COLLECTiEF

Performance Measurement & Verification Protocol – concepts and methods for performance evaluation of COLLECTiEF solutions

Project acronym: COLLECTiEF

Project title: Collective Intelligence for Energy Flexibility

Call: H2020-LC-SC3-EE-2020-2

Disclaimer

Project no.	101033683
Project acronym:	COLLECTiEF
Project title:	Collective Intelligence for Energy Flexibility
Call:	H2020-LC-SC3-2018-2019-2020
Start date of project:	**01.06.2021**
Duration:	48 months
Deliverable title:	
Deliverable No.:	D5.1
Document Version>	10
Due date of deliverable:	31.05.2022
Actual date of submission:	31.05.2022
Deliverable Lead Partner:	Partner No. 1, NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET NTNU
Work Package:	5
No of Pages:	142
Keywords:	Performance Measurement & Verification, smart readiness, energy, indoor environmental quality, energy flexibility, climate resilience, impacts, key performance indicators.

Name	**Organization**
Silvia Erba	NTNU
Mohammadreza Aghaei	NTNU
Amin Moazami	NTNU

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Salvatore Carlucci	CyI
Panayotis Papadopoulos	CyI
Antonio Luparelli	CETMA
Vahid Nik	ULUND
Jelena Lazic	GEO
Giuseppe Mastandrea	E@W
Greta Tresoldi	LSI-LASTEM
Peter Riederer	CSTB
Maxime Raynaud	CSTB
Marco Pietrobon	R2M
Runar Solli	EM
Jens Brage	NODA

Dissemination level

PU	Public

History

Version	Date	Reason	Revised by
1.1	01.09.2021	Deliverable structure draft – First version	Silvia Erba, NTNU
1.2	01.12.2021	Second version	Silvia Erba, NTNU
1.3	10.02.2022	Third version	Silvia Erba, NTNU Mohammadreza Aghaei, NTNU

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

1.4	31.03.2021	Contributions from Partners	Salvatore Carlucci, CyI Panayotis Papadopoulos, CyI Antonio Luparelli, CETMA Jelena Lazic, GEO Greta Tresoldi, LSI-LASTEM Giuseppe Mastandrea, E@W Runar Solli, EM Vahid Nik, ULUND Peter Riederer, CSTB Maxime Raynaud, CSTB Jens Brage, NODA
1.5	02.05.2022	Fourth version	Silvia Erba, NTNU Mohammadreza Aghaei, NTNU
1.6	18.05.2022	Document review	Marco Pietrobon, R2M
1.7	29.05.2022	Updated version	Silvia Erba, NTNU Mohammadreza Aghaei, NTNU
1.8	30.05.2022	Document approval	Marco Pietrobon, R2M
1.9	31.05.2022	Final version	Silvia Erba, NTNU
1.10	31.05.2022	Final approval	Amin Moazami, NTNU

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Executive Summary

Referring to international protocols and standards, the deliverable describes the measurement and verification (M&V) protocol developed for the pilot buildings in COLLECTiEF.

The deliverable is structured in 10 chapters:

1. Chapter 1 provides an overview of reference M&V protocols and standards available in literature and describes the overall approach adopted in COLLECTiEF.
2. Chapter 2 reports the nomenclature and a list of operative definitions available in standards and literature related to smart readiness, energy, indoor environmental quality (IEQ), energy flexibility and climate resilience in order to provide a consistent and common framework for effective communication.
3. Chapter 3 describes in detail the process of measurement and verification in COLLECTiEF: the three phases of the protocol, namely, planning, installation and operation are presented specifying the most relevant steps.
4. Chapter 4 presents the methodology and the key performance indicator (KPI) selected in COLLECTiEF to assess the impacts on the smart readiness of buildings.
5. Chapter 5 presents the methodology, the KPIs and the metering systems selected in COLLECTiEF to measure and assess impacts affecting energy domain.
6. Chapter 6 presents the methodology and the sensors chosen in COLLECTiEF to measure and assess impacts on IEQ, identifying a set of relevant parameters able to provide optimal information about health and comfort of occupants.
7. Chapter 7 presents the methodology and the KPIs identified in COLLECTiEF to assess energy flexibility, with the aim to support the integration of the COLLECTiEF system into local demand-response schemes.
8. Chapter 8 presents the methodology and the KPIs identified in COLLECTiEF to assess climate resilience.
9. Chapter 9 outlines the strategy adopted in the project to engage occupants and end-users.
10. Chapter 10 contains the conclusions of the report.

The deliverable presents also 7 Annexes:

- Annex 1 – Description of weather database for real weather conditions
- Annex 2 – Primary Energy Factors (PEF) in the Pilots' countries
- Annex 3 – Electricity Tariff and Grid Rent Pricing in Norway
- Annex 4 – Pilot Installation: monitoring specifications
- Annex 5 – Post Occupancy Evaluations: the Brief questionnaire (DRAFT)
- Annex 6 – POE Brief questionnaire with designed graphics (DRAFT)
- Annex 7 – Post Occupancy Evaluations: the Satisfaction questionnaire (DRAFT)

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table of Contents

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

List of Acronyms

ADR	Active Demand Response
AMS	Advanced Measurement Systems
AF	Agility Factor
ANOVA	Analysis Of Variance
API	Application Programming Interface
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMI	Body Max Index
BMS	Building management system
CETMA	Centro Di Ricerche Europeo Di Tecnologie Design E Materiali
CO_2	Carbon dioxide
CARE-C	Climate and Atmosphere Research Center
CFA	Confirmatory factor analysis
CDD	Cooling Degree Days
CPP	Critical Peak Pricing
CAO	Cyprus Atmospheric Observatory
CERA	Cyprus Energy Regulatory Authority
CyI	Cyprus Institute
CTSO	Cyprus Transmission System Operator
DFF	Demand Flexibility Factor
DSM	Demand Side Management
DR	Demand Response
dTOU	Dynamic Time-Of-Use
EPBD	European Energy Performance of Buildings Directive
EN	European Norm
EFA	Exploratory factor analysis
GWh	Giga Watt hour
GOB	Guy Ourisson Building

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
HAN	Home Area Network
ICC	Intraclass Correlation Coefficient
IEQ	Indoor Environment Quality
ISO	International Standard Organization
KPI	Key Performance Indicators
MV	Measurement and Verification
MS	Member States
P, NREN	Non-renewable primary energy factor
Obj	Objective
PCA	Principal Component Analysis
PM	Particle Matter
POE	Post-Occupancy Evaluation
PEF	Primary Energy Factor
PCA	Principal component analysis
QoS	Quality of Service
RH	Relative Humidity
RTP	Real time pricing
RQ	Research question
P, REN	renewable primary energy factor
SRI	Smart Readiness Indicator SRI
TOU	Time-Of-Use
P, TOT	Total primary energy factor
TSO	Transmission System Operator
UV	Ultra Violet
VPP	Variable Peak Pricing
VOC	Volatile Organic Compound
WP	Work Package

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

List of Figures

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

List of Tables

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

1 Introduction

The Measurement and Verification protocol is a necessary part of energy-efficiency programs and it is generally used to verify that a building performs according to design expectations, suggesting energy efficiency measures to be adopted. The M&V plan is a document which describes in detail the proposed M&V activities, procedures and methods that are used to determine the actual energy savings. M&V improves engineering design and facility operations and maintenance, ensuring high levels of comfort and user satisfaction. It also increases the awareness of building owners/managers with respect to energy uses and it demonstrates the effectiveness of energy policies [1]. The most relevant references are the International Performance Measurement and Verification Protocol (IPMVP) [2] and the ASHRAE Guidelines 14 [3]. More references are reported in Table 1.

