str;
- Migration origin category, dtype: category (str), in ['None', 'city', 'country', 'foreign EU', 'foreign non-EU']
- Minority category, dtype: category (str), in ['None', #categories defined case by case]
- Language spoken at home is aligned, dtype: bool

Units:

Three types of assessment outputs are specified: **distribution (DC_{dist})** of occupants/inhabitants in different cohorts, **trends (DC_{trend})** in different cohorts over time, and **segregation (DC_{seg})** of cohorts spatially.

Building: % of population (DC_{dist}), % rate of change (DC_{trend})

Neighbourhood: % of population (DC_{dist}), % rate of change (DC_{trend}), 100-point scale (DC_{seg})

Calculation:

Of the diverse community assessments, distribution is not calculated, but obtained by showing the number of people in each cohort. For trend calculations the cohort measurements of current year are divided by the last available measurement and returned as a percentage.

$$DC_{trend,cohort} = \frac{N_{cohort,n}}{N_{cohort,n-5}}$$

(45)

Where:

$DC_{trend,cohort}$: short-term trends in demographic composition in any variable, any cohort

$N_{cohort,n}$: population measured in any cohort of any variable, in year n

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[32] to define specific minority categories local social development or urban development strategies must be screened for notable cultural, ethnic, religious groups that are prevalent locally.

For segregation outputs, an index of similarity is calculated, using the neighbourhood grid to subset population, and taking the cohort populations in each subset to compare similarity between grid cells. The aggregation of dissimilarities between cells is the final index for segregation.

$$DC_{seg} = \frac{1}{n} \cdot \sum_{i=1}^{n} \left| \frac{a_i}{A} - \frac{b_i}{B} \right| \cdot 100 \qquad (46)$$

Where:

DC_{seg}: segregation index for any variable in the neighbourhood

a_i: population of cohort "a" in cell "i", where "a" is a cohort of interest

b_i: population of cohort "b" in cell "i", where "a" is a control cohort

A: total population in cohort "a"

B: total population in cohort "b"

n: number of grid cells

Social cohesion

Description:

Social cohesion in the syn.ikia context refers to the ability of a (building or neighbourhood) community to "hold together", that is: to proliferate shared values and a sense of belonging, to form strong trust-based bonds, to maintain a social network with high social capital, to have the capacity to integrate diverse inhabitants, referring to both leveraging diverse values, and handling potential conflicts [85], [103], [104]. Social cohesion is a multifaceted dimension with a wide range of individual, circumstantial, socioeconomic, and cultural components. This indicator focuses on the way a vibrant and inclusive built environment fosters cohesion through the provision of shared spaces to spend time, increase the number of encounters, exchanges, interactions, and, in general, provides interfaces for strong social networks to form [93], [105].

Assessment:

Social cohesion is assessed by simultaneously monitoring a normative performance and all descriptive built environment features that are (1) actionable on building/neighbourhood scales, and (2) influence the social cohesion.

Specifically, the normative component is measured by inhabitants self-reporting a list of tests that evaluate the components of their personal resilience attributed to belonging to the community [85], [104]. To perform the test, a survey of a statistically significant subset of building occupants/neighbourhood inhabitants must be made annually. The specific information to be retrieved is summarized in Table 30. Both the individual answers and a respondent score summed from the responses must be registered during the survey. The tests are standalone, each is assessed separately – with equation N (47) – and as an aggregate – with equation N (48).

Table 30. Survey variables for social cohesion

Test	Variables	Format of evaluation [scoring]
Support network	Overall social support is adequate, with access to close people to count on, concern shown by other people, and practical help from neighbours in case of need.[33]	Poor, intermediate, strong [0; 0,5; 1]

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[33] https://ec.europa.eu/eurostat/cache/metadata/en/hlth_det_esms.htm

Care habits	Informal care or assistance provided to people suffering from some age-related problem, chronic health condition or infirmity, at least once a week.[33]	None, mainly to relatives, mainly to non-relatives [0; 1; 1]
Belonging	There is a strong sense of local community belonging.	True, false [1; 0]
Values	All residents share/learn/adapt a common set of values necessary for living together.	True, false [1; 0]
Trust	Residents can be trusted.	True, false [1; 0]
Discrimination	There is no discrimination because of skin colour, age, ethnic origin, religion, gender.	True, false [1; 0]

Regarding the descriptive component of the indicator, the assessment consists of evaluating the building/neighbourhood through a checklist of enabling/hindering factors of social cohesion (Table 31). The data source for this is the technical documentation of the building and urban design documentation of the neighbourhood for new projects and site visits for existing projects.

Table 31. Descriptive list of enablers for social cohesion

Enabler	Scale of application	Evaluation format
Streets are supplied with amenities for pedestrian comfort for stay activities, including an adequately wide sidewalk, street lighting, places to sit, vegetation.	BN	True, false
There is a variety of publicly accessible places where people can meet, such as shops, cafés, bars, restaurants, parks, squares, cultural spaces, etc.	N	True, False
There are no environmental hazards, such as noisy highways, railway lines, industrial polluters, dust storms.	BN	True, False
Activities and public programs occur in public spaces at least monthly in the high season.	N	True, False
There are active and popular street-level functions in the buildings accessible by the public.	BN	True, False

Units:

The indicator is assessed through the normative **social cohesion test** (SC_{aggr}) output, and the descriptive **list of enablers** (SC_{ena}).

Building: 6-point-scale (SC_{aggr}), qty of available enablers (SC_{ena}).

Neighbourhood: 6-point-scale (SC_{aggr}), qty of available enablers (SC_{ena}).

Calculation:

The normative social cohesion test (SCaggr) is presented as the mean of respondent scores on a 6-point scale and share of "True" responses (or 1 scores) for each question. The descriptive list of enablers (SCena) is simply the list of enablers present/absent from the evaluated building/neighbourhood.

$$SC_{aggr} = \frac{1}{6} \cdot \sum_{i=1}^{6} SC_{test,i} \qquad (47)$$

Where:

SC_{aggr}: normative social cohesion output

$SC_{test,i}$: score of individual test "i" of social cohesion, see equation N (48).

Additionally, each social cohesion test is to be tracked separately:

$$SC_{test} = \frac{SC_{test,True}}{N} \cdot 100 \qquad (48)$$

Where:

SC_{test}: score of any individual test of social cohesion

$SC_{test,True}$: number of responses for any test of social cohesion (Table 30), where the answer corresponds to a 1 score

N: number of respondents

Interpretation:

The result of the normative social cohesion output is a score internal to syn.ikia, with no other benchmark than reaching the top score eventually with at least hitting the score from the last evaluation. The scoring for both aggregated and individual test scores are on a 100-point scale, where lower values refer to lower degree of social cohesion. While the aggregated score is to be used only to set targets and compare buildings/neighbourhoods, each individual survey test refers to a characteristic area of social cohesion that are interpreted and addressed differently (Table 32).

Table 32. Interpretation of individual social cohesion tests

Test (SC_{test})	Interpretation	Is the list of enablers for social cohesion (SC_{ena}) relevant?
Support network	If overall social support is 0, the local opportunities to build social networks, and the accessibility of pre-existing networks (that are not specific to this location) must be evaluated. This means especially, but not exclusively: opportunities for civic participation, communal work, shared programs and activities, untraded interactions.	Listed enablers need to be checked if support network score is low.
Care habits	If informal care is 0, the root causes must be identified, and whether it is linked to available time, resources, to attitudes, or to a mismatch between care demand and supply. On the neighbourhood scale, the latter two are manageable through social interventions, while lack of time and resources is indicative of larger scale problems.	Listed enablers do not influence care habits score.
Belonging	If community/place belonging is 0, there is a sign of disengagement from local matters, activities, places of interest – all of which are potential points of intervention in either a social program or urban design. This might mean there are not enough of them in the first place, they are not relevant for the people that live there, or they are not adequate in quality.	Listed enablers may directly influence scoring in belonging.
Values	If values is 0, it might be because alignment of values is expected to happen over time for people exposed to one another consistently and frequently. If there is also an underperformance in "personal safety", the consistency and frequency of interactions among inhabitants should be investigated in follow-up studies.	Listed enablers need to be checked if values score is low.
Trust	Trust is very closely connected to shared values; however, respondents might not register adequate sharing of values with some inhabitants without distrusting them. A lack of trust is therefore a more impactful	Listed enablers need to be checked if trust score is low.

	underperformance, with implications for "personal safety". Follow-up studies are necessary, with distrusted parties mapped, followed by a strategy for mediation among them.	
Discrimination	In case high discrimination is reported, "demographic composition" and "diverse communities" indicators must also be measured, and a performance distribution audit must be measured to collect evidence for discrimination and inform any further actions.	Listed enablers do not influence discrimination score.

Personal safety

Description:

Personal safety refers to security in public and shared (e.g. courtyards, parks, or squares) spaces, including a crime-free community, traffic safety, hazard- and accident-free environments. Public and shared spaces by design should project safe and non-intrusive uses [86]. The indicator refers to both actual and perceived safety, as worrying over becoming crime victims, feeling unsafe when walking alone at night or spending time in public spaces may gate off entire social groups from using public spaces, amenities, interact with others, choose sustainable modes of transport [104] – inhibiting areas of performance that rely on people using public spaces.

Assessment:

Personal safety is assessed by simultaneously monitoring a normative objective and subjective performance and all descriptive built environment features that are (1) actionable on building/neighbourhood scales, and (2) influence the personal safety.

Specifically, the normative component is measured using statistical data on crime and traffic safety collected by Eurostat. The availability and source of neighbourhood-scale data depends on the specific country – the auditor must consult local government or national/autonomous subnational law-enforcement agencies or query Eurostat directly for microdata [91]. Where microdata is not available, subjective safety data must be surveyed annually on a statistically representative segment of the building occupants/neighbourhood inhabitants. The survey consists a series of tests to evaluate perceived safety. Metadata of respondents listed in the variables for "demographic composition" (Table 24) and "diverse community" (Table 29) must also be collected in case disaggregation is needed. The objective and subjective variables are summarized in Table 33. Both the individual answers and a respondent score summed from the responses must be registered during the survey.

Table 33. Survey variables for personal safety

Test	Variables	Format of evaluation [scoring]
Traffic safety	People killed in road accidents per 10 000 population below 40% of the median [Eurostat dataset: urb_ctran, indic_ur: TT1060I]. If not attainable, share of building occupants/neighbourhood inhabitants feeling safe to walk/cycle in the neighbourhood considering traffic.	True, false [1; 0]
Crime	Share of the building occupants/neighbourhood inhabitants who reported that they do not face the problem of crime, violence, or vandalism in their local area[34].	True, false [1; 0]

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[34] https://ec.europa.eu/eurostat/cache/metadata/en/sdg_16_20_esmsip2.htm

Sense of security	Share of the building occupants/neighbourhood inhabitants who reported not being worried of becoming a victim of crime in the neighbourhood.	True, false [1; 0]
Alertness	Share of the building occupants/neighbourhood inhabitants who feel safe walking alone at night in the neighbourhood.	True, false [1; 0]

Regarding the descriptive component of the indicator, the assessment consists of evaluating the building/neighbourhood through a checklist of enabling/hindering factors of personal safety (Table 34). The data source for this is the technical documentation of the building and urban design documentation of the neighbourhood for new projects and site visits for existing projects.

Table 34. Enabling factors for personal safety.

Criterion	Scale of application	Evaluation format
Car speed mitigated through physical design elements (trajectory shifts, obstacles, bumps, foliage) and traffic management to 20-30 km/h in the vicinity of the building (B), or in the neighbourhood (N).	BN	True, false
Spaces between buildings planned for specific uses.	BN	True, False
Clear boundaries between public/private/shared spaces.	BN	True, False
Discouraged casual intrusion to private/shared spaces.	B	True, False
Lack of places to hide, obscured areas, viewpoints with high occlusivity[35].	BN	True, False
Permeability of space, multiple points of exit	BN	True, False
Building layout and window placements allow for monitoring of public/shared spaces.	BN	True, False
Vulnerable points of buildings are visible by other residents or passers-by.	B	True, False
Public/shared spaces are adequately lit, sudden dark/bright zones are avoided.	BN	True, False
Finishes and glass surfaces from ground level to 2 metres are graffiti/vandalism resistant.	B	True, False
A security measure allows to control permission of entry to shared/private spaces (e.g. an entry phone).	B	True, False

Units:

Personal safety indicator is assessed through a normative **perceived safety** (PS_{aggr}) output, and a descriptive list of **safety enablers** (PS_{ena}).

Building: 4-point-scale (PS_{aggr}), qty of available enablers (PS_{ena}).

Neighbourhood: 4-point-scale (PS_{aggr}), qty of available enablers (PS_{ena}).

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[35] The amount of spaces hidden from any given viewpoint

Calculation:

The normative perceived safety (PS_{aggr}) is presented as the mean of respondent scores on a 4-point scale and share of "True" responses (or 1 scores) for each question. The descriptive safety enablers (PS_{ena}) is the set of enablers present/absent from the evaluated building/neighbourhood.

$$PS_{aggr} = \frac{1}{4} \cdot \sum_{i=1}^{4} PS_{test,i}$$

(49)

Where:

    PS_{aggr}: normative personal safety output

    $PS_{test,i}$: score of individual test "i" of personal safety, see equation N (50).

    N: number of respondents

Additionally, each personal safety test is to be tracked separately:

$$PS_{test} = \frac{PS_{test,True}}{N} \cdot 100$$

(50)

Where:

    PS_{test}: score of any individual test of personal safety

    $PS_{test,True}$: number of responses for any test of personal safety, where the answer corresponds to a 1 score

    N: number of respondents

Interpretation:

The result of the normative output is a score internal to syn.ikia, with no other benchmark than reaching the top score eventually with at least hitting the score from the last evaluation. The scoring for both aggregated and individual test scores are on a 100-point scale, where lower values refer to lower degree of social cohesion. While the aggregated score is to be used only to set targets and compare buildings/neighbourhoods, each individual survey test refers to a characteristic area of safety that require different methods of further diagnosis and different interventions (Table 35).

Table 35. Interpretation of individual personal safety tests.

Test (PS_{test})	Interpretation	Is the list of enablers for personal safety relevant PS_{ena}?
Traffic safety	Low (close to 0) scores indicate unsafe local traffic, which must be narrowed to certain places for targeted interventions. Traffic safety is closely linked to "sustainable mobility" and is most likely to be influenced through urban design. Both the enablers of "sustainable mobility" and "personal safety" can significantly improve traffic safety. Additionally, "accessibility of amenities" and "accessibility of services" are both known influencers of mobile behaviour, thus traffic safety.	Enablers directly influence score, must be checked whenever it underperforms.
Crime	Low (close to 0) crime score indicate objectively unsafe environments. Crime and perceived crime may both be mitigated through good architectural and urban design, but it is also linked to the socioeconomic status of the neighbourhood, and whether a strong local community maintains a safe, welcoming environment. With crime underperformance, it is advised to investigate "demographic composition", "diverse communities", and "social cohesion" indicators for further investigation.	Listed enablers may contribute to lower crime scores, they can be checked to prove or disprove this.

Sense of security; alertness	When either test underperforms (score close to 0), perceived security is inadequate. The reasons behind low sense of security or high alertness is the same as behind perceived crime. However, they also have a direct impact on the use of public space, namely it inhibits all built environment enablers of other indicators, such as "sustainable mobility".	Listed enablers may contribute to lower sense of security and alertness scores, they can be checked to prove or disprove this.