Table 1 List of most relevant references related to Measurement and Verification Protocols

IPMVP	Efficiency Valuation Organization (EVO), International Performance Measurement & Verification Protocol (IPMVP) - Concepts and Options for Determining Energy and Water Savings, Volume I, 2002
M&V Protocol for Net ZEBs	IEA SHC/ECBCS Task 40/Annex 52 – Towards Net Zero Energy solar Buildings. M&V protocol for Net ZEB. A technical report of STA, 2013
ASHRAE Guideline 14	ASHRAE Guideline 14-2014, Measurement of Energy and Demand, and Water Savings
ISO 17741:2016	General technical rules for measurement, calculation and verification of energy savings of projects
EN ISO 52000-1:2017	Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures
ISO 17742:2015	Energy efficiency and savings calculation for countries, regions and cities
ISO 17743:2016	Energy savings - Definition of a methodological framework applicable to calculation and reporting on energy savings
ISO 50001:2018	Energy management systems - Requirements with guidance for use
ISO 50002:2014	Energy audits - Requirements with guidance for use
ISO 50003:2021	Energy management systems - Requirements for bodies providing audit and certification of energy management systems

In the building sector, there is a growing interest in including IEQ monitoring as part of the M&V plan [4], however, currently it is used mainly in demonstration projects or by a few ambitious building operators. Further, literature shows examples of demand response M&V [5], which refer to the application of appropriate statistical and load research techniques to measure and verify the load reduction impact resulting from the utilization of a demand response program.

In COLLECTiEF project, a M&V plan has been defined to evaluate the implementation of the COLLECTiEF solutions targeting not only energy savings and IEQ but also including the methods to measure and verify the impacts related to load reduction and management, resulting from the utilization of energy flexibility strategies, and the impacts on climate resilience.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

As highlighted in the IPMVP, each M&V Plan must be established addressing the unique characteristics of the project and thus, an integrated approach to evaluate all the above-mentioned impacts has been outlined in COLLECTiEF.

Figure 1 describes the overall approach which has been followed to define the M&V plan. The first step focused on the literature analysis of existing performance measurement and verification protocols and international standards. This allowed to create a framework aligned to international regulatory policies and to identify a set of operative definitions to allow effective communication among the Partners. The following stage has regarded the definition of the M&V objectives and the assessment of the interactions with the other project work packages. In COLLECTiEF five domains are considered: building smartness, energy, indoor environmental quality, energy flexibility and climate resilience. Afterwards, the timeline including a baseline period (before the implementation of the systems) and an assessment period (after the implementation) has been defined and for each domain relevant data and key performance indicators have been identified. To understand the monitoring boundaries and identify the sensors needed to collect the data, detailed analysis of the pilot buildings has been carried out. In parallel, a dedicated plan for the engagement of pilots' users has been included. Finally, the installation procedures have been outlined and the preliminary indications for the operation phase have been considered. Detailed information will be contained in the following deliverable D5.2 - Ongoing performance evaluation of the COLLECTiEF system implemented in the pilot cases.

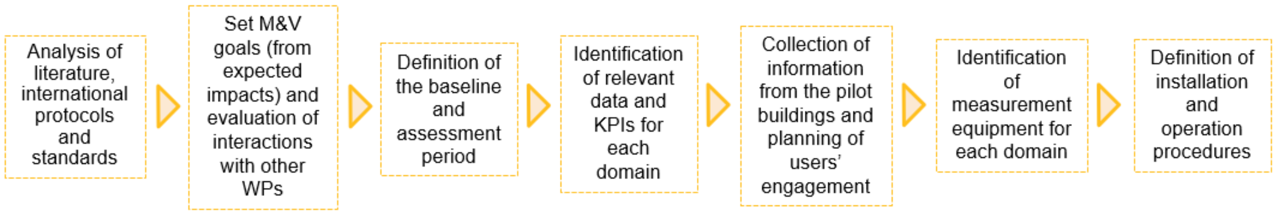


Figure 1 Overall approach considered

The M&V plan documents the following:

- A list of definitions related to smart readiness, energy, indoor environmental quality, energy flexibility and climate resilience, according to international standards and reference literature.
- The selected measurement approach.
- The baseline and assessment data referred to the domains under study: smart readiness, energy, indoor environmental quality, energy flexibility and climate resilience.
- The KPIs for impacts' assessment.
- The measurement procedure and specifications about the measurement equipment.
- The quality control procedures.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

2 Definitions & standards

This section reports the main definitions available in standards and literature related to smart readiness, energy, IEQ, energy flexibility and climate resilience in order to provide a consistent and common framework for effective communication.

2.1 Smart Readiness

References: [6–8]

- **Smart Readiness Indicator (SRI):** it is an indicator based on a common EU methodology, which rates the smart readiness of buildings (or building units) in their capability to perform 3 key functionalities: (i) optimise energy efficiency and overall in-use performance; (ii) adapt their operation to the needs of the occupant; (iii) adapt to signals from the grid (for example energy flexibility).
- **Smart ready services:** services delivered to the building user or the energy grid through the use of Smart Ready Technologies. These smart ready technologies can either be digital ICT technology (e.g. communication protocols or optimization algorithms) or physical products (e.g. ventilation system with CO_2 sensor, cabling for bus systems) or combinations thereof (e.g., smart thermostats).
- **Service group:** aggregation of different smart ready services.
- **Technical domain:** a collection of smart-ready services which, together, realise an integrated and consistent part of the services expected from the building or building unit. In the developed SRI service catalogues the smart ready services are structured within nine “technical domains”: heating, cooling, domestic hot water, controlled ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, monitoring and control.
- **Functionality level:** degree (level) of smartness. For each service up to 5 functionality levels (level 0 – level 4) are defined. A higher functionality level reflects a “smarter” implementation of the service, which provides more beneficial impacts to the building.

2.2 Energy

References: [9,10]

- **Energy need for heating or cooling**: heat to be delivered to or extracted from a thermally conditioned space to maintain the intended space temperature conditions during a given period of time.
- **Energy need for domestic hot water**: heat to be delivered to the needed amount of domestic hot water to raise its temperature from the cold network temperature to the prefixed delivery temperature at the delivery point without the losses of the domestic hot water system.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

- **Energy use for space heating or cooling or domestic hot water**: energy input to the heating, cooling or domestic hot water system to satisfy the energy need for heating, cooling (including dehumidification) or domestic hot water respectively.
- **Energy use for lighting**: electrical energy input to the lighting system.
- **Energy use for ventilation:** electric energy input to a ventilation system for air transport and heat recovery
- **Energy use for other services:** energy input to appliances providing services not included in the energy performance of buildings (EPB) services. E.g. Elevators, escalators, home appliances, TV, computers, etc. (if not covered under EPB services).
- **Auxiliary energy:** electrical energy used by technical building systems to support energy transformation to satisfy energy needs. This includes energy for fans, pumps, electronics, etc.
- **Delivered energy**: energy, expressed per energy carrier, supplied to the technical building systems through the assessment boundary, to satisfy the uses taken into account or to produce the exported energy. (Note that delivered energy can be calculated for defined energy uses or it can be measured).
- **Primary energy**: energy that has not been subjected to any conversion or transformation process. Primary energy includes non-renewable energy and renewable energy. If both are taken into account, it can be called **total primary energy**.
- **Energy from renewable sources, renewable energy:** energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases.
- **Non-renewable energy:** energy taken from a source which is depleted by extraction (e.g., fossil fuels)**.** Resource that exists in a finite amount that cannot be replenished on a human time scale.
- **Renewable primary energy factor:** renewable primary energy for a given distant or nearby energy carrier, including the delivered energy and the considered energy overheads of delivery to the points of use, divided by the delivered energy.
- **Non-renewable primary energy factor:** non-renewable primary energy for a given energy carrier, including the delivered energy and the considered energy overheads of delivery to the points of use, divided by the delivered energy.
- **Total primary energy factor:** sum of renewable and non-renewable primary energy factors for a given energy carrier.
- **Hourly temperature difference:** difference between a specified base temperature and the external air temperature during a given hour when the difference is positive, otherwise zero.
- **Accumulated hourly temperature difference:** sum of all hourly temperature differences over a given period, e.g., day, month, season, year.

2.3 Indoor Environmental Quality

References: [11–13]

- **Air speed**: the rate of air movement at a point, without regard to direction.
- **Air temperature**: the temperature of the air at a point.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

- **Average air speed (V_a):** the average air speed surrounding a representative occupant. The average is with respect to location and time. The spatial average is for three heights as defined for average air temperature t_a. The air speed is averaged over an interval not less than one and not greater than three minutes. Variations that occur over a period greater than three minutes shall be treated as multiple different air speeds.
- **Average air temperature (t_a)**: the average air temperature surrounding a representative occupant. The average is with respect to location and time. The spatial average is the numerical average of the air temperature at the ankle level, the waist level, and the head level. These levels are 0.1, 0.6, and 1.1 m for seated occupants and 0.1, 1.1, and 1.7 m for standing occupants. Time averaging is over a period not less than three and not more than 15 minutes.
- **Clothing insulation (I_{cl})**: the resistance to sensible heat transfer provided by a clothing ensemble, expressed in units of clo. (Informative Note: The definition of clothing insulation relates to heat transfer from the whole body and thus, also includes the uncovered parts of the body, such as head and hands).
- **Humidity**: a general reference to the moisture content of the air. It is expressed in terms of several thermodynamic variables, including vapor pressure, dew-point temperature, wet-bulb temperature, humidity ratio, and relative humidity. It is spatially and temporally averaged in the same manner as air temperature. (Informative Note: Any one of these humidity variables must be used in conjunction with dry-bulb temperature in order to describe a specific air condition).
- **Mean daily outdoor air temperature ($t_{mda(out)}$)**: any arithmetic mean for a 24-hour period permitted in Section 5.4 of the standard [11]. Mean daily outdoor air temperature is used to calculate prevailing mean outdoor air temperature.
- **Mean radiant temperature**: the temperature of a uniform, black enclosure that exchanges the same amount of heat by radiation with the occupant as the actual surroundings. It is a single value for the entire body and accounts for both long-wave mean radiant temperature and short-wave mean radiant temperature.
- **Mechanical cooling:** cooling of the indoor environment by mechanical means used to provide cooling of supply air
- Note 1: This includes fan coil units, chilled ceilings and beams cooled surfaces, etc.
- Note 2: Opening of windows during night and day time or mechanical supply of cold outdoor air is not regarded as mechanical cooling
- **Mechanical ventilation**: ventilation system where air is supplied or extracted from the building or both by a fan using air terminal devices, ducts and roof/wall devices
- **Metabolic rate (met)**: the rate of transformation of chemical energy into heat and mechanical work by metabolic activities of an individual, per unit of skin surface area (expressed in units of met) equal to 58.2 W/m^2, which is the energy produced per unit skin surface area of an average person seated at rest.
- **Natural ventilation**: ventilation provided by thermal, wind, or diffusion effects through doors, windows, or other intentional devices in the building designed for ventilation
- Note 1: Natural ventilation systems may be either manually or automatically controlled.
- **Operative temperature (t_o)**: the uniform temperature of an imaginary black enclosure, and the air within it, in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual nonuniform environment.
- Operative temperature is calculated according to [14] as:

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

$$t_0 = \frac{h_c \cdot t_a + h_r \cdot t_r}{h_c + h_r} \quad (1)$$

t_a is the air temperature;

t_r is the mean radiant temperature;

h_c is the heat-transfer coefficient by convection;

h_r is the heat-transfer coefficient by radiation.

- **Optimal operative temperature:** operative temperature that satisfies the greatest percentage of occupants at a given clothing and activity level in the current thermal environment
- **Outdoor running mean temperature (T_{rm-i})**: exponentially weighted running mean of the daily mean outdoor air temperature
- **Prevailing mean outdoor air temperature ($t_{pma(out)}$)**: when used as an input variable for the adaptive model, this temperature is based on the arithmetic average of the mean daily outdoor temperatures over some period of days in accordance with the following:

A. It shall be based on no fewer than seven and no more than 30 sequential days prior to the day in question.

B. It shall be a simple arithmetic mean of all of the mean daily outdoor air temperatures $t_{mda(out)}$ of all the sequential days in section A.

2.4 Energy flexibility

References: [15–18]

- **Building energy flexibility:** the ability to manage the building demand and generation according to local climate conditions, user needs and grid requirements. Energy Flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding grids [15].
- **Demand Side Management (DSM):** A utility action that reduces or curtails end-use equipment or processes. DSM is often used in order to reduce customer load during peak demand and/or in times of supply constraint. DSM includes programs that are focused, deep, and immediate such as the brief curtailment of energy-intensive processes used by a utility's most demanding industrial customers, and programs that are broad, shallow, and less immediate such as the promotion of energy-efficient equipment in residential and commercial sectors [16].
- **Demand Response (DR):** Demand response programs are incentive-based programs that encourage electric power customers to temporarily reduce (generally, in most cases) or increase (generally, in a limited cases) their demand for power at certain times in exchange for a reduction in their electricity bills and/or a financial remuneration. Some demand response programs allow electric power system operators to directly reduce/increase load, while in others, customers retain control. Reductions/increases in demand may involve actions such

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

as curtailing load, operating onsite generation, or shifting electricity use to another time period. Demand response programs are one type of demand-side management.

- **Implicit Demand Response:** Implicit DR implies that end-users adjust their consumption behavior to time-varying electricity prices. In this case, end-users are remunerated for their flexibility actions through the optimization of the cost of their electricity bill (remuneration of end-users by their electricity supplier).
- **Explicit Demand Response**: Explicit DR implies that end-users respond to a specific request to change their consumption pattern after that they have indicated in advance how much flexibility they have available at which moment. In this case, end-users are remunerated for their flexibility actions through their direct participation in electricity markets (often requires a certain minimum level of flexibility power; remuneration of end-users by market players) or a contract with a flexibility operator who by aggregating flexibility power from different buildings/sites participates in electricity markets (remuneration of end-users by a flexibility operator, who is remunerated by the markets).