Energy consciousness

Description:

Energy consciousness addresses the psychological factors of the energy/environmental performance of the SPEN. The focus of this indicator is on the roots of environmental and energy consciousness (or lack thereof) and inertia towards new technologies and behaviour change. A preliminary assessment and the continuous monitoring of psychological factors are critical, as behavioural barriers (such as user inertia/indifference, lack of trust, lack of commitment, hostile attitudes) are among the major obstacles for coordinated, conscious energy management [106]. This is especially relevant in the context of syn.ikia, where the flexibility of the energy system – necessitating demand-side adaptivity – is in focus.

Assessment:

The indicator is assessed through an annual survey on a statistically representative subset of building occupants/neighbourhood inhabitants. It extracts personal beliefs towards three subjects: environment, energy consumption, and novel technologies. The survey follows a logic built on the combination of the theory of planned behaviour (TpB) [107] and goal framing theory (GFT) [108] to sufficiently differentiate major drivers of intentions (Figure 23). The model allows to isolate drivers that are actionable on building/neighbourhood scales, through community action, awareness raising, smart appliances, attractive business models, or physical design.
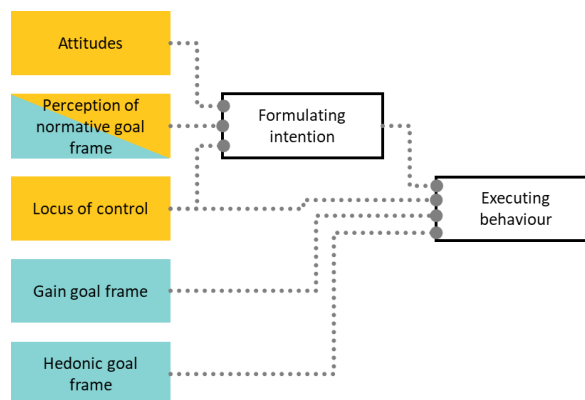
Figure 23. Syn.ikia model for behavioural determinants. Gold determinant types are inherited from TpB, blue ones from GFT.

The indicator can be assessed both on building and neighbourhood scales without any methodological adjustment, the exact information to be retrieved from the surveys is summarised in Table 36. Likert scale responses must be formulated as follows: Strongly likely/agree, agree/likely, neutral, disagree/unlikely, strongly disagree/unlikely. Survey results must be plugged into equation N (51) both as a whole and disaggregated to behavioural determinant types.

Table 36. Survey variables for energy consciousness.

Type	Variables	Format of evaluation [scoring]
Attitude	Trust in the role of new technology in improving energy efficiency.	5-point Likert scale

Attitude	Trust in passive energy efficiency gains.	5-point Likert scale
Attitude	Trust in cooperative approaches to energy flexibility.	5-point Likert scale
Attitude	Willingness to invest a small amount in energy information.	5-point Likert scale
Attitude	Trust in energy tracking to improve energy efficiency.	5-point Likert scale
Attitude	Motivation to improve energy efficiency and flexible energy consumption.	5-point Likert scale
Gain	Awareness of one's own energy consumption.	5-point Likert scale
Gain	Awareness of the energy label of the building and home appliances.	5-point Likert scale
Gain	Awareness of savings potential in energy efficiency and flexibility.	5-point Likert scale
Gain	Motivation to be energy efficient and flexible to reduce costs.	5-point Likert scale
Hedonic	Perceived ability to do more to protect the environment.	5-point Likert scale
Hedonic	Motivation against energy efficiency and flexibility due to discomfort.	5-point Likert scale
Locus of control	Perceived degree of control over HVAC systems.	5-point Likert scale
Locus of control	Perceived degree of control over indoor air quality.	5-point Likert scale
Locus of control	Perceived degree of control over humidity and moist control.	5-point Likert scale
Locus of control	Perceived degree of control over thermal comfort.	5-point Likert scale
Locus of control	Perceived degree of control over natural lighting.	5-point Likert scale
Subjective norm	Perceived importance of environmental protection in social network.	5-point Likert scale
Subjective norm	Motivation to be energy efficient and flexible to reduce carbon footprint.	5-point Likert scale

Units:

The indicator is measured through the **energy consciousness** aggregated output (EC_{aggr}).

Building: 5-point-scale (EC_{aggr}).

Neighbourhood: 5-point-scale (EC_{aggr}).

Calculation:

Each individual response returns a score between 1 and 5. Additionally, scores must be aggregated by type of determinant, and for all responses. All aggregations are by taking the mean of individual scores:

$$EC_{aggr} = \frac{1}{N} \cdot \sum_{i=1}^{N} EC_{ind,i} \qquad (51)$$

Where:

EC_{aggr}: energy consciousness aggregated output

$EC_{ind,i}$: energy consciousness individual response score, for respondent "i"

N: number of respondents

The result of the output is a score internal to syn.ikia, with no other benchmark than reaching the top score eventually with at least hitting the score from the last evaluation. However, each individual survey question can be linked to an area of intervention, and each determinant type require different methods of further diagnosis and different interventions (Table 37). It must be noted that none of the factors influence energy conscious behaviour in isolation, and certain factors may override others. However, it is not possible to set a one-size-fits-all hierarchy among the factors, thus the results must be examined in combination to make educated interpretations.

Table 37. Interpretation of energy consciousness results, disaggregated by behaviour determinant type.

Type	Interpretation
Attitude	Attitude refers to feelings and thoughts shaped by experiences and personality. Lower (close to 0) EC_{ind} scores indicate in-grained opposition or indifference towards energy consciousness. There is no quick fix to change attitudes other than to provide exposure to positive experiences, address past negative ones, engage with the community consistently, on the long term, build trust, and phase out interventions into smaller packages.
Gain goal frame	Gains refer to the improvement of one's own resources. If gains goal frame is strong (EC_{ind} scores closer to 5), energy flexibility is best addressed by convincing occupants through attractive business models, highlighting benefits, savings in terms of operational expenditures, and options to mitigate investment costs.
Hedonic goal frame	The hedonic goal frame refers to gratification, prompting efforts to "feel better now". Strong hedonic goal frames (EC_{ind} scores closer to 5) can be addressed by measures to mitigate discomfort associated with change, e.g. by limiting construction time using prefabricated systems.
Locus of control	Locus of control refers to the perceived ability to do something, which influences both intentions and actual behaviour. Lower (closer to 0) EC_{ind} scores mean people do not feel they can be energy conscious, indicating and untapped potential to more sustainable occupant behaviour. Smart appliances that improve awareness, give more control over indoor environmental quality, energy use, and tools/methods to build capacity to operate in an energy-flexible way can improve locus of control.
Subjective norm	Subjective norms refer to a personal assessment of what is appropriate, "how things should be done". If a strong normative goal frame guides behaviour (EC_{ind} scores closer to 5), these norms can be leveraged to support energy flexibility. However, if the goal frame is strong and the norms do not support energy flexible behaviour, most interventions will be met with inertia. In this case, concerted awareness raising, leveraging social network dynamics is necessary to adjust norms.

Healthy community

Description:

In the syn.ikia context, health is monitored through its spatial patterns to uncover any disparities that could be linked to a single building or to certain parts of the neighbourhood. Alongside the commonly surveyed health outcomes (e.g. cardiovascular diseases), healthy behaviour and preventive measures (e.g. taking flu shots) are also monitored to further approximate any potential environmental health determinant [85].

Assessment:

The indicator is assessed through an annual survey on a statistically representative subset of building occupants/neighbourhood inhabitants. Alongside a series of health and healthy behaviour-related questions, the location of responses is also collected. This will feed into a measure of spatial disparities (see "Units"

section). To be able to calculate this, the map of the neighbourhood must also be sectioned into a grid of n-sized squares (1 km <= n), where n is chosen according to urban structure case by case as the smallest area where social segregation is still meaningful. Additionally, where relevant, the variables specified in "demographic composition" (Table 24), and "Diverse community" (Table 29) must also be collected as metadata. The assessment variables are summarized in Table 38.

Table 38. Survey variables for healthy community.

Category	Variables	Format of evaluation
Healthy behaviour	Have a family doctor	True, false
Healthy behaviour	Saw a health professional in the past year with preventive purposes	True, false
Healthy behaviour	Saw a dentist in the past year.	True, false
Healthy behaviour	Received a flu shot in the past year.	True, false
Healthy behaviour	Walk 30+ minutes per day.	True, false
Healthy behaviour	Sleep more than 6 hours per night.	True, false
Healthy behaviour	Spend less than 2 hours in front of a screen outside work.	True, false
Healthy behaviour	Eat fast food less than twice per week.	True, false
Healthy behaviour	Physically active at least 150 minutes per week.	True, false
Healthy behaviour	Drink under 14 units[36] of alcohol per week, spread over at least 3 days.	True, false
Healthy behaviour	Non-smoker.	True, false
Health conditions	Good self-reported health.	True, false
Health conditions	Good self-reported mental health.	True, false
Health conditions	Healthy body mass index.	True, false
Health conditions	No report of asthma	True, false
Health conditions	No report of arthritis.	True, false
Health conditions	No report of high blood pressure.	True, false
Health conditions	No report of high stress levels.	True, false
Health conditions	No report of mood or anxiety disorder.	True, false

Units:

For both health conditions and healthy behaviour, two outcomes are measured: **overall health** (HC_{aggr}, reported as a percentage of True responses) for both building and neighbourhood scales, **disparities in health** (HC_{disp}, reported as a segregation measure) for neighbourhood scale.

Building: % of population (HC_{aggr}).

Neighbourhood: % of population (HC_{aggr}), 100-point-scale (HC_{disp}).

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[36] To calculate alcohol units: strength (alcohol by volume %) x volume (ml) ÷ 1000 = units

Calculation:

The overall health output is calculated by returning the mean of the share of True responses in either healthy behaviours, health conditions, or both. Each individual response returns a score between 1 and 5. Additionally, scores must be aggregated by type of determinant, and for all responses. All aggregations are by taking the mean of individual scores:

$$HC_{cat,aggr} = \frac{1}{N} \cdot \sum_{i=1}^{N} \frac{HC_{cat,ind,i}}{N}$$

(52)

Where:

$HC_{cat,aggr}$: overall health output for either health conditions or behaviour category

$HC_{cat,ind,i}$: number of True responses for question "i" in category=category

N: number of respondents

For disparities calculation, an index of dissimilarity is calculated, using the neighbourhood grid to subset population, and taking the cohort populations (number of True and False responses) in each subset to compare similarity between grid cells. The aggregation of dissimilarities between cells is the final index for disparity for a single response. When aggregating responses for a category (behaviour or conditions) or overall, the mean of individual disparity scores is used.

$$HC_{cat,disp} = \frac{1}{N} \cdot \sum_{z=1}^{N} \frac{1}{n} \cdot \sum_{i=1}^{n} \left| \frac{a_i}{A} - \frac{b_i}{B} \right| \cdot 100$$

(53)

Where:

$HC_{cat,disp}$: disparities index for any health category in the neighbourhood

a_i: population of cohort "a" in cell "i", where "a" is a cohort of interest (True responses)

b_i: population of cohort "b" in cell "i", where "a" is a control cohort (False responses)

A: total population in cohort "a"

B: total population in cohort "b"

n: number of cells

N: number of respondents

Interpretation:

While both indicators are normative, overall health alone is not necessarily indicative of building/neighbourhood performance, given the range of external health determinants. However, if disparities are present within the neighbourhood (high scores for disparities in health), it is indicative of an environmental determinant which must be further investigated. In this case, overall health and disparities must also be disaggregated to healthy behaviours and conditions to be able to rule out some of the more obvious, non-environmental determinants. In case there are spatial disparities, it is also advised to look for other disparities, i.e. the segregation measures of indicators "demographic composition" and "diverse community", and also a performance distribution audit for health conditions. If disparities of health score is low, a low overall health score still signals neighbourhood/occupant community issues that could be targeted with environmental interventions – however, it is not straightforward without further investigations, whether they would prove effective.

Guidelines for measurement and calculation

This section outlines some practical guidelines on how to monitor and evaluate social performance in SPEN buildings and on the neighbourhood scale. In general, the workflow consists of a data collection, a preprocessing, and an auditing phase (Figure 24). Data collection is further broken down into collecting physical and human information, as the former requires more technical, the latter more social science expertise to carry out. This information is merged into a coherent database of social performance inputs that is readily actionable by either machine or human indicator calculation during the preprocessing phase. Once the indicator results are returned, the auditing phase consists of a mandatory interpretation of results, and an optional further examination of how these results distribute across various social groups.
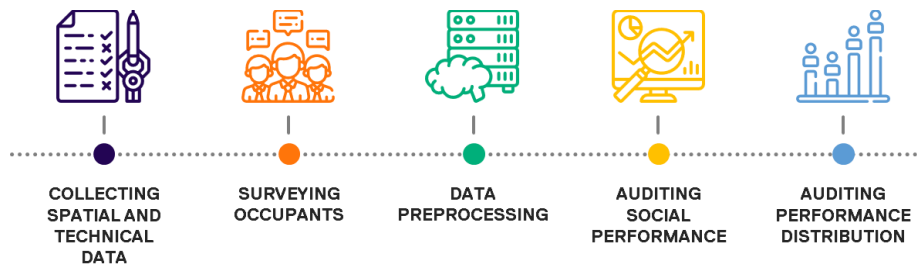

| COLLECTING SPATIAL AND TECHNICAL DATA | SURVEYING OCCUPANTS | DATA PREPROCESSING | AUDITING SOCIAL PERFORMANCE | AUDITING PERFORMANCE DISTRIBUTION |

Figure 24. Process of monitoring and evaluating social performance.

Collecting spatial and technical data

The assessment of social performance begins with the collection of physical information. This means (1) mapping the location around buildings or in the neighbourhood, or (2) screening the technical attributes of buildings and outdoor spaces. Multiple indicators require some form of mapping, which simply means identifying and registering **points of interests (POIs)** – such as bus stops for "access to services" – and some of their attributes – such as the presence/absence of audio-visual guidance systems in junctions for "universal design". POIs must be placed in a SPEN-specific cartesian reference system, where the auditors define the origin and the axes freely, but consistently. It is recommended to either follow dominant street directions, or align the system to cardinal directions, and avoid having to rely on negative coordinates. The following indicators involve mapping POIs:

- Access to amenities
- Access to services
- Universal design

Additionally, residential buildings must be registered as special POIs to be mapped together with their population (number of occupants), and access areas – as defined in the accessibility indicators.[37]

For some indicators, it is also necessary to **define a grid,** to subset the neighbourhood into smaller areas, where segregation measures can be calculated. The minimum size of the grid is 1 km by 1 km, however, the auditor must choose a grid size that outlines meaningful cells in the specific urban fabric for the purposes of social segregation calculation. The grid is used in the following indicators:

- Demographic composition
- Diverse community
- Healthy community

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[37] In case the buildings are already stored as polygons or 3D models in a neighbourhood database/digital twin, only the access areas need to be mapped, from their centre of mass.

Finally, the map must also register the **boundaries of the SPEN,** and an extended boundary parallel to it, with a distance equalling to the largest characteristic distance, as defined in the accessibility indicators. Figure 25 illustrates how all the pieces would appear on a map.

Figure 25. Illustration of how to register mapping data.

In addition to mapping, several indicators require **screening technical parameters** on either building or neighbourhood scale. These indicators provide a checklist of items the auditor must go through. The checklist either contains criteria for normative indicators (indicator outputs) – in which case, collecting the data is already an evaluation – or enablers for descriptive indicators (indicator outputs) – in which case, data collection does not require expert judgement. What exactly is being screened depends on the phase of the evaluation: in design phase, only technical documentation is screened, while during operation, and for existing buildings/neighbourhoods, additional site visits are prescribed. Table 39 summarizes all screening activities.

Table 39. All technical screening activities.

Indicator	Checklist items	Type of criteria	Common data sources[38]
Democratic legitimacy	4	Normative	Consultation plan; consultation report
Living conditions	2	Normative	Floor plan; structural diagnostic report; architectural specifications; building digital twin; site visits
Sustainable mobility	10	Descriptive	Online map; floor plan; public transportation website; site visits
Universal design	10	Normative	Floor plan; architectural specifications; site visits

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[38] The possible documents to be screened may vary by location. Most commonly used documents are listed in the table.

Social cohesion	5	Descriptive	Site plan; floor plan; urban planning instruments; social media; site visits
Personal safety	10	Descriptive	Site plan; floor plan; architectural specifications; site visits
Personal safety	1	Normative	Local government statistics

Surveying occupants/inhabitants

Most of the data for social performance is collected from the occupants/inhabitants of the audited building/neighbourhood through surveys. There are two types of surveys in the syn.ikia framework, the **annual household survey**, and the **quinquennial household survey** – which is to be taken every five years. For some indicators, the survey variables can be substituted by micro-scale data, as they align to information routinely collected in the EU-SILC survey (for annual survey data), and in national censuses (for quinquennial survey data). It is therefore advised to involve the local government prior surveying to synchronise surveying efforts, and check if there is already available data for the audited neighbourhood. The exact data specification, to which the indicators align, are given in the assessment section where relevant. The following indicators contain variables that align with European survey metrics (with an indication whether all variables are aligned, or only some – full/partial alignment):

- Affordability of energy: fully aligned
- Affordability of housing: fully aligned
- Demographic composition: fully aligned
- Living conditions: partially aligned
- Sustainable mobility: partially aligned
- Diverse community: partially aligned
- Social cohesion: partially aligned
- Personal safety: partially aligned

Once all possible substitutions are explored, the remaining data needs to be filled through surveying. For all surveys a representative sample of population (building occupants or total neighbourhood inhabitants) must be accessed. Under syn.ikia standards, the acceptable margin of error is 5% at a confidence interval of 95%. The size of the sample must be calculated using equation N (54) and (55), assuming that the total populations are always known.

$$P_{sample} = \frac{P_{tot} \cdot X}{(X + P_{tot} - 1)} \tag{54}$$

Where

P_{sample}: survey sample size

P_{tot}: total population size

and

$$X = \frac{1,96^2 \cdot p \cdot (1 - p)}{0,05^2} \tag{55}$$

Where

p: sample proportion

Once sample sizes are determined, the survey questionnaire can be designed. The following indicators have explicitly formulated survey questions to avoid collecting sensitive data:

- Affordability of housing
- Affordability of energy

For the remaining indicators, survey questions are not explicit in the descriptions to allow the auditor to translate and tailor the questions to the audience. Instead, specifications of the variables are given, which the questioning must return accurately. As not all indicators that require either annual or quinquennial surveys are core, the exact surveys handed out will be different case by case. Table 40 summarizes indicators with survey activities.

Table 40. Overview of survey activities

Indicator	Survey variables	Frequency	Format of evaluation
Democratic legitimacy	10	Unique	True, false
Affordability of energy	2	Annual	True, false
Affordability of housing	1	Annual	True, false
Affordability of housing	1	Annual	Numerical
Demographic composition	3	Quinquennial	Multiple choice
Living conditions	2	Quinquennial	True, false
Sustainable mobility	3	Annual	Numerical
Diverse community	4	Quinquennial	Multiple choice
Social cohesion	4	Annual	True, false
Social cohesion	2	Annual	Multiple choice
Personal safety	3	Annual	True, false
Energy consciousness	19	Annual	5-point Likert scale
Healthy community	18	Annual	True, false

Data preprocessing

The data collected following the assessment guidelines must be go through a **standard quality assurance protocol (DQA)** before being plugged into the calculations. DQA can be partially automated, but it is also possible for the auditor to perform all tasks by hand. The potentially automated tasks include various missing data measures, while the remaining tasks are compiled as a criteria checklist, all of which must pass for the DQA to pass. DQA must be performed each time a new survey is taken, or a new data source is acquired. DQA is not necessary for mapping and screening, unless they are supplied through third-party, or automated means (e.g. POIs filled up from open-source online GIS, or consultation reports are screened by an NLP engine).

The missing data workflow must be initiated whenever surveys return incomplete data and follow a strict protocol of different actions for different patterns of missing data. Table 41 describes the protocol in full.

Table 41. Missing data handling protocol

Task ID	Task description
A.1	If a time series of data exists with at least 10 measured points, and at least 7 of the last 10 data on the time series are maximum 1 standard deviation far from its mean (of the last 10 data points), carry the last observation forward. Else, proceed to A.2

A.2	Measure the magnitude of completeness by dividing the number of missing records with the total number of records for each variable. If the magnitude is less than 30% of total number of records, proceed to A.3, else repeat the survey.
A.3	The scope of auxiliary attributes must be enumerated, meaning the number of variables that are complete must be counted. If at least 50% of variables and at least 5 are complete, impute the missing values using k-nearest-neighbours algorithm on the complete variables. Else, proceed to A.4.
A.4	Check if data is not missing at random by calculating the Pearson correlation coefficient between missingness and each "demographic composition" and "diverse community" variable. If correlations are high (0,7<), the survey must be repeated for the cohorts that failed to produce data. Else, proceed to A.5. If neither indicator is measured, proceed to A.5.
A.5	If dropping the missing value records does not increase the margin of error above 5%, drop the records. Else, fill the missing values with the mean of all values.

The criteria checklist evaluation on the other hand has no particular order linked to it, however all criteria must pass for the data to be considered admissible. If there is no trust in the quality of data (any of the criteria failed), the survey must either be repeated, extended, or a plausible reasoning for admitting the data anyway must be provided for the community. Table 42 describe the criteria in full.

Table 42. Data quality checklist.

Criterion	Validation
Aggregation	Appropriate metadata is collected to make aggregation, disaggregation, output filtering possible where relevant.
Consistency	The survey question intuitively reflects the survey variable for any respondent. Where questions had to be rephrased, the responses are consistent with the variable specification.
Reliability	The response is credible, the respondent can be trusted to answer survey questions freely, honestly, without any motivation to gain anything from a particular response.
Accessibility	The cost (amount of effort) to produce the data is reasonable. There is no significant burden on neither the respondent, neither the audit.
Reasonableness	The complete dataset is plausible, it has no anomalies that cannot be explained, new surveys do not produce volatile results.
Validity	Two different auditors would likely produce the same data with the given methodology, on the same sample.

Auditing social performance

Social performance on building/neighbourhood scale is audited by plugging in adequate quality input data to the calculations for each different indicator. The outcomes are either shown as numerical scores, in some cases supplemented by lists of descriptive features. Once the results are published, two steps remain to be taken: (1) setting up target values for monitoring, and (2) optionally expanding the scope of monitoring to audit performance distribution.

With few exceptions, normative social performance indicators do not have predefined target values. Targets can be set by comparing to a baseline, by deriving from strategic goals, or by benchmarking. In the design phase of tabula rasa neighbourhood developments, many indicators will have projected outputs, while when applying the framework to an existing neighbourhood for the first time, the indicators will reveal a snapshot of the status quo. In both cases, this initial assessment provides a baseline, to which future assessments can refer to. Alternatively, on the strategic level, specific targets can be set according to the goals of the community, building owners/occupants, or any decision-making authority. Finally, existing, published

monitoring of reference, similar, frontrunner buildings and neighbourhoods can be benchmarked to get actionable targets. However, in all cases, both the limitations of the local context, and the usual rate, at which social performance areas change must be considered when setting explicit expectations for improvement.

Auditing performance distribution

Description:

It is not always sufficient to evaluate overall social performance, as it might obscure disparities among social groups. One of the core pillars of social performance at the SPEN scale is equity, with related indicators signalling potential injustice inequalities in the access to goods, resources, opportunities, decision-making for high standards of living and wellbeing. The role of auditing performance distribution is to recognise such injustices by disaggregating KPI outcomes to:

1. systematically disadvantaged groups (such as ethnic minorities);
2. vulnerable groups (such as elderly people);
3. groups to whom individual KPIs might be more important (such as having access to schools for families).

A performance distribution audit can be triggered by the community or recommended by the auditor based on the results of the two indicators describing composition: "demographic composition", and "diverse community".

Assessment:

A performance distribution audit examines whether being a member of a highlighted group correlates with certain levels of performance in any given indicator. Mathematically, this means testing for the null hypothesis that the distribution among different groups is equal.

$$H_0: \bar{x}_1 = \bar{x}_2 = \bar{x}_3 = \cdots = \bar{x}_k \qquad (56)$$

Where $\bar{x}$ denotes sample means for the k groups.

The hypothesis is rejected if any of the sample group distributions differ significantly. The testing is done via one-way analysis of variance (ANOVA) for pairs of groups where k_1 is always the highlighted group of interest, and k_2 is a relevant control group, specific for each group of interest. The null hypothesis is rejected for a statistical significance level of 0.05, meaning a 5% risk of concluding that a difference exists when there is no actual difference.

Calculation:

A sample calculation on a dummy database is shown in Appendix F – Sample calculation on a dummy database.

The prerequisite for auditing performance distribution is the existence of both household-scale and individual-scale metadata, which is tied to the monitoring of every other KPI. This makes it possible to disaggregate KPI results along attributes listed in the household metadata. For syn.ikia, Table 43 lists a set of metadata to be collected, however any individual SPEN may choose to expand this list, or use it selectively, when reasonable to do so. Possible reasons to omit attributes from the household metadata include data protection concerns, upholding the citizen's autonomy over their personal data, or irrelevance of attribute in the local context.

Attribute	Specification	Reference
Gendered household	Male: all adult occupants are male. Female: all adult occupants are female. Non-binary: all adult occupants are non-binary. Standard (control): all other households.	
Elderly occupancy	True: at least one occupant is above the age of 65. False (control): all other households.	[85]
Elderly household	True: all adult occupants are above the age of 65. False (control): all other households.	[91]
Household size	Couple with children Couple without children Single adult with children Single adult without children Other type of household Control: to be set to the largest stratum, or to a stratum chosen as the standard for the context by the auditors.	[91]
Child occupancy	True: at least one occupant below the age of 18 False (control): all other households.	[85]
Ethnic household	If at least one occupant self-reports to be of ethnic origin, strata must be defined on a case-by-case basis. When designing questionnaires, locally present ethnic groups must be explicitly offered.	[85]
Immigrant household	National: at least one occupant moved from outside the municipality as an adult. EU: at least one occupant moved from outside the country, but within the EU/EEA as an adult. Global: at least one occupant moved from outside the EU/EEA. Local: all other households. Control: may be defined either as "local" or as "local" OR "national". It is recommended to use the former in rural, and the latter in urban context.	[85]
Low-income household	True: household income is below the 60 % of the median household income of the examined country. False (control): all other households.	[91]
Disabled occupancy	True: at least one occupant has long-term "physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others". False (control): all other households.	[109]
Disabled household	True: all adult occupants have long-term "physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder	[109]

	their full and effective participation in society on an equal basis with others". False (control): all other households.	

For auditing a single observed KPI, the auditor selects a relevant target group and a relevant control group, and prepares a 2D labelled data structure (dataframe, table etc.) with a single feature: "group", and a single independent variable: "performance". The data structure is to be sampled or bootstrapped to two equally sized samples with the same amount of records in both the control and target groups. Depending on the specific KPI, additional preprocessing steps, especially missing data handling, might be necessary. One-way ANOVA is then to be performed on the preprocessed data structure with F-ratio (with both degrees of freedom), p-value, and eta-squared outputs. The null hypothesis is rejected by testing either the F-ratio with an appropriate critical F-ratio table[39], or the p-value. The threshold for statistical significance is 0.05.

Interpretation

In the case of a reported potential inequality, the auditor recommends further investigations whether the relationship between being part of a cohort and performance is causal and whether it stems from discriminatory practices and injustice in opportunities or procedures. Also, the magnitude of the effect of being in a certain group is to be reported by referring to the eta-squared value.

Optionally, multiple features may be included in the audit to test whether there is a clear separation among different groups. However, as this may obscure the results for certain smaller groups, multiple-feature testing is always to be performed in addition and not instead of single-feature testing. Additionally, it might also be relevant to test input data of certain KPIs instead of the KPI score directly, such as when a KPI score itself is discretized.

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[39] such as: http://users.sussex.ac.uk/~grahamh/RM1web/F-ratio%20table%202005.pdf

9. Smartness and Flexibility KPIs

Introduction

This chapter focuses on two core KPIs, the flexibility Index and the Smart Readiness Indicator (SRI). The Flexibility Index has been developed at DTU during the past years, and several publications which explain it in details are available, such as [110], [111]. Those publications explain how the index is built and describe specific applications of it. In contrary, the SRI is developed mainly by VITO, and has been adopted by the EU as the main measure to evaluate how smart-ready buildings are[40].

Table 44. Smartness & Flexibility key performance indicators: the Sub-KPI are referred to as "Impact Domains" in [112].

Category	Sub category	KPI type **Core or Sub (secondary/co mplementary)**	KPI	Unit (B/N/BN)[41]
Smartness and Flexibility	Flexibility Index	Core KPI	Flexibility Index	BN: -
	Smartness Readiness Indicator (SRI)	Core KPI	Delivered energy per energy carrier	BN: -

Definition of KPIs

Flexibility Index

The flexibility index is defined as the savings due to utilising energy flexibility for a given price-signal [111]. For example, given a price-signal, a building or a neighbourhood obtaining a Flexibility Index of 0.1 means that the building or neighbourhood is able to save 10% of its energy costs, by applying energy flexibility, for that particular price signal. An example of this is shown in Figure 26. Comparison of flexible and non-flexible heating of an office building. Top plot shows the temperatures, middle plot shows the heating schedule and price, while bottom plot shows accumulated costs, where the top plot shows the temperature of an office building if it is heated in a smart way in green, and in a regular way in red. The middle plot shows the cost of energy consumption of time in black, while the heating schedules are shown in green and red. The bottom plot shows the accumulated cost for each of the heating schedules, and the final values (to the right) are the total costs for this period that can be used to compute the flexibility index, which in this case is around 0.1.

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[40] https://smartreadinessindicator.eu/

[41] B and building, N as neighbourhood and BN as both building and neighbourhood level.
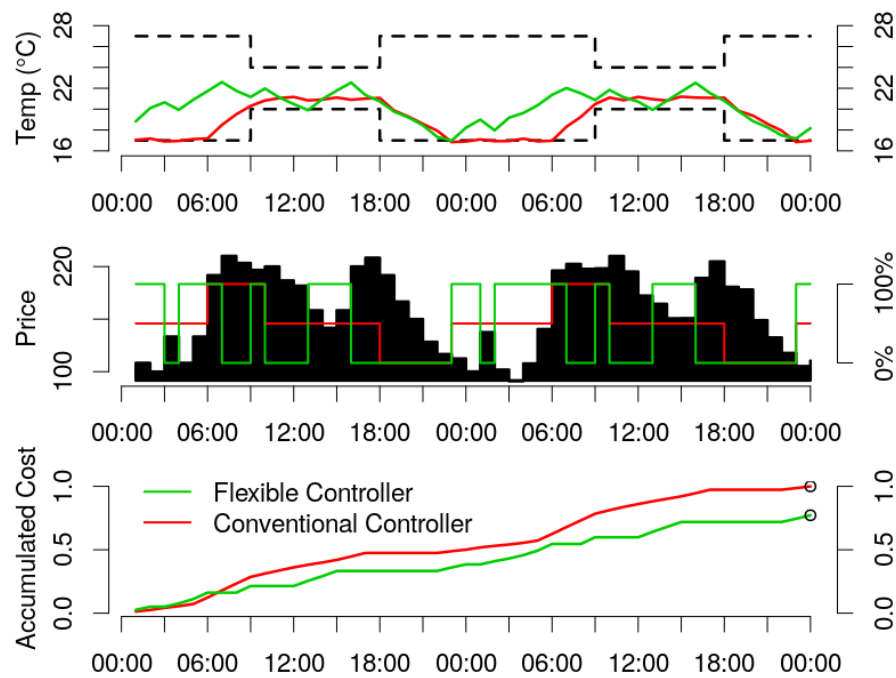
Figure 26. Comparison of flexible and non-flexible heating of an office building. Top plot shows the temperatures, middle plot shows the heating schedule and price, while bottom plot shows accumulated costs.