- **Reference/baseline**: a reference/baseline is "an estimate [in the in reality, it did not happen] of the electricity, non-electricity & generation that would have been consumed by end-user in the absence of a DR event". A reference/baseline is what the performance of a DR event is measured against.[17]
- **Peak shaving**: reduce the energy demand at peak periods [18]
- **Load shifting**: shift the energy consumption from high load periods to low-load periods [18]
- **Valley filling**: increase energy use during off-peak times [18]
- **Shedding DR**: DR event during which an order or incentive to reduce their energy demand (in particular during peak shaving or load shifting) is sent to end-users [17].
- **Shifting or rising DR**: DR event during which an order or incentive to increase their energy demand (in particular during load shifting or valley filling) is sent to end-users.
- **Dynamic pricing:** There are several power pricing models that could add dynamicity to varying degrees to the final consumer price: Real time pricing (RTP), Time-Of-Use (TOU), Dynamic Time-Of-Use (dTOU), Variable Peak Pricing (VPP), Critical Peak Pricing (CPP).
    - Real time pricing (RTP), which serves to reflect the real-time cost of electricity. The price changes can occur on an hourly basis, every quarter-hour or even more often. Usually, the price variations are achieved through coupling with the wholesale market. RTP is typically the pricing model that adds the largest dynamicity to the final power price.
    - Time-Of-Use (TOU), where the electricity prices are set for specific periods of time such as peak and off-peak hours.
    - Dynamic Time-Of-Use (dTOU),where electricity prices and the peak and off-peak periods change regularly, which allows for a more accurate reflection of the situation in the energy market.
    - Variable Peak Pricing (VPP) - a hybrid between TOU and RTP where specific periods of electricity price fluctuations are defined in advance. The price fluctuations that occur in the defined periods, vary depending on the energy supplier and the market conditions.
    - Critical Peak Pricing (CPP) involves the raising of the price of electricity substantially during periods of excessive demand or of a particularly low feed-in from renewables. The peak rate can be either defined beforehand or determined dynamically based on the market conditions.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

2.5 Climate resilience

Climate resilience can be considered as a part of *climate change adaptation* that focuses on *capacity building to cope with extreme climate events*. Knowing that there will be more frequent and stronger extreme events in the future, becoming climate resilient needs to [19]:

- **Adapt** to climate change: through increasing the flexibility in the energy system to absorb shocks and the share of decentralized generation to enhance alternative solutions.
- **Plan and prepare** for extreme climate events: through understanding the system dynamics, learning from past events and predictive analysis.
- Build **resistance** against extremes: through making the systems robust and more stable.
- **Recover** from extreme events: through planning for remedies and alternative solutions.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

3 M&V process for COLLECTiEF

For the development of a M&V Plan the following project development phases should be considered: planning, installation and operation. According to reference protocols [20], a list of steps for the implementation of the M&V protocol can be defined for each phase, as shown in Figure 2. The phase of planning has been completed during the first year of the project and we are currently carrying out the installation of the measurement equipment necessary for the monitoring of the data during the baseline period (discussed in chapter 3.1.2).

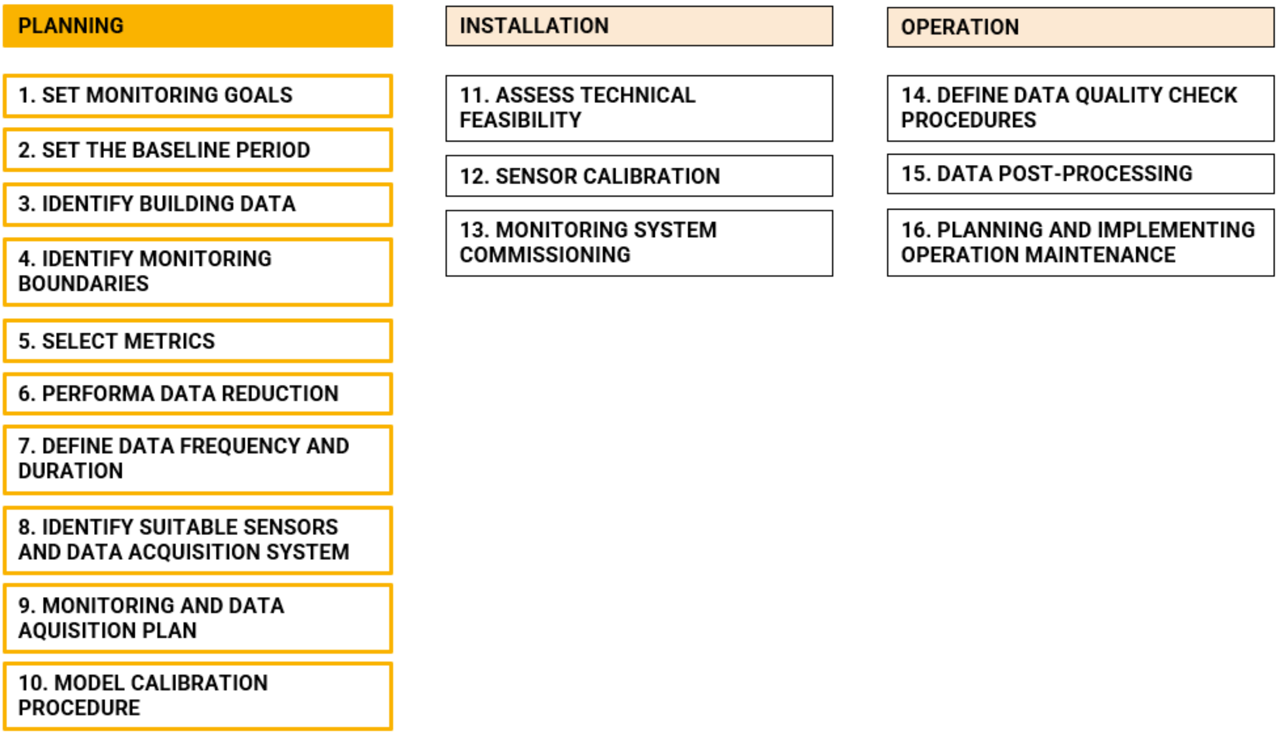


Figure 2 – M&V process: planning, installation and operation stages

The planning phase is fundamental to identify the monitoring goals and related monitoring boundaries, select the key performance indicators needed to assess the impacts and identify the necessary monitoring equipment. After the planning phase, the installation phase has to be detailed to assess the technical feasibility, the sensors calibration and the monitoring system commissioning. Finally in the operation phase, the procedure for data quality check must be identified together with the data post-processing and the necessary maintenance of the monitoring systems.

In general, each M&V plan must be established addressing the unique characteristics of the project. In COLLECTiEF, 14 case studies have been selected to test and qualify the systems. This deliverable describes the common characteristics of the M&V process and points out the specificities of each pilot building (or group of pilots). While the objectives are common, in fact each pilot presents particular characteristics depending on the type of building, existing building energy systems, energy uses affected by the intervention, end users, which must be taken into account in the definition of the M&V plan.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

In all the pilots, a certain number of zones has been identified to test the systems and measure the impacts. For example, in the Italian pilots, the solutions will be implemented in 12 apartments out of a total of 109 apartments in the three building blocks. The measured impact of the intervention, limited to the boundary of the selected apartments, will then be scaled-up to the whole building block using calibrated simulations. Therefore, the final impact assessment will be extended at the building level.

In this regard, the consortium plans to collect the data to calibrate the energy models of the pilots, which will be used to assess the impacts on larger scales than the demonstration environment. Further, the simulation models will be exploited to test the algorithms at the edge and cluster node and assess the key performance indicators which cannot be calculated directly through measured data. The definition of the monitoring goals is thus interconnected with the objectives of the algorithm training and reinforcement for control strategies of COLLECTiEF System (developed in WP2).

In the following chapters, the three phases and the related steps synthesized in Figure 2, are described in detail.

3.1 Planning

3.1.1 Set monitoring goals for COLLECTiEF

The aim of setting up a M&V protocol is to qualify the COLLECTiEF system, i.e. the system must prove to work in its final form and to meet the design specifications. The achievement of the COLLECTiEF qualification is based on the evaluation of six main expected impacts that have been defined according to the call text. They are summarized in Figure 3 and described in Table 2.

To assess these impacts, different parameters and performance indicators available in literature and in international standards have been identified and are described in detail in the following chapters. Key Performance Indicators (KPIs) will be calculated using data measured in the pilot buildings and/or data obtained from calibrated simulations. The list of KPIs used to assess the mentioned impacts might be updated throughout the project in relation to the development of the system and to the necessity to better investigate and express its potential.