Smart Readiness Indicator

According to the executive summary [112] on the "Smart Readiness Indicators", the aim of the SRI is to "make the added value of building smartness more tangible for building users, owners, tenants and smart service providers".

The report presents a picture (*Figure 27*) where the advantaged provided by the SRI are listed.
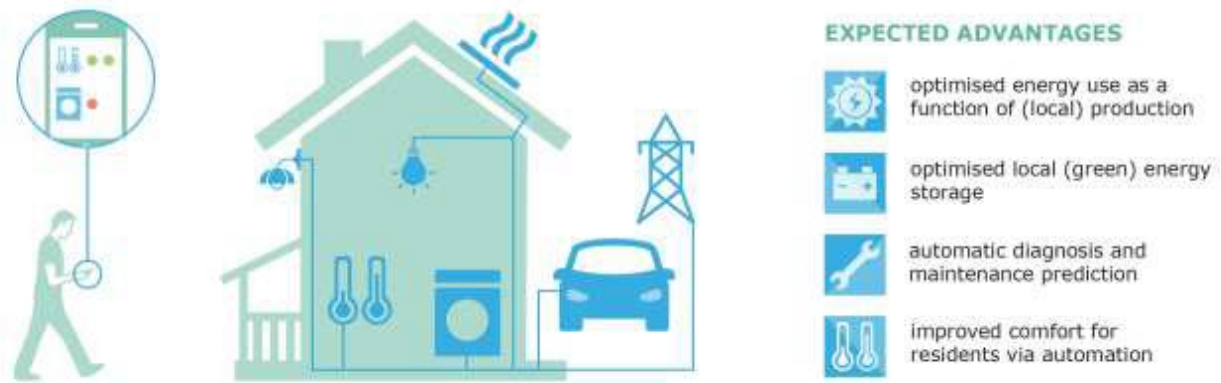

Figure 27. Expected advantages of smart technologies in buildings, source: [112]*.*

The SRI executive summary also provides a definition of smartness of a building:

> *"Smartness of a building refers to the ability of a building or its systems to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation to the operation of technical building systems or the external environment (including energy grids) and to demands from building occupants"* [112]*.*

In order to apply the definition above to neighbourhood level, the definition can simply be adapted to neighbourhoods as follows:

> *"**Smartness of a neighbourhood** refers to the ability of a neighbourhood or its systems and its buildings to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation to the operation of technical building systems or the external environment (including internal neighbourhood's energy grid and the external energy grids) and to demands from the occupants and the users of the different buildings and services".*

Following again the SRI executive summary, it can be stated that the readiness of neighbourhood to be smart is related to three aspects: adapt in response to the needs of the occupants and users, facilitate the maintenance and operation process, adapt in response to (price) signals from the grid (Figure 28).

Figure 28. Areas of readiness that the SRI refers to [112].

A mnemonic (possibly tri-partite) of the SRI is not ready yet, but the Executive Summary indicates some possible outcome, as reported in Figure 29.

Figure 29. Examples of mnemonics to convey the overall SRI score/rank and sub-score/ranks for the three SRI "pillars" [112].

At time of the creation of this report (June 2020), the calculation procedure is not out yet (it should be out in July 2020). However, from the Executive Summary it can be observed that 3 different calculation methods are to be expected (Figure 30);

- **Procedure (A)** is quick and for small residential buildings
- **Procedure (B)** is detailed (requires up to one day for a building depending on the complexity of the building)
- **Procedure (C)** is for in-use assessment.

Only procedure B and C could be used in the case of neighbourhoods, because of the complexity levels of those.
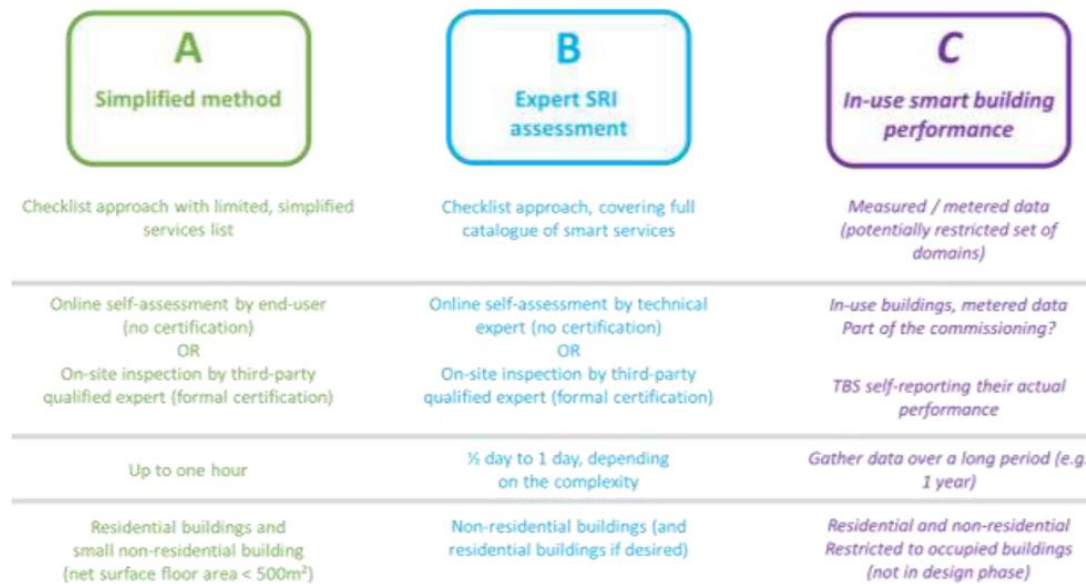
Figure 30. Examples of mnemonics to convey the overall SRI score/rank and sub-score/ranks for the three SRI "pillars" [112].

Guidelines for measurement and calculation

Design phase

Flexibility Index

The general approach to computing the Flexibility Index is to:

- Simulate the energy flexible system (in this case the energy use of a building or a neighbourhood) *without* using energy flexibility; The time-series of the energy use will be stored in the vector Y_0.
- Simulate the energy flexible system *using* energy flexibility to minimise cost, given a price-signal, λ, storing the time-series of demand in the vector Y.
- Obtain the cost of running the system *without using* energy flexibility, by multiplying the demand at each time-step with the corresponding price, and summing up all time steps, $C_0 = \sum_{k=0}^{N} Y_0^t \lambda_t$.
- Compute the cost of running the system *using* energy flexibility, $C_1 = \sum_{k=0}^{N} Y_t \lambda_t$.
- Compute the fractional savings, $\text{FI} = 1 - \frac{C_1}{C_0}$.

Price signal

The price-signal should reflect what use-case the energy flexibility is being tested for. For example, the price signal might reflect the time-varying CO_2-content in the electricity grid for a given country, in which case the flexibility index will assess the value of the energy flexibility when using it to minimize CO_2-emissions for the given country. Similarly, historical market prices can be used, to see the potential for bidding the energy flexibility into these markets. Finally, the price-signal might be completely artificial, but consist of variation that tests certain aspects of the energy flexibility that one is interested in. The bottom-line is that the price signal determines what kind of energy flexibility is being tested. See [113] for more discussion on choosing price-signals.

For a given price-signal, the only challenge is to compute the demand. If a simulation model is available, this can be done by simulating the system controlled according to the price-signal. Notice that it is not possible to compute the flexibility index without a price-based controller, and similarly the flexibility index will vary for different choices of controllers. If possible, this simulation approach should be used, since it is simple and accurate when a simulation model with price-based controller is available.

The calculation methods shall become public in summer 2020, according to internal sources of VITO. The method represents nine domains and seven impact criteria:

The nine domains are [112]:	*The seven impact criteria are:*
1. Heating	1. Energy savings on site
2. cooling	2. Flexibility for the grid and storage
3. domestic hot water	3. Comfort
4. controlled ventilation	4. Convenience
5. lighting	5. Wellbeing and health
6. dynamic building envelope,	6. Maintenance and fault prediction
7. electricity	7. Information to occupants
8. electric vehicle charging and	
9. monitoring and control	

In the Executive Summary [112], a structure of domains and impact criteria is proposed (and here reported in Figure 31). For the exact calculation procedure, it is referred to the publications of VITO on https://smartreadinessindicator.eu/milestones-and-documents. At this stage and with the available information, it is not foreseen to face any difficulty in adopting the SRI procedure from a building level to a neighbourhood level. However, the exact calculation procedure is not available and it is hence not possible to indicate if the SRI is a necessary KPI for the evaluation of the syn.ikia demo-cases. It is important to consider that many of the syn.ikia categories have similarities and overlapping contents with the SRI "impact criteria":

1. the SRI impact criteria "**Energy Savings on Site**" has potential similarities with the syn.ikia category "**Energy and Economic**"
2. the SRI impact criteria "**Flexibility for the GRID and Storage**" has potential similarities with the syn.ikia category "**Flexibility**"
3. the SRI impact criteria "**Comfort**" has potential similarities with the syn.ikia category "**IEQ**"
4. the SRI impact criteria "**Convenience**", "**Well-being and Health**" and "**Information to Occupants**" has potential similarities with the syn.ikia category "**Social**"
5. the SRI impact criteria "**Maintenance and Fault Predictions**" has potential similarities with the syn.ikia category "**Smartness**"

Given the fact that the calculation procedure was not published by time of creation of this deliverable, nor it was it yet possible to calculate the SRI for specific buildings through an online tool, the calculation of the SRI is not mandatory for syn.ikia demos[42]. However, the calculation of the SRI is recommended, if possible, once the calculation tools will be available, and in particular the recommended calculation method is the "expert SRI assessment" accordingly to *Figure 30*. Since the SRI is designed for buildings, preliminary contacts between VITO and the syn.ikia consortium to verify the possibilities to use the SRI also for neighborhoods have been initiated.

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[42] The SRI calculation procedure was published in October 2020. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12365-Implementation-modalities-of-the-smart-readiness-indicator-for-buildings
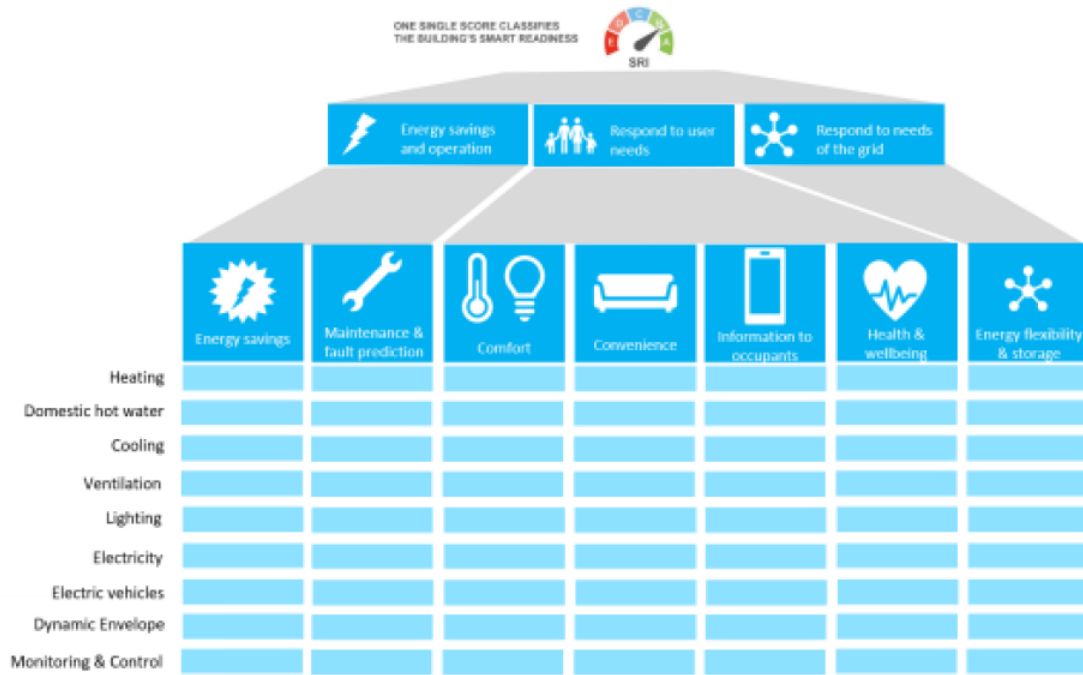
Figure 31. Proposed structure of domains and impacts criteria [112].

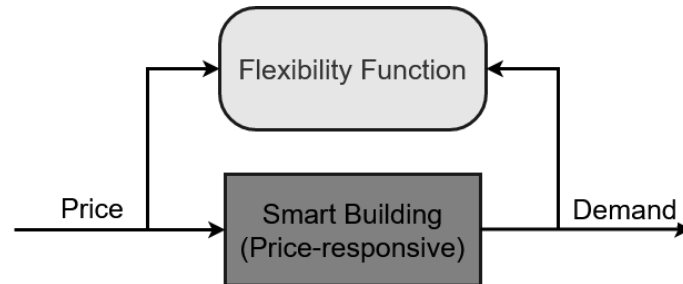## Evaluation phase

Flexibility Index

Figure 32. The Flexibility Function is estimated using price as input and demand as output.

If, instead of a simulation model, there is data available of the energy flexible building being controlled according to time-varying prices, then system identification can be used to estimate a flexibility function. The basic procedure here is to use price as *input* and demand as *output*, as shown on Figure 32.

From this point on, the task is to find a suitable model that predicts the output for given inputs. An advantage of this approach is that the data can be obtained for existing smart buildings, even while they are still in use. Since the relationship is dynamic (the current demand is influenced not only by the current price but also previous prices), the model should be dynamic as well. In [111] it is suggested to use a finite impulse response model, which is a well-known and simple linear model of the form

$$Y_t = \sum_{k=0}^{M} h_k \lambda_{t-k}$$

(57)

Where

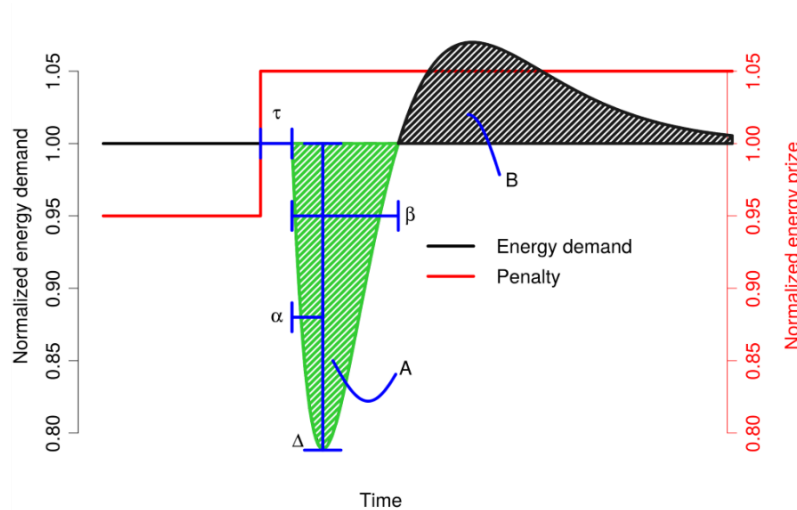h_k are parameters (the impulse response) that need to be estimated.

Figure 33. General shape of change in demand, due to a step-increase in price.

The accuracy of this is limited, and thus in [110], it was suggested to use a system of stochastic differential equations instead. Although unfamiliar territory for most, this greatly increases accuracy and interpretability. After estimating the flexibility function, the result is a model that, for given prices predicts demand, similarly to what is illustrated in Figure 32. The Flexibility Function is estimated using price as input and demand as output. For all buildings and neighbourhoods, the general response to a step-increase in price should follow that of Figure 33. It shows a general shape of change in demand, due to a step increase in price, with a decrease in demand that maxes out at some value, Δ, and returns to zero after some time, β, with a possible rebound effect.

Smartness readiness indicator

Information on the in-use calculation methods are not available at time of writing, therefore it is referred to the final report from VITO on the SRI.

10. References

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11. Acknowledging EU funding

12. Appendix A – Glossary of Terms

Table 45. Glossary of terms

Term	Description
CEN	European committee for standarization
CHP	Combined heat and power
DAG	Directed acyclic graph
DER	Distributed energy resources
DG	Distributed generation
DHW	Domestic hot water
DQA	Standard quality assurance protocol
DR	Demand response
EED	Energy efficiency directive
EMS	Energy management system
EP	Energy performance
EPB	Energy performance of a building
EPBD	Energy performance of a building directive
EV	Electrical vehicle
GFT	Goal framing theory
GHG	Greenhouse gas
HI	Heat index
HVAC	Heating, ventilation, air conditioning
IAQ	Indoor air quality
ICT	Information and communications technology
IED	Integrated energy design
IEQ	Indoor environmental quality
IRR	Internal rate of return
KPI	Key performance indicator
M&E	Measurement and evaluation
MCA	Multi criteria analysis
NC	Noise criteria
NPV	Net present value
NR	Noise rating
nZEB	Nearly zero energy building
PEB	Positive energy building
PED	Positive energy district

PMV	Predicted mean vote
POI	Point of interest
PPD	Predicted percentage dissatisfied
PV	Photovoltaic
RER	Renewable energy ratio
RES	Renewable energy resources
RH	Relative humidity
SBS	'Sick building syndrome'
SDG	Sustainable development goal
SGI	Services of general interest
SPEN	Sustainable positive energy neighbourhood
SRI	Smart readiness indicator
VOC	Volatile organic compound
WEC	World energy council

13. Appendix B – Primary energy weighting factors and non-renewable CO2 emission coefficients

*Table 46. Default primary energy factor and non-renewable emission coefficients from ISO-52000.*

Energy carrier Delivered from distant			Primary energy weighting factor			Non-renewable CO_2 emission coefficient
			Renewable	Renewable	Total	g/ kWh
1	Fossil fuels	Solid	1.1	0	1.1	360
2		Liquid	1.1	0	1.1	290
3		Gaseous	1.1	0	1.1	220
4	Bio fuels	Solid	0.2	1	1.2	40
5		Liquid	0.5	1	1.5	70
6		Gaseous	0.4	1	1.4	100
7	Electricity [c]	2.3	0.2	2.5	420	
	Delivered from nearby					
8	District heating [a]	1.3	0	1.3	260	
9	District cooling	1.3	0	1.3	260	
	Delivered from on-site					
10	Solar	PV-electricity	0	1	1	0
11		Thermal	0	1	1	0
12	Wind	0	1	1	0	
13	Geo-, aero-, hydrothermal	0	1	1	0	
	Exported					
14	Electricity [b c]	To the grid	2.3	0.2	2.5	420
15		To non EPB uses	2.3	0.2	2.5	420

[a] Default value based on natural gas boiler. Specific values are calculated according M3.8.5.

[b] It is possible to differentiate between different sources of electricity like wind or solar.

[c] These values are established in line with the default coefficient provided in Annex IV of Directive 2012/27/EU. This default coefficient is currently being reviewed and a later amendment of the above factor could be needed.

14. Appendix C – Energy and environmental performance sub KPIs

Energy produced on-site

Description:

The energy produced on-site refers to the energy that is produced on the premises and the parcel of land on which the building(s) is located and the building itself (Figure 34).
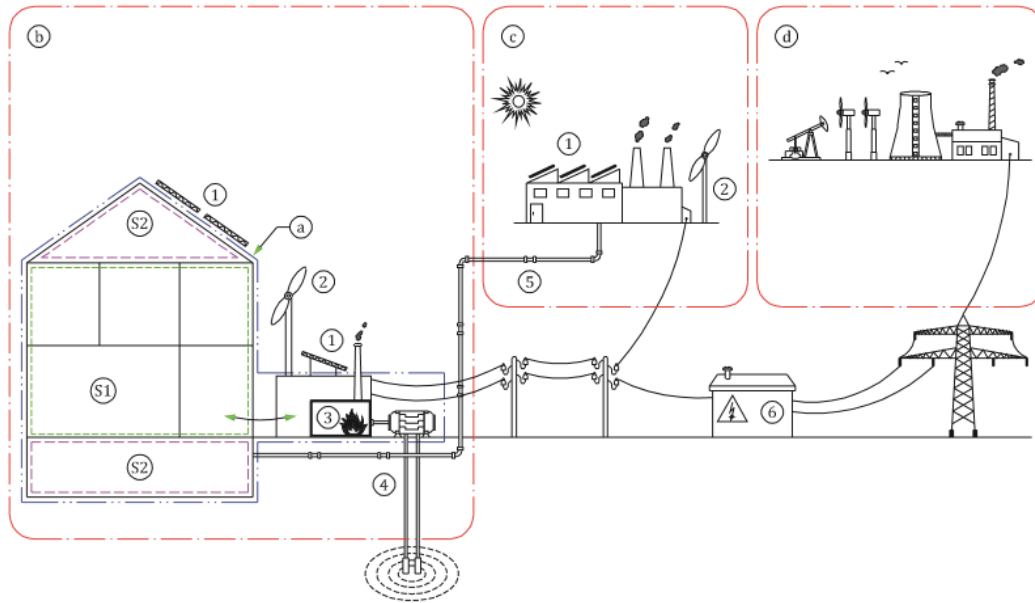
a – assessment boundary (use energy balance)	*1 – PV, solar*
b – perimeter: on-site	*2 – wind*
c – perimeter: nearby	*3 – boiler room*
d – perimeter: distant	*4 – heat pump*
S1 – thermally conditioned space	*5 – district heating/cooling*
S2 space outside themal envelope	*6 – substation (low/medium voltage and possible storage)*

Figure 34. Example of a scheme representing the concept of perimeters and assessment boundary [13].

Unit:

Building: kWh

Neighbourhood: kWh

Calculation:

$$E_{prod,i} = \sum_j E_{prod,i,j} \tag{58}$$

Where:

$E_{prod,i}$ – Energy produced on-site of energy carrier i

$E_{prod,i,j}$ – Energy produced on-site for energy carrier *i* and renewable energy system *j*

Electrical vehicle energy consumption

Description:

Year after year the number of sold electric vehicles (EVs) increases and the expectations are quite optimistic for future years to come. Regarding households, as most common EV batteries have a capacity of 24 kWh, which is more than the average household daily consumption, it seems obvious that the impact of EVs on daily energy consumption curves will be more than considerable. To evaluate and reduce the effects of EVs in buildings, it is important to count on smart energy management systems capable of optimizing the EV charges according to the instantaneous and the expected energy consumption of the building. These systems might also bring environmental and economic benefits to the building, which is why it is included also in syn.ikia [114].

In order to include smart charge policies, it is important to determine the amount of energy per charge that the EV would need, and mark down the arrival and departure times of the EV [114].

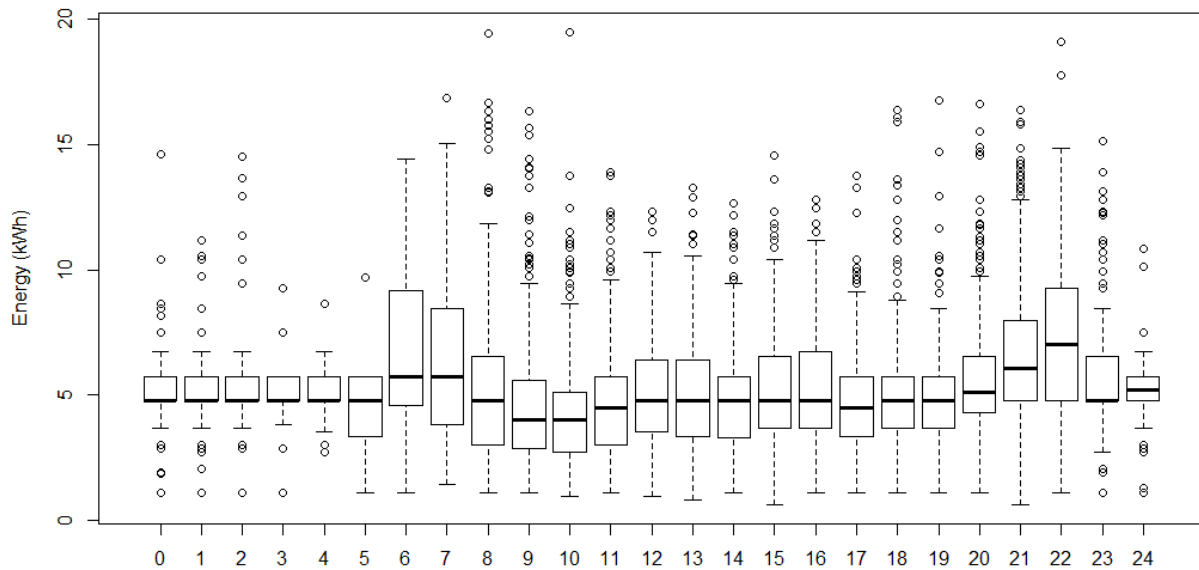*Figure 35. Boxplot of the energy of charges profile depending on the arrival time of the vehicle (hour on the X-axis)* [114].

Unit:

Building: kWh

Neighbourhood: kWh

Calculation:

$$EVC = \sum_i \int_{t_{arr}}^{t_{dep}} EVC_i(t) \cdot dt \qquad (59)$$

Where:

EVC – Total electric vehicle consumption

EVC_i – Energy consumption of an electric vehicle i

t_{arr} – arrival time

t_{dep} – departure time

# 15. Appendix D – Social performance KPIs methodology and metadata

This section introduces the basis upon which social indicators are defined and the practicalities unique to this subset of SPEN performance. It begins with identifying the scope of social performance monitoring in SPENs from its definition and core objectives, followed by a brief introduction to social sustainability assessment in general. The section finishes with the specification of the necessary metadata assigned to the social KPIs steaming from their unique standing among performance monitoring dimensions.

The objective, scope and justification of social performance is derived from the social aspects inherent in the definition of the SPEN. According to the local definition, a SPEN focuses on "indoor environmental quality, occupant satisfaction, social factors (co-use, shared services and infrastructure)". Its conceptualisation has evolved from a purely technical, energy-focused mindset of PENs to a more comprehensive and holistic approach. A SPEN is characterised by the integration of a neighbourhood energy balance, and neighbourhood-scale energy management in the context of neighbourhood governance (formal and informal institutions), social dynamics, occupant experience. On the one hand, this transition was necessary to underscore the synergies, multiplicative effects, trade-offs, conditions and other interactions between a plus-energy performance and social variables that together contribute to comprehensive sustainability. The complexity of occupant behaviour and energy use [115], the impact of energy efficiency on affordable living [116], and the health and wellbeing dimensions of environmental quality [117] indicate such interactions. On the other hand, the syn.ikia project is preparing a technical infrastructure that will allow the governance of pooled, distributed resources (energy assets, produced and stored energy, and flexibility services) with the involvement of stakeholders and communities. In the proposed SPEN, this infrastructure culminates in a management system (the cloud hub) with capabilities of model predictive control, that influences shared energy management and occupant behaviour. Ultimately this translates into the digital layer of an energy community, because in a SPEN, energy management is a pooled endeavour delegated to the neighbourhood/district scale. This means that its sustainable operation is measured also on the efficacy, stability, vitality, and fairness of its emergent organisational model, a place-based energy community [106]. In addition to this, the success of the SPEN depends on a vital and fair social network where necessary insights to make informed decisions are accessible in a timely and efficient manner, providing ample participation opportunities for all.

When measuring social performance, several unique considerations apply due to the contested, diverse and volatile character of the social dimension of sustainability [81], [83]. It could be argued that there is not enough standardisation in the theoretical definition of social sustainability, as the concept has emerged from a collection and interpretation of case-specific practices and political agendas [118]. Because of this, reference projects and existing indicator pools yield far more unique indicators with far less consistency than any other dimension of sustainability. Because of this limitation, methodological adjustment "A" has been applied to the social indicator research, which expands the sample of KPI from reference indicator pools until it is no longer feasible to explore more – i.e. the database is saturated.

Methodological adjustment "A": data saturation index

A data saturation index is defined as an objective stop-function for collecting KPIs for review. The index is specified based on previous algorithms to rationalize sample sizing and works as follows. Each new reference investigated yields a number of unique labels (KPI), both are registered. In each subsequent reference, only the labels that were not mentioned before are registered. Then, the series of unique labels are plotted (y axis) against the enumeration of references (x axis), forming the data saturation curve. It is expected that as more references are opened, the number of unique labels slowly diminish. The data saturation index is a slope on this curve the researcher chooses to stop opening new references, reasoned by their diminishing returns. In the scope of this project, the index is set to a slope of 1.00 for the last 3 and 5 references, with a minimum number of references set to 10. Data saturation was reached at 12 references, accumulating 56 unique labels, pooled from 338 relevant indicators.