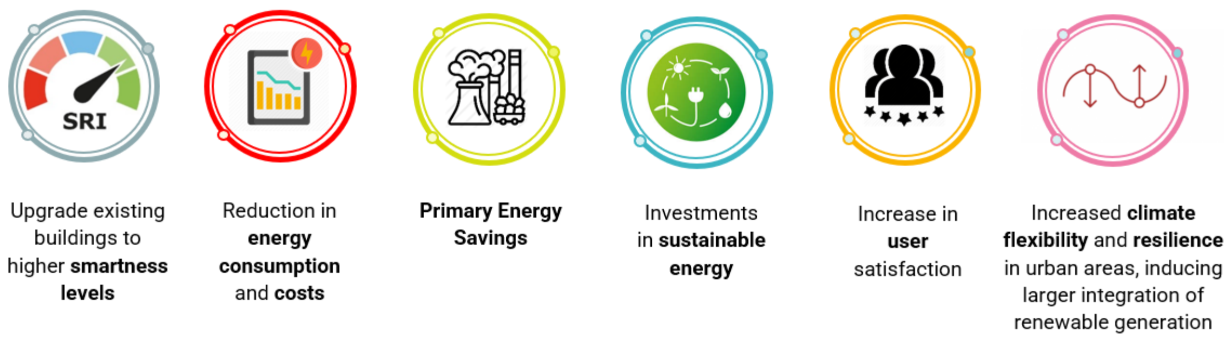


Figure 3 – COLLECTiEF expected impacts

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 2 – Description of COLLECTiEF expected impacts, according to GA

1	The COLLECTiEF system is estimated to upgrade the existing pilot buildings with **at least one level of smartness according to SRI scoring methods**.
2	Depending on building thermal quality and climate zone **9%-27% relative energy reduction and 0.2-3 €/m² annual energy cost savings** are estimated for buildings after installation of COLLECTiEF system and upgrading by one level of smartness.
3	An average of **16% reduction in primary energy** use of the pilot buildings is estimated, equivalent of 0.93 (GWh/year).
4	**Up to 52% increase in self-consumption rate** can be achieved due to optimal operation provided by the COLLECTiEF system, which can bring up to 364 EUR per year additional income for a typical four-person family household with PV system.
5	We aim at **increasing user satisfaction** with respect to some of the components of the indoor physical environments **by at least 15%** thanks to the implementation of smart occupant-centric sensoring and self-learning control algorithms.
6	Based on our recent studies for Stockholm, depending on the season and considering heating or cooling demand, CI-based control can increase the demand flexibility between 24% to 58% and the agility of the system between 27% to 40% (agility is an indicator to assess climate resilience and the recovery speed after/during shocks). By counting for extreme climate in the energy system design we can increase the renewable energy penetration above 30%.

In the project, the main challenges are represented by:

- the different domains which are affected by the system implementation (building smartness, energy, indoor environmental quality, climate flexibility and resilience), which require different metrics, monitoring parameters, measurement equipment, frequency and duration of measurements;
- the different intended use and end-users of the pilot buildings, which require adjustments to address the specificity of each case study (from monitoring objectives to measurement instruments and post occupancy evaluations);
- the different level of smartness which characterizes the pilot buildings, since the COLLECTiEF system is thought to cover a portfolio of legacy equipment with different functionality levels that will be upgraded during the project to higher level to increase, as a result, the overall SRI of the building;
- the relation between the information acquired at the single room level (edge node) and its extension to the building/cluster of building level (cluster node).

Each of these aspects has been carefully discussed within the Consortium and a strategy has been defined to address the critical issues.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

3.1.2 Set the baseline period

The COLLECTiEF M&V protocol requires to set a baseline period, i.e. a period of time selected as representative of the building before the implementation of the system. The essential role of the baseline is highlighted in the reference protocols and standards (e.g. IPMVP and the ASHRAE Guideline 14-2014) which, focusing on energy conservation measures, state that savings cannot be directly measured because they represent the absence of energy use. Instead, actual savings are determined by comparing measured use before and after the implementation of a project and making appropriate adjustments for changes in conditions.

The same approach will be used for evaluating the impacts in COLLECTiEF, thus requiring as first step to setting the baseline. Where possible, the baseline operating conditions should be similar to the expected operating conditions for the post-implementation period, to minimize bias or error from unaccounted for factors.

In COLLECTiEF we chose to consider as baseline a full year (2nd year of the project) because of the weather-dependent loads affecting the implementation of the systems. After M24, it will be possible to evaluate the impacts twice (3rd and 4th year) and assess possible improvements after adapting and improving the algorithms developed during the project (Figure 4).

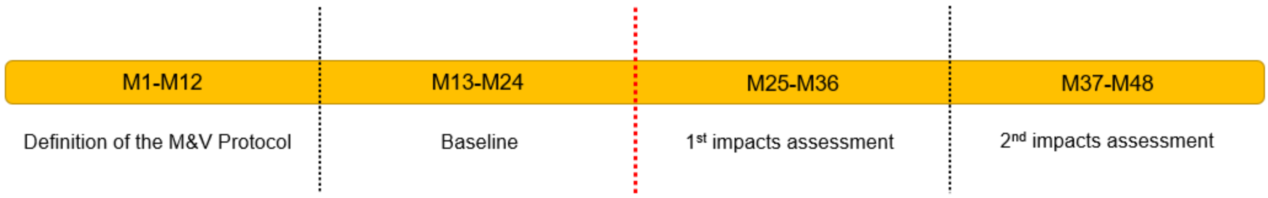


Figure 4 – COLLECTiEF timeline highlighting the baseline period and the 1st and 2nd period of impacts assessment

Before the beginning of the baseline period, it is important to identify relevant independent variables which are variables that directly or indirectly can affect the performance of the building and which can change during the baseline and/or post-installation period. The most significant independent variables must then be measured over the periods of interest, and considered in any savings (or impacts) computation. The identified variables in COLLECTiEF are the weather, the occupancy and the system operating hours. Thus, verification to have the same uses (occupation, ventilation, etc.) in the pilot buildings during the two periods will be performed.

Weather data is the most common independent variable affecting energy use and renewable energy generation. Data from existing weather stations will be used in the project. Table 3 reports the details of the weather stations, according to their proximity to the pilot sites, which provide real weather data from 2018-2021 in form of EPW file. The monitored parameters are: outside air temperature, relative humidity, solar radiation, cloud cover, precipitation and wind (a description of all variables and assumptions can be found in Annex 1 – Description of weather database for real weather conditions). Some pilot sites have additional local measurements available, as reported in Table 3, that will be compared to assess and improve the reliability of the sources.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 3 Meteorological stations: reference pilot and details

Id	Pilot	Location	Details	Available onsite measurements
B1	Eidet Omsorgsenter	Norway	Alesund / Vigra	Outdoor air temperature
B2	Ellingsøy Idrettshall	Norway	Alesund / Vigra	Outdoor air temperature
B3	Flisnes Barneskole	Norway	Alesund / Vigra	Outdoor air temperature
B4	Hatlane Omsorgsenter	Norway	Alesund / Vigra	Outdoor air temperature
B5	Moa Helsehus	Norway	Alesund / Vigra	Outdoor air temperature
B6	Spjelkavik Ungdomskole	Norway	Alesund / Vigra	Outdoor air temperature
B7	Tennfjord Barneskole	Norway	Alesund / Vigra	Outdoor air temperature
B8	Green'ER	France	Grenoble-Lvd	Temperature, Relative Humidity, Rain intensity, Solar irradiance, Wind speed and direction, atmospheric pressure
B9	Guy Ourisson Building (GOB)	Cyprus	Alsancak / Kibris	Temperature, Relative Humidity, Rain intensity, Solar irradiance, Wind speed and direction, atmospheric pressure *Nicosia, Cyprus Atmospheric Observatory (CAO), Climate and Atmosphere Research Center (CARE-C), The Cyprus Institute (https://cao.cyi.ac.cy/nicosia/)
B10	Graduate School (GS)	Cyprus		
B11	Novel Technologies Laboratory (NTL)	Cyprus		
B12	Valsesia Tower C2	Italy	Milano / Linate	Outdoor air temperature
B13	Valsesia Tower C3	Italy	Milano / Linate	Outdoor air temperature
B14	Valsesia Tower C4	Italy	Milano / Linate	Outdoor air temperature

3.1.3 Identify building data

The collection of building data is one of the first steps of the M&V process (Figure 2). Collecting data is fundamental not only to describe the building but also to:

- point out the energy flows occurring from, to and within the building;
- easily identify the measurements required to quantify the impacts;
- know which monitoring devices need to be installed prior to the baseline period;
- understand the potential for energy flexibility of each pilot;
- identify which appliances and lighting system could be controlled with smart plugs;
- create the energy models, which will be developed in WP2;
- evaluate the smart readiness before the implementation of the COLLECTiEF system.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

A comprehensive template has been developed to collect all the necessary information in a clear, organized and homogeneous way. This tool has facilitated the responsible partners of each pilot to carry out the task in the most efficient way and it allows easy-to-read analysis of the main features of the building and direct comparison between the different case studies.

The template, which has been developed in Excel, is structured in five sections (Figure 5):

- General data
- Building services
- Monitoring
- Baseline
- SRI – Functionality levels

COLLECTiEF - Questionnaire for Pilots description

COLLECTiEF Partner responsible for pilot

1	**BUILDING DATA AND THERMAL PERFORMANCE** **Please, complete this section with the required information, if available**	
		Units (S.I.)
BUILDING DATA	Name	-
	Country	-
	Address	-
	Owner/type of ownership	-
	Year of construction	-
	Building state (original, renovated). If renovated, list the year of renovation and the main applied interventions	-
	Energy Performance (e.g. nZEB, class A, B, C)	-
	Building type (residential, educational, healthcare, commercial, industrial,..)	-
	Brief description (e.g. apartment block)	-
	Number of buildings/units/apartments (if applicable)	-
	Number of floors	-
	Total number of occupants	-
	Type of users (e.g. average age, workers, etc.)	-
GEOMETRY	Building footprint	m
	Floor plan shape (e.g. L shape, rectangular, irregular)	-
	Total floor area of the building	m^2
	Net floor area of the building	m^2
	Net floor area of thermally conditioned spaces	m^2
	Total height of the building	m
	Net height of storey	m
	Conditioned (net) building volume	m^3
	External wall area above ground level	m^2
	External wall area below ground level	m^2
	Window to wall ratio	%
	Window to wall ratio (North, South, East, West)	%
	Roof - window ratio	%
	Technical drawings (3D model, plans, sections, detail.., material properties, windows and doors specifications)	
	Opaque walls - U value	W/m^2K
	Opaque walls - overall thickness	m
	Opaque walls - if available provide the details of each layer: thickness, thermal conductivity, density, specific heat capacity	
	Opaque walls - structure type	-

GENERAL DATA | BUILDING SERVICES | MONITORING | BASELINE | SRI - FUNCTIONALITY LEVELS

Figure 5 – Template for building data collection: extract

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

General data

The section "general data" is divided into five parts:

- Building data (e.g. year of construction, number of floors, type of users, etc.)
- Geometry (area, height, window to wall ratio, building footprint, etc.)
- Thermal behavior (U values, thermal bridges, heat capacity, etc.)
- Operation time and internal gains (this input is very important to shape the schedules for energy modeling on the type and behavior of occupants and appliances; it also helps to understand the potential of load shifting, etc.)
- Energy price

Building services

This section aims to collect information about existing building services (heating, domestic hot water, cooling, ventilation, renewable energy sources, electric vehicle charging, building management system, energy management, appliances), the main parameters (e.g. efficiency, heat source, etc.) needed to characterize them, the availability of renewable sources.

Monitoring

The aim of this section is to collect information about the existing (already installed) metering and sensors to measure energy flows and IEQ parameters. The sheet requires to compile the type of sensor, the sampling interval, the existing number of measurement points, the level (building, flat, single appliance, etc.) and the location. This information has been collected to understand if existing sensors and meters could be used to collect the data needed to build the baseline conditions during the period M13-M24 or if any devices should be installed before the beginning of the baseline period.

Baseline

In this section, the main identified performance indicators (see section 3.1.5) are listed. This sheet aims to collect information about available data (e.g. delivered energy) and related sources (e.g. energy bills, smart meters, energy simulations, etc.).

SRI – Functionality levels

This sheet is based on the SRI methodology and lists all the smart ready services and for each of them, a set of functionality levels. The pilot responsible is required to highlight the functionality level and to provide any other relevant information (e.g. the smart ready service "Heat emission control" indicates for the second level of functionality the following description "Individual room control (e.g. thermostatic valves, or electronic controller)". It collects information about the type of control, the control logic, etc. (e.g., thermostatic valves or thermostat?).

The template has been filled out for each pilot building and is available in the partners' repository.

3.1.4 Monitoring boundaries

Boundaries are strictly dependent on the basis of the objective, the impact and related KPI under evaluation (i.e. for some impacts it is necessary the whole building approach while submetering can

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

be necessary for the assessment of specific loads). As defined in ASHRAE 14, boundaries are necessary to segregate equipment and/or systems that are relevant to savings determination from those that are not.

In COLLECTiEF, the energy flows are monitored at the zone level (e.g. flat or single office), and at the building level. Further details are reported in section 5.4. Thermal comfort and indoor air quality are monitored at the level of the zone (e.g. flat or single office), as described in section 6.6.2.

3.1.5 Metrics and relevant data

Performance indicators are metrics used to determine the success of the project in reaching its objectives and creating an impact. The performance indicators should be SMART (specific, measurable, achievable, relevant and time-bound). In COLLECTiEF, after a literature analysis and according to international standards, a list of KPIs has been defined.

Since each identified impact requires a set of parameters and related monitoring criteria, equipment and measurement duration, in the following a specific chapter is dedicated to each domain: building smart readiness, energy, IEQ, energy flexibility and climate resilience.

The minimum requirements are the data needed for the impacts assessment, including those needed for the climate adjustments. However, calibrated models will be used to assess KPIs when measured data are not available and to extend the impact to the whole building level.

A literature review on existing KPIs for each domain has been carried out. The selected KPIs are described in detail in the specific section of the present deliverable. Further KPIs might be considered during the development of the project to better evaluate the performance of the system and to test the applicability of control algorithms. In this case, an updated version of the selected KPIs will be made available.

3.1.6 Data reduction

Monitoring

During monitoring phase, all the data available from existing measurement equipment (e.g. in Norwegian pilots, all the data from BMS) and from new installed systems (e.g. Sphensor™ units for thermal comfort and IAQ assessment) will be collected. However, in the project some approximations will be taken into account to reduce the number of deployed sensors, thus reducing the efforts and monitoring costs.