Data saturation monitoring
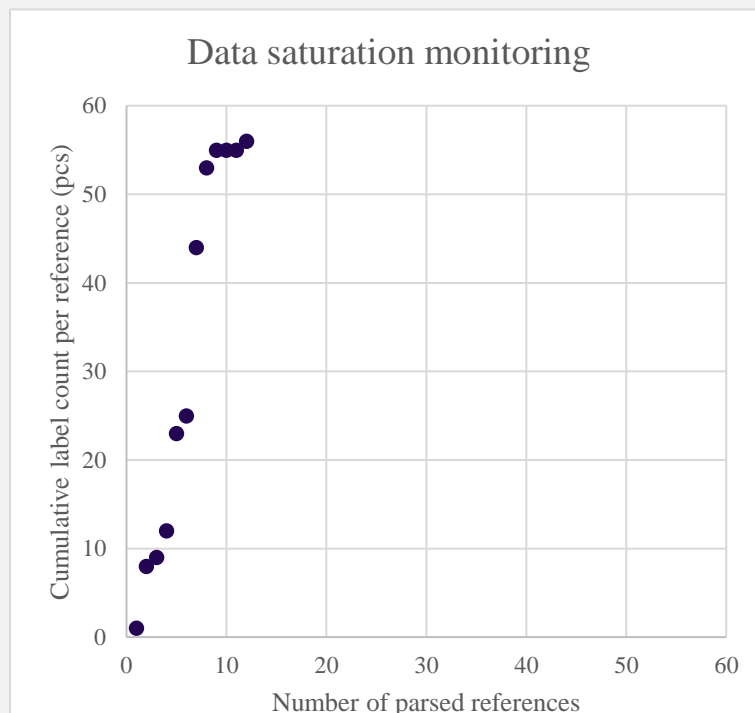
Considering that social sustainability is usually defined on a case-specific basis, setting up ex ante guidelines becomes necessary for identifying what constitutes social performance in the context of a SPEN. The most important factor for adjusting the scope of references is scale. In many cases, different components of social sustainability are discussed on varying scales, such as social cohesion on national, employment on city, social interactions, and environmental quality at hyperlocal (neighbourhood) scales [83] in the case of a SPEN, its size suggests the relevance of neighbourhood scale indicators, focusing on local environment and social networks, group dynamics. However, the SPEN also involves the collaborative management of energy assets, resources, infrastructure, meaning some protocols, institutions are expected to emerge (e.g. an energy community). This means that indicators relating to justice, legitimacy, participation, and in general the way decisions are collectively made – usually appearing first on the urban scale [119] – become relevant. Finally, performance tied to individual human outcomes, such as health, economic stability traditionally, and experiences, such as behaviour, wellbeing more recently, are subdimensions monitored indiscriminately in most projects at all scales [81]. These three subdimensions represent the core of social performance in syn.ikia, which is also well represented in the definition of social sustainability proposed by Polese and Stren that is taken as the working definition in this project as well [82]:

Additionally, the three subdimensions for social performance are reformulated as three tests to streamline the collection of indicators as methodological adjustment "B".

Methodological adjustment "B": SPEN social performance conceptual framework

During parsing the references for indicators, before plugging them into the data saturation function, the retrieved indicators are met with three tests to assess their thematic relevance to the SPEN concept of social performance. The tests are derived from relevant literature reflecting the urban scale, neighbourhood scale, and scale-independent approaches social sustainability. With the three tests, a pool of 445 general indicators from 12 references was filtered to 338 relevant indicators.

Test 01: **Equity**. The indicator describes the fair, just, legitimate functioning of a place-based community or institution. It refers to the presence or absence of procedural, social or environmental discrimination, the equitable access both local services (such as education, green spaces, adequate and affordable housing, public transportation), and to decision-making in matters of relevance, especially those related to the management of pooled assets and resources. It includes normative values furthering equal opportunities, social justice, human dignity, democratic legitimacy in the apportionment of resources, regardless of identity, gender, religion, wealth, or location.

Test 02: **Community**. The indicator describes the ability of the community to maintain itself and thrive. On the one hand, this refers to the stability of the community, its overall maintenance of balance, with a healthy turnover rate accepting new, active citizens, while maintaining a base of long-term residents. On the other hand this refers to the ability of the social network to accumulate and distribute social capital, signified by features such as trust, interactions, conflicts, cooperation, actionable heterogeneity in both the social network itself, and in the use of place occupied by the community.

Test 03: **People**. The indicator describes individual or aggregated human experiences, behaviour, choices, and outcomes. It relates both to hard, basic human needs, such as health, employment, education, security, and also to soft themes, such as wellbeing, happiness, comfort and quality of life. It also refers to high quality living environments, that enable or hinder these human outcomes through environmental impacts. Finally, it may also describe the way people (sustainably) experience, use, exploit, and manage the environments, infrastructure, assets and resources physically embedded in or otherwise associated with the community – such as occupant behaviour.

Given that the tests did not filter enough indicators for the pool to be processed for data saturation assessment at this point, an additional pooling round was conducted to set a common label for indicators and metrics that were either outright duplicates, or measured the same thing with from a different approach, scope, or methodology. This exercise ran in parallel with data saturation monitoring, pooling 338 unique indicators into 56 labels.

A final round of filtering was conducted once saturation was reached in internal Delphi sessions. Labels belonging categories such as indoor environmental quality metrics, number of electrical sockets, and others that were vaguely relevant and/or not actionable at the SPEN scale, such as migration, were excluded. However, some metrics were retained as contextual metadata necessary for interpreting KPI results. This final round of selection resulted in the 16 KPIs presented in this document.

Finally, it is worth mentioning that some social performance related considerations will influence the way information is organised and interpreted, even if they will affect the definition of KPIs itself. These considerations will be handled by introducing structural metadata (in the form of tags), and a set of specific guidelines that are unique to social KPI to provide more user-friendly filter logic when evaluating monitoring results. In brief, we refer to: (1) the ambivalence in the subject of monitoring, (2) the contestability of normative values, and (3) the importance of perceived performance.

The first consideration relates to the monitoring of the social KPIs which can focus either on the individual or emergent properties of people, the properties of the protocols among people, or the properties of the conditions where people are present – i.e. the built environment. Social sustainability metrics and frameworks have been criticised in the past for focusing almost exclusively on people [120], while recent scholars continuously seek ways to formulate interpretations of sociological concepts in architectural or urban contexts [121]. Because of the physical scale of a SPEN, both approaches are important, and it is worth considering each monitoring factor individually, may it be people, protocols, or environment that requires specific attention. They have thus been added as tags to social KPI metadata as part of methodological adjustment "C".

The second consideration is the contestability of normative values renders the analysis of social KPI far more interpretative and far less straightforward than any of the more engineering-driven information. In many cases it is not self-evident whether more/less for a given KPI is inherently good or bad. In some cases, there is an optimum, such as internal cohesion, which, when too low, would lead to the disintegration of the community, while, when too high, could lead to a very isolated community. Where the optimum lies, is heavily context-dependent, making benchmarking and comparisons especially difficult. In other cases, higher scores for a KPI might indicate something positive, while lower scores indicate nothing, such as for participation rate in collective decisions-making. Because of this ambiguity, many KPIs will not be explicitly normative, at least not on their own. It is possible that there are several markers or proxies of optimal group cohesion, and only if none of them are hit, can we give a normative evaluation that cohesion is lacking. Because it is also possible that some metrics might serve as a normative KPI for one performance, and would have to bundled together with other proxies for another, it is necessary to signal the role(s) of the indicator in its metadata – as described by a set of non-exclusive tags in methodological adjustment "C".

The third consideration relates to the unique standing of the social KPIs describing occupant experiences and perceptions. It is a common pitfall to believe that because performance monitoring reports on the functionality of a system, people will be satisfied with the system [122]. Therefore, it is crucial that individual and aggregated perceptions of performance are coupled with their objective assessment. This is necessary to (1) see if a KPI is adequately benchmarked for the specific community, (2) diagnose any anomalies, such as missing causal links to a performance, (3) raise awareness to the varying impacts of certain aspects of the SPEN to certain people. This latter is particularly important to foster intra-community empathy, as decisions will be made collectively, for the collective interest, and the trade-offs must be known to ensure their legitimacy [123]. As part of methodological adjustment "C", subjective KPIs are tagged accordingly, with a reference to any objective KPI that is coupled with them.

Methodological adjustment "C": metadata unique to social KPI

Anthropological: indicators with this tag measure properties of persons and properties emergent in the association of multiple people.

Spatial: indicators with this tag measure properties of the physical conditions of social performance, including, but not limited to spatial quality, spatial configurations, infrastructure, built and natural environment.

Protocol: indicators with this tag measure properties regarding the organization, interactions, rules, and regulatory aspects of the community.

Normative: indicators with this tag have a clear representation of a desirable status, with a scoring scheme representing progress towards it. Normative indicators are comparable, and benchmarkable.

Descriptive: indicators with this tag describe a performance without any indication of a desirable status. Descriptive indicators are contexts to other indicators for specific interpretation.

16. Appendix E – Tag based KPI structure

#	KPI list	Tag logic									
		Domain of sustainability	Life cycle	Scale	Functio nality	Type	Authority	5D	5S	SPEN framework	Syn.ikia masterplan
1	Non-renewable primary energy consumption	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Occupant, Facility manager,Grid operator, Building owner	Design, Decarboniza tion	Save, Shave	Self consumption, GHG emission, Energy Performance	Climate neutral, energy efficient, surplus RES energy, Sustainable operation
2	Renewable energy ratio	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Occupant, Facility manager,Grid operator, Building owner	Design, Decarboniza tion, Decentraliza tion	Save, Shave	Self consumption, GHG emission, Energy Performance	Climate neutral, energy efficient, surplus RES energy
3	Load cover factor	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager,Grid operator	Decarboniza tion, Decentraliza tion	Save, Shave	Self consumption, Energy Performance, Grid interaction	Climate neutral, energy efficient, surplus RES energy
4	Supply cover factor	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager, Grid operator	Decarboniza tion, Decentraliza tion	Save, Shave	Self consumption, Energy Performance, Grid interaction	Climate neutral, energy efficient, surplus RES energy

5	Grid purchase factor	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager,Grid operator	Decarboniza tion, Decentraliza tion	Save, Shave	Self consumption, Energy Performance, Grid interaction	Climate neutral, energy efficient, surplus RES energy
6	Peak power (delivered/ex ported)	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager,Grid operator, Building owner	Design, Decarboniza tion, Decentraliza tion	Shave, Share, Scale	Self consumption, Grid interaction	Climate neutral, energy efficient, surplus RES energy, Sustainable operation
7	Net energy duration curve (energy carrier)	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager,Grid operator, Building owner	Design, Decarboniza tion, Decentraliza tion	Shave, Share, Scale	Self consumption, Grid interaction	Climate neutral, energy efficient, surplus RES energy, Sustainable operation
8	Connection capacity credit	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager,Grid operator	Design, Decarboniza tion, Decentraliza tion	Shave, Share, Scale	Self consumption, Grid interaction	Climate neutral, Sustainable operation
9	Total GHG emissions	Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager,Grid operator, Building owner, Policy developer	Design, Decarboniza tion	Save, Scale	Self consumption, Energy Performance, GHG emission	Climate neutral
10	Delivered energy per energy carrier	Environmental	Design, Operation	Building, Neighbour hood	Sub	Numerical	Facility manager,Grid operator, Building owner	Design, Decarboniza tion, Decentraliza tion	Save, Share	Self consumption, Energy Performance, GHG emission	Climate neutral, energy efficient
11	Exported energy per	Environmental	Design, Operation	Building, Neighbour hood	Sub	Numerical	Facility manager,Grid	Design, Decarboniza tion,	Save, Share	Self consumption, Energy	Climate neutral, energy efficient

#	Indicator	Dimension	Phase	Scale	Type	Measure	Stakeholders	Driver	S	Category	Goal
	energy carrier						operator, Building owner	Decentralization		Performance, GHG emission	
12	Energy use of buildings	Environmental	Design, Operation	Building, Neighbourhood	Sub	Numerical	Facility manager,Grid operator, Building owner	Design, Decarbonization	Save	Self consumption, Energy Performance, GHG emission	Climate neutral, energy efficient
13	Energy produced on-site	Environmental	Design, Operation	Building, Neighbourhood	Sub	Numerical	Facility manager,Grid operator, Building owner	Design, Decarbonization, Decentralization	Save, Share	Self consumption, Energy Performance, GHG emission	Climate neutral, energy efficient, surplus RES energy
14	Electrical Vehicle Energy consumption	Environmental	Design, Operation	Building, Neighbourhood	Sub	Numerical	Occupant, Facility manager,Grid operator, Building owner	Design, Decarbonization, Decentralization	Scale	Energy Performance, Grid interaction, GHG emission	Climate neutral
15	Flexibility Index	Environmental ,Economical	Design, Operation	Building, Neighbourhood	Core	Index	Facility manager,Grid operator, Policy developer	Decentralization	Shave, Share	Self consumption, GHG emission	Active management of energy flows
16	Smart readiness indicator	Environmental ,Economical, Social	Design, Operation	Building, Neighbourhood	Core	Index	Facility manager,Grid operator, Policy developer	Digitalization	Shave, Share	Self consumption, GHG emission	Active management of energy flows
17	Investment cost	Economical	Design	Building, Neighbourhood	Sub	Numerical	Building owner, Policy developer	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
18	Other cost	Economical	Design, Operation	Building, Neighbourhood	Core	Numerical	Facility manager	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation

19	Operation related cost	Economical	Design	Building, Neighbour hood	Core	Numerical	Facility manager	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
20	Requirement related cost	Economical	Design, Operation	Building, Neighbour hood	Core	Numerical	Facility manager	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
21	Maintenanc e related costs	Economical	Design, Operation	Building, Neighbour hood	Core	Numerical	Building owner, Facility manager	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
22	Share of investment covered grants	Economical	Design	Building, Neighbour hood	Core	Numerical	Building owner, Policy developer	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
23	Net Present Value	Economical	Design	Building, Neighbour hood	Sub	Numerical	Occupant, Building owner, Policy developer	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
24	Internal Rate of Return	Economical	Design	Building, Neighbour hood	Sub	Numerical	Occupant, Building owner, Policy developer	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
25	Economic Value Added	Economical	Design	Building, Neighbour hood	Sub	Numerical	Occupant, Building owner, Policy developer	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
26	Payback Period	Economical	Design	Building, Neighbour hood	Sub	Numerical	Occupant, Building owner, Policy developer	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
27	NZEB Cost Comparison	Economical	Design	Building, Neighbour hood	Sub	Numerical	Occupant, Building owner, Policy developer	Design	Save	Cost efficiency	Economic sustainability, Sustainable operation
28	CO2 concentratio n	Environmental , Social	Operation	Building	Sub	Numerical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort

29	Predicted Mean Vote (PMV)	Environmental, Social	Design, Operation	Building, Neighbourhood	Core	Categorical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort
30	Predicted percentage of dissatisfied (PPD)	Environmental, Social	Design, Operation	Building, Neighbourhood	Core	Categorical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort
31	Temperature	Environmental, Social	Design, Operation	Building, Neighbourhood	Sub	Numerical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort
32	Relative humidity	Environmental, Social	Design, Operation	Building, Neighbourhood	Sub	Numerical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort
33	Daylight factor	Environmental, Social	Operation	Building, Neighbourhood	Core	Categorical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort
34	Illuminance	Environmental, Social	Design, Operation	Building, Neighbourhood	Sub	Numerical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort
35	Sound pressure level	Environmental, Social	Operation	Building, Neighbourhood	Core	Categorical	Facility manager, Occupant	Democracy, Design	Shine	IEQ, Occupant satisfaction	Improved user comfort
36	Access to amenities	Social	Design, Operation	Neighbourhood	Sub	Numerical	Occupant	Democracy, Design	Save, Shine	Occupant satisfaction, Social factors	Good architectural and spatial qualities
37	Access to services	Social	Design, Operation	Neighbourhood	Core	Numerical	Occupant	Democracy, Design	Save, Shine	Occupant satisfaction, Social factors	Good architectural and spatial qualities