In thermal comfort assessments, the operative temperature is identified as the reference quantity for the evaluation of several key performance indicators. Operative temperature is defined as the uniform temperature of an enclosure in which an occupant (in a certain position) would exchange the same amount of heat by radiation plus convection as in the existing non-uniform environment. According to EN ISO 7726 [14], where the relative velocity is small (< 0,2 m/s) or where the difference between mean radiant temperature (MRT) and air temperature is small (< 4°C), the operative temperature can be calculated with sufficient approximation as the mean value of air and mean radiant temperature. According to ISO 7726, MRT can be assessed by measuring globe temperature, air temperature and air velocity, or it can also be calculated from measured values of the temperature of the surrounding

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

walls, their area and their position in relation to a person (calculation of geometrical shape factors, which depend on the position of the person within the room). However, in both cases, a significant investment in sensors, data analysis and possible annoyance for users (several sensors distributed in the space) needs to be taken into account. For this reason, based on a literature review [21] and considering the fact that in buildings characterized by a well-insulated envelope the air temperature can be considered as sufficiently representative of the operative temperature of the indoor environment, in all the pilots of the project only air temperature sensors will be deployed. Moreover, the calibrated models will be used to supply missing data and check the reliability of the assumption. Another limitation is based on the air velocity which will be not measured and considered in the thermal comfort assessment.

Deployment, testing and implementation

To develop light weight algorithm and address the challenge of low storage capacity at the edge node (raspberry Pi based gateway: BRiG), reducing the required computation power and costs, the final solution will be based on minimum data requirements which will reduce the number of required sensors. Moreover, considering the specificity of the diverse pilots and the different application domains the COLLECTiEF solution will face, the BRIG device that will be responsible for the data gathering, will be able to receive and send data in different ways. Particularly, using a communication approach based on the utilization of asynchronous protocols (i.e. MQTT protocol) data reception could be events triggered and function as an event-driven communication flow (e.g. for the Smart Valves and Smart Plug). At the same time on the basis of the control strategy calculation and its scheduling, a frequency can be defined (e.g. every 10 minutes) for instance, to gather the energy consumption data.

3.1.7 Frequency and duration of measurements

The frequency at which the data is recorded depends on the type of measured parameter and the case studies, characterized by different meters' configurations. For example, in the case studies where detailed and continuous monitoring is available (e.g. Norwegian pilots) a trade-off between accuracy and physical/technical capacity of the system will be considered to define the time frequency (a good compromise could be a temporal resolution of 10-15 minutes). Further details are given in section 6.6 for IEQ assessments.

Energy and IEQ measurements during the baseline will be carried out for an entire year, while during the assessment period they will cover two years.

3.1.8 Identification of suitable sensors and data acquisition system

On the basis of the metrics, measurement duration and desired accuracy, the proper equipment has been identified in all of its components. In Chapter 5.4 the sensors technologies for the measurement of energy flows in each pilot is described. In Chapter 6.6 the IEQ sensors for the measurement of indoor environmental quantities are presented.

The costs of the measurement equipment is provided in Table 4.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 4 Cost of the measurement equipment

Component	Euro
Sphensor™	100-300
BRiG	200
Smart thermostat	200-300
Smart valve	60-75
Smart Plug	15-35

3.1.9 Monitoring and data acquisition plan

Norwegian Pilot

BMS

An Application Programming Interface (API) to access all the analog data produced in the Norwegian pilot is available and below is shown an example of the data read through the API, in JSON format:


```
[
 {
  "ID": 1,
  "ZoneLetter": "T",
  "Description1": "Uteføler",
  "Description2": "320.01.RT00",
  "MaxNumberOfZones": 1500,
  "MaxValue": 30,
  "MinValue": -20,
  "MaxAllowed": 9999,
  "MinAllowed": -10000,
  "DaySetPoint": 21,
  "DeltaTemperature": 0,
  "LowSetPoint": 17,
  "ClosedSetPoint": 11,
  "PMin": 20,
  "Type": 2,
  "Acceleration": 0,
  "AccelerationStr": "",
  "Unit": "°C",
  "InndorRef": 0,
  "OverrideStatus": "",
  "BackColorString": "FFFFFF",
  "ForeColorString": "000000",
  "ActualValue": 11.2,
  "SetValue": 0,
  "Gain": 0,
  "OutdoorTemperature": 11.2062448500801,
  "RefZoneLetter": "",
  "RefZoneID": 0,
  "HasEffectCalculation": 0,
  "HasEffectRegulation": false,
  "IsEffectRegulationOn": false
 }]
```


This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

The plan is to call the API every minute to get the actual value measured. At the moment all the data collected from the API is stored, the amount of data will be periodically evaluated to know if it is necessary to perform cleaning procedures.

BRIG

Sphensor™ data are published using MQTT protocol. MQTT is one of the most widely adopted IoT communication protocols that support an event-driven architecture, and it is based on the Publish/Subscribe pattern of communication using an MQTT Broker for coordinating the delivery of events.

A MQTT server will be set up by E@W in the first week of June with one topic dedicated to Norwegian Pilot on which the database (through a dedicated interconnection module) will subscribe to read all the data published.

The connection module is already developed, it must be only checked the connection with the real MQTT server as soon as it is available. The structure of the grouped instant message will be this:

sphensor/<border router serial>/<sensor serial>/grouped_inst

The format is an array of JSON:

```
[
{
"timestamp": "2020-01-03 06:03:27",
"sensor_type": "opt3001_4",
"value": 2.2177724838256836,
"result": "ok",
"channel_index": 0
},
……...
]
```

In Table 5 there is a list of the possible couples *sensor_type/channel_index.*

Table 5 List of possible couples *sensor_type/channel_index*

sensor_type	channel_index	name
sht3x	0	Air temperature
sht3x	1	Relative humidity
ms5607	0	Cell temperature
ms5607	1	Atm. pressure

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

opt3001_0	0	Lux 1
opt3001_1	0	Lux 2
opt3001_2	0	Lux 3
opt3001_3	0	Lux 4
opt3001_4	0	Lux 5
adc_uva	1	UVA

Smart plug devices

The smart plug selected are able to communicate using MQTT but at the moment they are not integrated to communicate to the server, it is ongoing the activity of understanding how to extract data and import them manually until they will be integrated in MQTT communication.

A module to import data from csv is already developed, as soon as data will be available it is ready to store data into the database.

French pilot

A complete database with high resolution data collected in the French pilot since 2015 is already available.

It is ongoing by CSTB the process of understanding how to develop an API to access automatically the data and to store them into NTNU server. API will be ready from September/October.

A module to call API from French pilot have been done, as soon as API will be ready it can start collecting data. Until API will be ready, CSTB will generate periodically a csv file with all the data generated. This file will be parsed and inserted into the project database using a module already available.

It is ongoing by CSTB the activity of selecting the data to collect from French pilot to store into the project server.

Italian Pilot

BRIG

Data from Sphensor™ sensors will be collected using MQTT protocol. The data received is in JSON format, it will be parsed and then saved in tables. E@W is configuring a MQTT server for the communication that will be online in the first week of June. A module for the communication with this server is done and ready to be tested on NTNU server.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Smart plug and valves

Smart Valves and Smart Plugs will be installed by mid- M 12 (May) and the integration with the brigs will take place in the subsequently. Therefore, for the first period the generated data will be downloaded from the app of these two components, which is the shelly manufacturer's app. The log files are generated in text format (CSV) can then be accessed and downloaded from these devices either locally or via http (or other protocols) and then saved into NTNU server. The procedure for parsing and storing CSV files is done and ready to be tested on NTNU server. The data generated by them will later be integrated into the BRIGS, which will be the main mode of data communication.

Heating system control system

Both Coster heating control system and allocators can produce CSV files with the log of measurements.

The partners will periodically download these files that can be parsed and stored in NTNU server using a specific module already done and ready to be tested.

Also, for heating system control and heat allocators, the communication methods just described for data access will be temporary. The data generated by them will later be integrated into the brig, which will be the main mode of data communication.