38	Democratic legitimacy	Social	Design, Operation	Neighbour hood	Core	Numerical	Occupant, policy developer	Democracy, Design	Share,Shine	Occupant satisfaction, Social factors	Sustainable operation
39	Demographic composition	Social	Design, Operation	Neighbour hood	Sub	Numerical	Occupant, policy developer	Democracy, Design	Shine	Occupant satisfaction, Social factors	Sustainable operation
40	Sustainable mobility	Social, Environmental	Design, Operation	Building, Neighbour hood	Sub	Numerical	Occupant	Democracy, Design	Save, Share	GHG emission, Energy performance	Sustainable operation, Energy efficiency
41	Personal safety	Social	Design, Operation	Building, Neighbour hood	Core	Categorical	Occupant	Democracy, Design	Shine	Occupant satisfaction, Social factors	Good architectural and spatial qualities
42	Social cohesion	Social	Design, Operation	Neighbour hood	Sub	Categorical	Occupant, policy developer	Democracy, Design	Share,Shine	Occupant satisfaction, Social factors	Sustainable operation
43	Universal design	Social, Environmental	Design	Building, Neighbour hood	Sub	Numerical	Occupant, Building owner	Democracy, Design	Shine	Occupant satisfaction, Social factors	Good architectural and spatial qualities
44	Affordability of housing	Social, Economical	Design, Operation	Building, Neighbour hood	Core	Numerical	Occupant, policy developer	Democracy, Design	Save,Scale	Cost efficiency	Economic sustainability
45	Affordability of energy	Social, Economical	Design, Operation	Building, Neighbour hood	Core	Numerical	Occupant, policy developer	Democracy, Design	Save,Share,Scale	Cost efficiency, Self consumption	Economic sustainability
46	Living conditions	Social, Environmental	Design, Operation	Building, Neighbour hood	Core	Numerical	Occupant	Democracy, Design	Shine	Occupant satisfaction, Social factors	Good architectural and spatial qualities, improved user comfort
47	Diverse community	Social	Operation	Neighbour hood	Sub	Numerical	Occupant, policy developer	Democracy, Design	Share,Shine	Occupant satisfaction, Social factors	Sustainable operation

48	Energy consciousness	Social, Environmental	Design, Operation	Building, Neighbourhood	Core	Categorical	Occupant, Facility manager	Democracy, Design	Share,Save	Cost efficiency, Self consumption	Sustainable operation, Energy efficiency
49	Healthy community	Social	Operation	Building, Neighbourhood	Sub	Numerical	Occupant, policy developer	Democracy, Design	Shine	Occupant satisfaction, Social factors	Good architectural and spatial qualities

17. Appendix F – Sample calculation on a dummy database

ANOVA demonstration

```
In [25]: import matplotlib.pyplot as plt
         import pandas as pd
         import numpy.random as random
         from scipy.stats import f
         import seaborn as sns
```

```
In [50]: #Randomized database of 100 values
         df_cats = pd.Series(random.choice(a=['group_1', 'group_2'], size=100, p=[0.5, 0.5]), name='group')
         df_ints = pd.Series(random.randint(0,100, size=(100)), name='performance')

         data = pd.concat([df_cats, df_ints], axis=1)
         data.head()
```

Out[50]:

	group	performance
0	group_1	4
1	group_1	16
2	group_1	84
3	group_2	21
4	group_2	21

```
In [85]: #Take equal-sized samples from the two groups
         size = min(data.groupby('group').size()) # smallest group defines index
         sample = data.groupby('group').apply(lambda x: x.sample(size))
         sample.reset_index(drop=True, inplace=True)
         sample.groupby('group').size()
```

```
Out[85]: group
         group_1    35
         group_2    35
         dtype: int64
```

```
In [86]: #Graphical EDA
         sns.set(style="whitegrid")
         plt.figure(figsize=(12,8))
         sns.boxplot('group', 'performance', data=sample, width=0.2)
```

```
Out[86]: <matplotlib.axes._subplots.AxesSubplot at 0x2471a203e48>
```
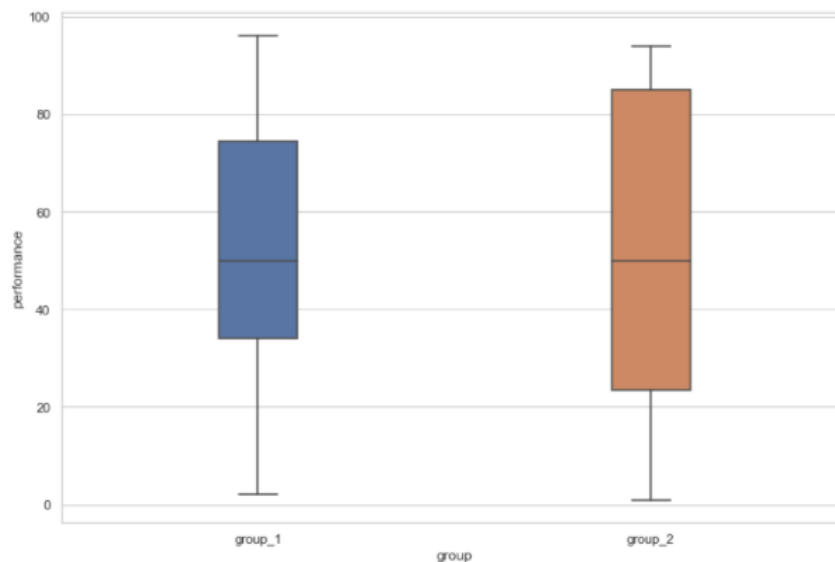


```
In [87]: #Parameters for ANOVA
         ctrl = data['performance'][data.group == 'control']

         grps = pd.unique(data.group.values)
         d_data = {grp:data['performance'][data.group == grp] for grp in grps}
         k = len(pd.unique(data.group))  #number of groups
         N = len(data.values)  #conditions times participants
         n = sample.groupby('group').size()[0] #observations in group
         k, N, n
```

```
Out[87]: (2, 100, 35)
```

```
In [137]: #Between
          SS_a = float(((((sample.groupby('group').mean() - sample.performance.mean()) **2) * n).sum())
          SS_a

Out[137]: 6.300000000000029
```

```
In [130]: #Within
          SS_sa_1 = ((sample[sample['group']=='group_1']['performance'] - sample.groupby('group').mean()['performance'][0]) **2).sum()
          SS_sa_2 = ((sample[sample['group']=='group_2']['performance'] - sample.groupby('group').mean()['performance'][1]) **2).sum()
          SS_sa = sum([SS_ta_1, SS_ta_2])
          SS_sa

Out[130]: 55338.68571428571
```

```
In [138]: #Total
          SS_t = SS_a + SS_sa
          SS_t

Out[138]: 55344.985714285714
```

```
In [144]: #Degrees of freedom
          df_a = k - 1 #numerator degree of freedom
          df_sa = N - k #denominator degree of freedom
          df_t = N - 1

          df_a, df_sa, df_t

Out[144]: (1, 98, 99)
```

```
In [139]: #Test statistic for F-test
          MS_a = SS_a/df_a
          MS_sa = SS_sa/df_sa
          F = MS_a / MS_sa
          F

Out[139]: 0.01115675213516357
```

```
In [145]: #Hypothesis test metrics
          p = f.sf(F, df_a, df_sa)
          eta_sqrd = SS_a/SS_t
          om_sqrd = (SS_a - (df_a * MS_sa))/(SS_t + MS_sa)

          #Reporting
          report_dict = {'F': F, 'PR(>F)': p, 'EtaSq': eta_sqrd, 'OmegaSq': om_sqrd}
          report_dict

Out[145]: {'F': 0.01115675213516357,
           'PR(>F)': 0.9160953700164286,
           'EtaSq': 0.00011383145046821948,
           'OmegaSq': -0.009987190133939243}
```

```
In [47]: import statsmodels.api as sm
         from statsmodels.formula.api import ols
```

```
In [142]: mod = ols('performance ~ group', data=sample).fit()
          aov_table = sm.stats.anova_lm(mod, typ=1)
          print(aov_table)

                       df       sum_sq     mean_sq        F     PR(>F)
          group       1.0     6.300000    6.300000  0.007741  0.930147
          Residual   68.0  55338.685714  813.804202      NaN       NaN
```

Results indicated that these means did not differ significantly, $F_{(2,98)} = 0.0112$, $p > 0.05$. The proportion of variance in satisfaction accounted for by group was approximately 0%, $\eta 2 = .0001$.

syn.ikia

Sustainable plus energy neighbourhoods

Post Occupancy Evaluation Survey
CHARACTERISATION OF THE INDOOR ENVIRONMETAL QUALITY

Building Occupant,

Syn.ikia project aims at achieving sustainable plus energy neighbourhoods while ensuring high quality indoor environment and well-being.

We would like to invite you to fill in the following short voluntary survey. This would help us to understand and improve your satisfaction levels over different aspects of the indoor environment. Please note that the survey is anonymised and data will be handled confidentially. It will take you approximately 15 minutes to fill it in.

Please be honest with your answers.
Your responses are extremely valuable to our research!

If you have any questions,
please do not hesitate to contact us
through the following e-mail:
[to be filled in by the interviewer
with his/her own email address]

Thank you for participating in this survey!
Your opinion counts!

———

Date:[to be filled in by the interviewer]
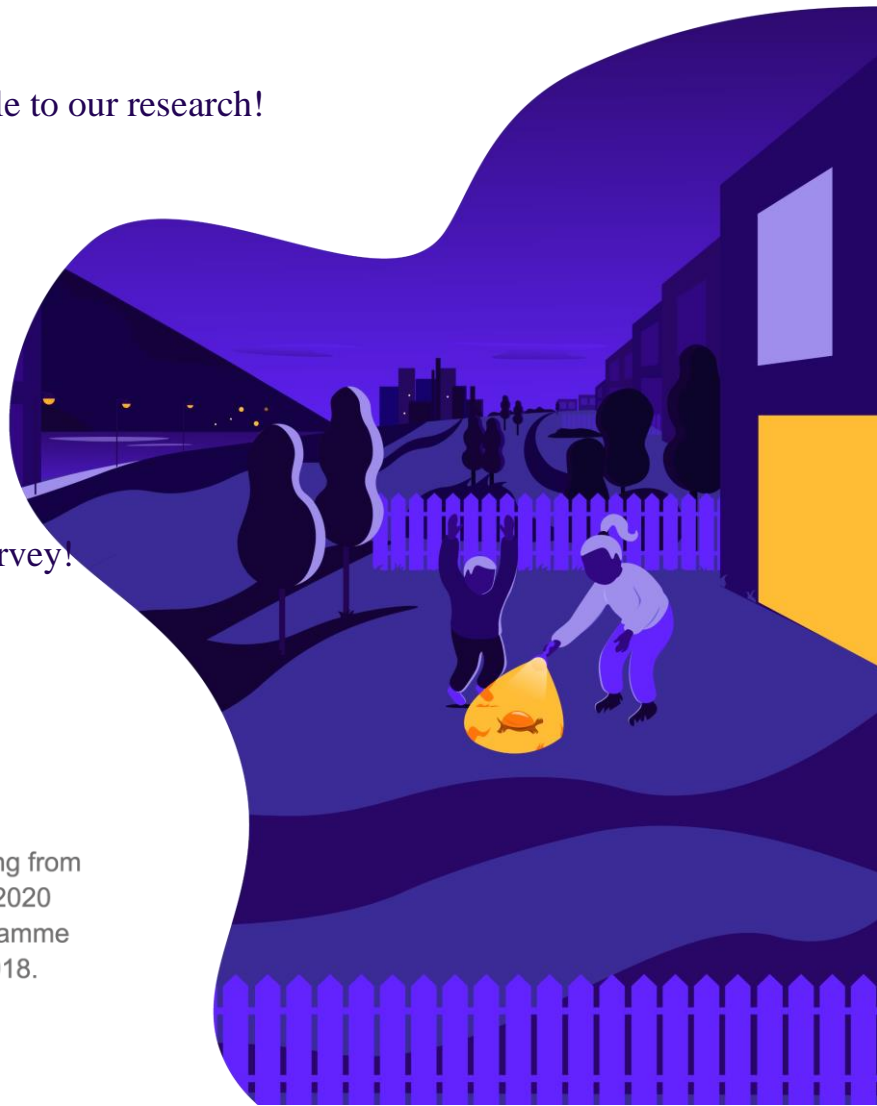
To be completed by the interviewer:

Country/City:

Pilot Project Name (Neighbourhood / District):

Name of Building:

Code name of apartment:

To be completed by the interviewee:

Gender

- Male
- Female
- Other
- Prefer not to say

General information

Are you a smoker?

- Yes
- No

What is the composition of the family living in this apartment?

- Individual
- Couple without children
- Couple with children
- Single parent family
- Other, please specify…

Please specify the number of occupants per gender living in this apartment?

- Male…
- Female…
- Other…

Please specify the number of persons per age group:

- 0 to 18 ….
- 19 to 30…
- 31-50…
- 51-65….
- ≥66 ….

What is your 'relationship' with this apartment?

- Owner
- Tenant
- Other

How long have you been living in this apartment in its current condition (pre- or post-renovation)?

- < 1 year
- 1 year
- 2 -5 years
- 5-10 years
- >10 years

Occupant's activity and control over the indoor environment

Please select your usual activity while being in the living room:

- Reclining (e.g. sleeping)
- Seated relaxed (e.g. watching TV)
- Sedentary activity (e.g. reading, eating)
- Standing, light activity (cleaning)
- Standing, medium activity (domestic work)
- Walking indoors
- Other….. (please specify)

Please refer to the table below and place a tick mark next to the clothing combinations that you are typically wearing inside the apartment during *Winter:*

Typical combinations of garments for daily wear clothing	
Panties, T-shirt, shorts, light socks, sandals	
Underpants, shirt with short sleeves, light trousers, light socks, shoes	
Panties, petticoat, stockings, dress, shoes	
Underwear, shirt, trousers, socks, shoes	
Panties, shirt, trousers, jacket, socks, shoes	
Panties, stockings, blouse, long skirt, jacket, shoes	
Underwear with long sleeves and legs, shirt, trousers, V-neck sweater, jacket, socks, shoes	
Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	

Please refer to the table below and place a tick mark next to the clothing combinations that you are typically wearing inside the apartment during *Summer*:

Typical combinations of garments for daily wear clothing	
Panties, T-shirt, shorts, light socks, sandals	
Underpants, shirt with short sleeves, light trousers, light socks, shoes	
Panties, petticoat, stockings, dress, shoes	
Underwear, shirt, trousers, socks, shoes	
Panties, shirt, trousers, jacket, socks, shoes	
Panties, stockings, blouse, long skirt, jacket, shoes	
Underwear with long sleeves and legs, shirt, trousers, V-neck sweater, jacket, socks, shoes	
Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	

Please specify the time slots that you are in the living room during typical *weekdays* (weekdays: Monday to Friday):

- 9:00-12:00
- 12:00-15:00
- 15:00-17:00
- 17:00-20:00
- 20:00-23:00
- 23:00-06:00
- 06:00-09:00

Please specify the time range that you are in the living room during a typical *weekend*:

- 9:00-12:00
- 12:00-15:00
- 15:00-17:00
- 17:00-20:00
- 20:00-23:00
- 23:00-06:00
- 06:00-09:00

On a typical year, which months do you turn on the heating?

- Sept-May
- Oct-Apr
- Nov-Mar

If you use the cooling system, which months are you using it?

_____

What is the set point temperature (programmed in the thermostat) of your room in during the heating season (winter)?

_____

What is the set point temperature (only if A/C is used) of your room during the cooling season (summer)?

_____

What is the set-back temperature for night during the heating season (winter)?

_____

What is the set-back temperature for night during the cooling season (summer)?

_____

_____

Do you open the windows in your living room in the Winter and for how long?

- In the morning
  - o 0-15 minutes
  - o 15-30 minutes
  - o 30-60 minutes
  - o More than 1 hour
- In the afternoon
  - o 0-15 minutes
  - o 15-30 minutes
  - o 30-60 minutes
  - o More than 1 hour
- At night
  - o 0-15 minutes
  - o 15-30 minutes
  - o 30-60 minutes
  - o More than 1 hour
- I do not open the windows in the winter
- Other….. (please specify)

Do you open the windows in your living room in the Summer?

- In the morning
    - 0-15 minutes
    - 15-30 minutes
    - 30-60 minutes
    - More than 1 hour
- In the afternoon
    - 0-15 minutes
    - 15-30 minutes
    - 30-60 minutes
    - More than 1 hour
- At night
    - 0-15 minutes
    - 15-30 minutes
    - 30-60 minutes
    - More than 1 hour
- I do not open the windows in the Summer
- Other….. (please specify)

Which is the main reason for opening windows and vents (in windows or walls)?

- To improve thermal comfort
- To remove indoor odours
- To refresh the indoor air

Which is the main reason for not making use of natural ventilation (open windows)?

- Noise
- Privacy
- Security
- Air pollution
- Maintain indoor temperature

What passive strategies for shading and ventilation do you use and when?

	Winter morning	Winter afternoon	Winter night	Summer morning	Summer afternoon	Summer night
External blinds						
Internal blinds/						
Curtains						
Canopies						
Natural ventilation						

Thermal environment

How do you generally perceive the thermal environment of the living room in the Summer during the day?

Very Cold ☹☹☹	Cold ☹☹	Cool ☹	Neutral! ☺☺☺	Slightly Warm ☹	Warm ☹☹	Very Hot ☹☹☹

How do you generally perceive the thermal environment of the living room in the Winter during the day?

Very Cold ☹☹☹	Cold ☹☹	Cool ☹	Neutral! ☺☺☺	Slightly Warm ☹	Hot ☹☹	Very Hot ☹☹☹

How satisfied are you with the temperature in your living room?

1	2	3	4	5	6	7

Very satisfied   Very dissatisfied

How do you perceive the thermal environment of the living room during the Summer?

Acceptable! ☺ ☺ ☺	Non-Acceptable ☹ ☹ ☹

How do you perceive the thermal environment of the living room during the Winter?

Acceptable! ☺ ☺ ☺	Non-Acceptable ☹ ☹ ☹

In general, how would you like the thermal environment to be during the Summer:

Cooler ☹	No change! ☺☺☺	Warmer ☹

In general, how would you like the thermal environment to be during the Winter:

Cooler ☹	No change! ☺☺☺	Warmer ☹

How do you feel in general in this space?

- Very comfortable
- Comfortable
- Slightly comfortable
- Not comfortable
- Not comfortable at all

What gave you discomfort in the Summer?

- Uncontrolled air flows
- Temperature differences within the rooms
- Daily temperature range
- Direct solar radiation
- Stagnant air (lack of ventilation)
- Other, please specify

What gave you discomfort in the Winter?

- Cold walls
- Cold floors
- Low sun gains

_____

How do you think the thermal comfort of your living room could be improved?

_____

How acceptable do you generally find the thermal environment during the Summer?

- Acceptable
- Non-acceptable

How acceptable do you generally find the thermal environment during the Winter?

- Acceptable
- Non-acceptable

If you were in discomfort how would you best describe the source of discomfort?

- Air too dry
- Air too humid
- Air movement too strong
- Direct solar radiation
- Heating/cooling system does not respond quickly to the thermostat

How do you generally perceive the thermal environment of the **bedroom** in the Summer during the **night**?

Very Cold ☹☹☹	Cold ☹☹	Cool ☹	Neutral! ☺☺☺	Slightly Warm ☹	Hot ☹☹	Very Hot ☹☹☹

How do you generally perceive the thermal environment of the **bedroom** in the Winter during the **night**?

Very Cold ☹☹☹	Cold ☹☹	Cool ☹	Neutral! ☺☺☺	Slightly Warm ☹	Hot ☹☹	Very Hot ☹☹☹

How do you perceive the thermal environment of the **bedroom** during the Summer **at night**?

- Clearly acceptable
- Acceptable
- Just acceptable
- Not acceptable
- Clearly not acceptable

How do you perceive the thermal environment of the **bedroom** during the Winter **at night**?

- Clearly acceptable
- Acceptable
- Just acceptable
- Not acceptable
- Clearly not acceptable

In general, how would you like the thermal environment to be during the **Summer in your bedroom at night**:

Cooler ☹	No change! ☺☺☺	Warmer ☹

In general, how would you like the thermal environment to be during the Winter **in your bedroom at night**:

Cooler ☹	No change! ☺☺☺	Warmer ☹

Indoor air quality

How satisfied are you with the air movement within the living room?

1	2	3	4	5	6	7

Very satisfied   Very dissatisfied

How would you characterize the air draft of your living room in a typical day?

1	2	3	4	5	6	7

Fresh 😊😊   ☹️☹️ Stale

1	2	3	4	5	6	7

Odourless 😊😊   ☹️☹️ Smells

How satisfied are you with the air quality in your living room?

1	2	3	4	5	6	7

Very satisfied   Very dissatisfied

In case you are not satisfied with the indoor air quality, which would be the reasons of your dissatisfaction?

- Bad odours from inside the house
- Bad odours from the outside
- Damp and too moisty air
- Presence of mould
- Window condensation

How do you perceive the indoor air quality?

- Clearly acceptable
- Acceptable
- Just acceptable
- Not acceptable
- Clearly not acceptable

How do you perceive the outdoor air quality OUTSIDE your house?

1	2	3	4	5	6	7

Extremely good! 😊😊   ☹️☹️

Extremely poor

Lighting and visual comfort

How satisfied are you with the amount of light in your living room?

1	2	3	4	5	6	7

Very satisfied   Very dissatisfied

How satisfied are you with the visual comfort of the lighting (e.g. glare, reflections)?

1	2	3	4	5	6	7

Very satisfied   Very dissatisfied

If you are dissatisfied with the lighting levels in your living room, what is the reason of your dissatisfaction?

- Too bright
- Too dark
- Not enough daylight
- Too much daylight
- Not enough artificial lighting
- Too much artificial lighting
- Glare
- Other …. (Please specify)

Acoustics comfort

How satisfied are you with the noise level in the room?

1	2	3	4	5	6	7

Very satisfied ☺☺   ☹☹ Very dissatisfied

How satisfied are you with the internal sound transmission to the living room from adjacent rooms?

1	2	3	4	5	6	7

Very satisfied ☺☺   ☹☹ Very dissatisfied

How satisfied are you with the outdoor noise level from the neighbourhood?

-

1	2	3	4	5	6	7

Very satisfied ☺☺   ☹☹ Very dissatisfied

Health symptoms related to the indoor environment

syn.ikia

1. **Do you have an allergy?**

Yes	No

2. **Do you have asthma?**

Yes	No

3. **Did you ever have eczema?**

Yes	No

4. **Are you feeling sleepy or tired?**

Yes	No

5. **Do you have headache?**

Yes	No

6. **Do you have itching or irritating eyes?**

Yes	No

7. **Do you have itching or irritating nose?**

Yes	No

8. **Do you have a dry or sore throat?**

Yes	no

9. **Do you have a cough?**

Yes	No

10. **Do you have difficulty in concentrating?**

Yes	No

Thank you for your cooperation

The above questions have been taken from standardised questionnaires and internationally approved organizations and EN standards such as the EN ISO 7730, ASHRAE Standard 55(American Society of Heating, Refrigerating and Air-Conditioning Engineers), the Centter for the Built Environment (CBE) survey of Berkeley and EPA (Environmental Protection Agency). Inputs from corresponding surveys of the EU projects such as EXCEED and GRowSmarter have also been taken into account for the development of this survey.

Indoor Environmental Quality Checklist

TO BE COMPLETED BY ASSESSORS
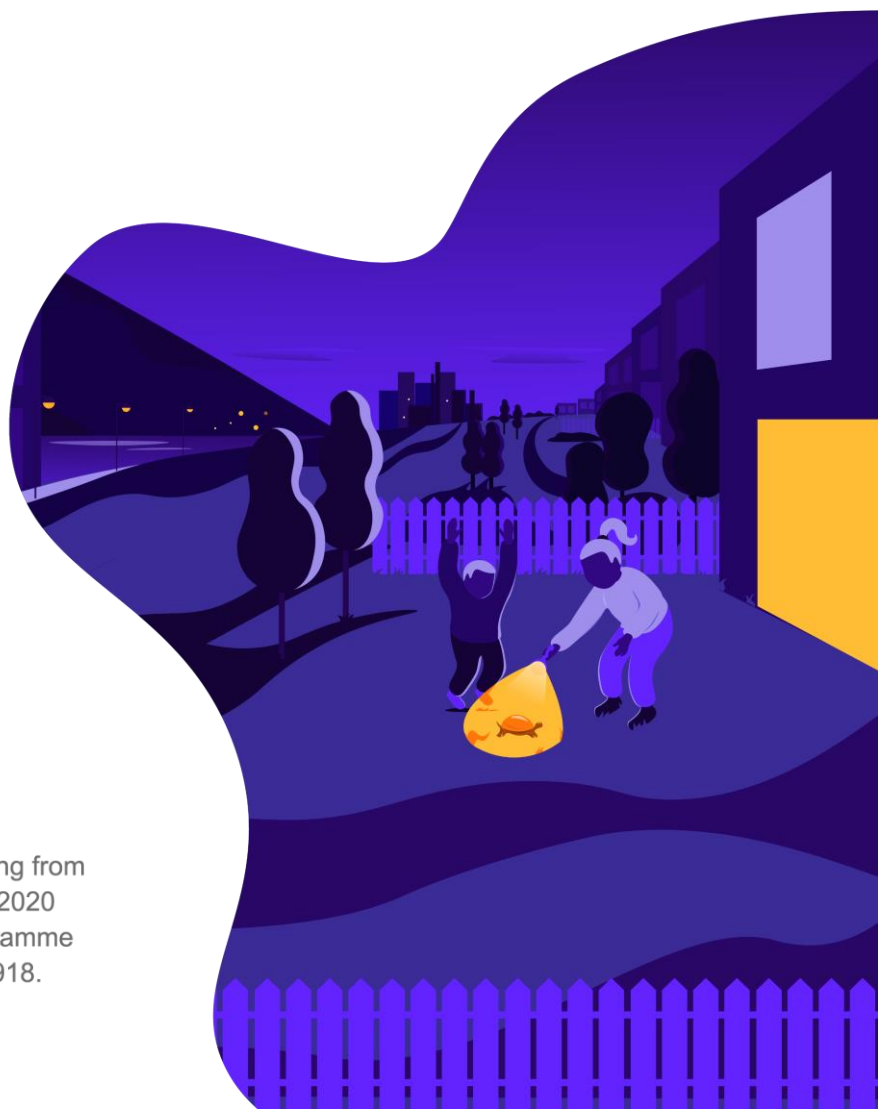
Sustainable plus energy neighbourhoods

The following information should be filled in by an assessor representing the pilot project. The consent of the building occupant will be also required to allow the assessor to enter the apartment and collect the required information under the supervision of the homeowner or building occupant.

In most cases, a walk through in the apartment is necessary for an odor and general visual inspection.

General information	
Pilot Name	
Location/Country	
Climate zone	
Project type (new/renovation)	
Construction date	
Building name	
Apartment code number	
Neighbourhood/ Building/Apartment description	
Provide short description of the surrounding area (neighbourhood) of the apartment (e.g. next to highly polluted street, next to park etc.)	
Building type (detached, semi-detached, multifamily building etc.)	
Number of exposed facades (orientation of exposed facades)	
Floor in which the apartment is situated	
Total floor area of apartment (m^2)	
Floor height (m) and Volume (m^3)	
Description of external wall's construction	
Description of internal wall's	
Window to wall ratio per orientation (m^2/m^2): S W N E	
Occupancy	
Number of occupants living in the apartment	
Occupancy pattern (number of hours per day/ weekday/ weekend)	
Is any of the occupants a smoker? If yes, does he/she smoke in the apartment?	
Presence of pets	
HVAC system-Thermal comfort	
Type of heating system	
Type of cooling system	
Type of ventilation system	
Type of filters in ventilation system	
Thermostat (central or individual)	
Are all rooms connected to the central thermostat?	

Presence of bathroom/ kitchen extractor)	
Rate of renewal of filters (e.g. times a year)	
How often heating systems are maintained (pipes, clogged drains that can lead to CO emissions)	
Proper functioning of thermostats	
Presence of supply fans	
Presence of extracting fans	
Overall characterisation of the thermal environment as evaluated by the assessor (e.g. good, fair, moderate, poor, very poor. Please also include a short description)	
Airborne concerns-Indoor Air Quality	
Presence of fireplace/wood stove	
Cracks in the foundation or floor (that can allow entrance of radon in risk areas)	
Garage attached to the dwelling	
Kitchen stove type (e.g. natural gas, coal, kerosene stoves) and risk of carbon monoxide emissions	
Presence of mould	
Presence of mould odours	
Condensation on exterior windows during winter	
Water stained or discoloured walls	
Water stained or discoloured ceilings	
Water stained or discoloured carpet	
Presence of carpet and material of carpet	
Floor covering (e.g. wood, tiles, marble)	
Paints and varnishes	
Textile furnishings	
Associated adhesives and sealants used in furnishings	
Overall characterisation of the indoor air quality as evaluated by the assessor (e.g. good, fair, moderate, poor, very poor. Please also include a short description)	
Lighting	
Light diffusers and dispersion of light (e.g. poorly distributed light, dark areas and uneven lighting)	
Lumens per room (based on installed lighting-for artificial lighting assessment)	
Brightness distribution (e.g. unbalanced)	
Glare effects	
Type of lighting (e.g. LED etc.)	
Features for adjusting lighting (e.g. dimmer etc.)	
Window shades (blinds, curtains etc.) available and usable	
Presence of compact fluorescent lights (if accidentally break can emit mercury)	

Overall characterisation of the lighting quality as evaluated by the assessor (e.g. good, fair, moderate, poor, very poor. Please also include a short description)	

Acoustics	
Outdoor noise levels acceptable (e.g. traffic, construction, etc.)	
HVAC noise present	
White noise of building (e.g. whirring fan, hissing radiator, humming air conditioner)	
Other internal noise (e.g. neighbours, floor above)	
Sound-absorbing material installed in wall (e.g. fabric faced glass fibre wall panels), ceiling or floor (e.g. carpet)	
Overall characterisation of the acoustics environment as evaluated by the assessor (e.g. good, fair, moderate, poor, very poor. Please also include a short description)	

Housekeeping activities	
Vacuum cleaners equipped with high efficiency filters	
Frequency of vacuuming	
Main cleaning agents used to clean the house	

Additional comments	

REFERENCES:

US Environmental Protection Agency, Indoor Air Quality Management Checklists, assessed in July 2020, available at: https://mn.gov/admin/assets/ieq_checklist_long_tcm36-207268.pdf

ENRIROPRO Indoor Environmental Specialists, Indoor Air Quality Checklist, Is your Health Affected by Poor Indoor Air Quality? If so, Maybe an Indoor Environmental Professional Can Help

Department of Employee Relations State Safety and Industrial Hygiene Unit, Indoor Environmental Quality Checklist, Including Background Information in Comment Section, assessed in July 2020, available at: https://mn.gov/admin/assets/ieq_checklist_long_tcm36-207268.pdf

Ismail, S. et al., 2012 Development of an indoor air quality checklist for risk assessment of indoor air pollutants by semiquantitative score in nonindustrial workplaces, Risk Management and healthcare Policy, DOI: 10.2147/RMHP.S26567

FOR COMMUNICATION ACTIVITIES:

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869918".

FOR INFRASTRUCTURE, EQUIPMENT AND MAJOR RESULTS:

"This [infrastructure][equipment][insert type of result] is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869918".