Cypriot Pilot

There are several streams of data within the Cypriot pilot located at the Cyprus Institute. One of these data streams category corresponds to the IEQ measurements form the Sphensor™ sensors that is a directional data communication path from sensors to database registers. Data will be transferred through a MQTT protocol, structured in a JSON format, parsed and stored in database registers.

Another data stream corresponds to the weather data collection. The Cyprus Institute owns a building integrated weather station operated by the Cyprus Atmospheric Observatory (CAO) that is part of the Climate and Atmosphere Research Center (CARE-C) of The Cyprus Institute, and offers Cyprus-based atmospheric research facilities and related infrastructures for better characterization of regional air pollution and climate change. An API is developed by the Cyprus Institute to access in real-time local weather data that are currently stored in a MySQL database in Cyprus and the available on-site measurements are listed in Table 3 Meteorological stations: reference pilot and details. Weather data are stored every 5 minutes and using a python MySQL Connector an API is developed to fetch data in an xarray dataset format.

About POE, having installed the sensors and configured the brig at the pilot buildings, it will also be possible to associate these with the POE. The questionnaires are hosted on a web space acquired from a service provider (Aruba.it), which guarantees GDPR compliance. The plan for acquiring the data generated by the POE involves the creation of an automated procedure (based on http protocol) through which the data is imported into the NTNU server.

As part of the project, low voltage energy meters will be installed at Cyprus pilots to monitor the energy consumption of buildings in near real time. The purchase and installation of the smart meters is ongoing. The mode of data acquisition and import into the NTNU server will be established later.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

3.1.10 Model calibration procedure

The calibration will be carried out individually on each pilot site. In general, in the case of identification of black box models for predictions, two periods are considered: a training period and a validation period. In the case of COLLECTiEF, and also related to the use of physical models instead of black-box models, the calibration will be on the complete evaluation period, ideally one season for heating and one season for cooling (or, if easier to achieve, one year). The reason for this is that the model shall be used for the comparison between the situation with and without COLLECTiEF algorithms. The situation without these algorithms corresponds thus to a complete season or year and the calibrated model should fit as much as possible to the complete period. The same period can then be simulated using the COLLECTiEF algorithms, which allows to compare the performance of COLLECTiEF algorithms on the same year and with the same boundary conditions as the measured period.

The criteria for calibration will be the indoor temperature, thermal energy demand and consumption (by energy carriers heat, electricity, gas, oil or biomass). The fit related to these criteria will be minimized using a RMSE method with weighting factors that have to be defined.

The first round of calibration will be performed based on the available historical data from the pilot buildings such as energy bills, stored Building Management System (BMS) data, stored data from Advanced Measurement Systems (AMS). During the project these models will be ameliorated based on high quality data collected during monitoring phase.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

3.2 Installation

3.2.1 Check of the technical feasibility for the installation

The installation of the monitoring systems requires a check of the technical feasibility to verify if the equipment selected can actually be installed in the building. At this stage of the project, we are verifying the technical feasibility for the installation of the Sphensor^{TM} units, the smart valves, the smart plugs and the BRIG device. The specifications regarding the integration process based on the characteristics of legacy equipment in each demonstration building will be contained in the deliverable *D4.1 - A complete requirements specification, covering both functional and nonfunctional requirements* and in *D4.2 - Action plan of implementation activities*.

Before the beginning of the baseline period (M13) the monitoring units, named Sphensor^{TM}, for assessing thermal comfort and indoor air quality will be installed in the pilots. Guidelines about the installation of the Sphensor^{TM} are reported in section 6.6.1. Check about the technical feasibility of the installation in each pilot, considering the specificities of each zone and related occupants' needs and wishes, are currently undergoing.

Before M13 BRIG device will be also installed to collect the data from the Shpensor^{TM} units. As part of WP3 the BRIG will be further developed between M13 and M24 to communicate with smart plugs and smart valves for applying controls.

The BRIG will activate and monitor the physical connectivity of the monitored devices by accessing the local network. The local network will be based on the IEEE 802.11 (WiFi) standard that offers significant signal coverage for devices installed in the building and can be extended through the use of repeaters. It also includes comprehensive security measures to protect the network and ensure privacy. Thread protocol will be used to communicate with the Sphensor^{TM}. To design the best configuration of the wireless LAN, four key aspects are being considered: coverage, capacity, performance, and installation.

Coverage is the area where WiFi devices are able to connect to the network. Since the local network intends to cover different rooms and apartments in the buildings considered, this variable depends on the physical configuration of the building (e.g. floor measurements, walls, etc.).

Capacity is the ability of each wireless access point to manage a number of devices connected to the network. The design of the network takes into account a minimum number of sensors, actuators and devices distributed within the building.

Network performance implies a minimum available bandwidth that is sufficient to allow devices and applications to carry out their activities in full operation. It is important to select technologies and systems that offer the highest levels of performance and scalability. Therefore, the design takes into account the latest high-speed WiFi technologies, such as 802.11g / n, rather than cheaper legacy products with lower performance.

The installation and implementation of the wireless communication network in the building depend on the distribution of the rooms, also evaluating the possibility of implementing a WiFi mesh network in the building spaces.

The final network configuration depends on the building measurements, so floor plans and blueprints are important to define the ideal infrastructure.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

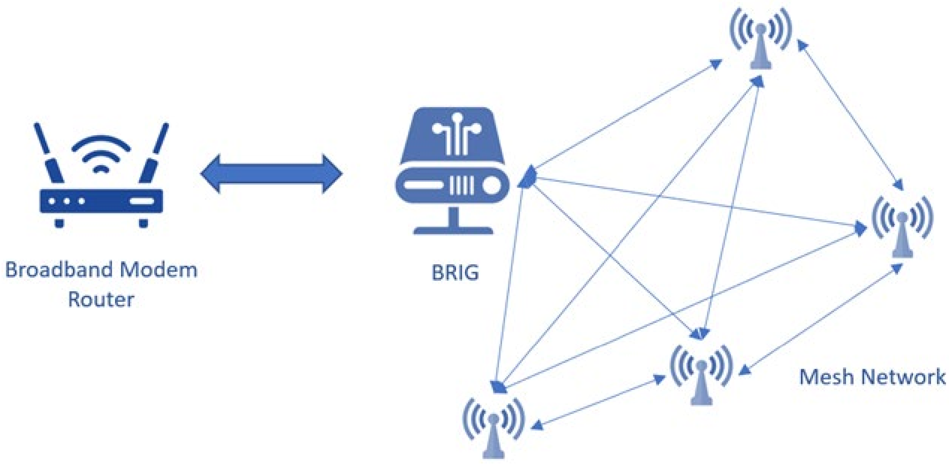


Figure 6 Physical connection of network devices

The Wireless Local Area Network will be deployed to cover the rooms and devices. The external internet network will be accessed through the local Broadband Modem/Router. The Internet Router will be directly linked to the BRIG device, acting as a communications proxy for all the devices of the building (i.e., final sensors and actuators). This device is the only one granted access to the Internet, so increasing the security configuration of the building devices. A local Wi-Fi mesh network could be deployed to increase the reachability of the devices by using specific routers and repeaters connected to the BRIG.

BRIG

BRiG provides Border Router functionality for the Thread radio network for the communication with Sphensor™ units through the use of Radio module based on Nordic nRF52840 chipset controlled through specific software daemon for OpenThread radio module for the Thread network management via a UDP/IPv6 socket.

In parallel, BRiG supports communication with smart-plugs and building energy parameters measurement devices in two main ways: (1) through the adoption of communication protocols directed to the physical equipment installed in the building (Rest API, MQTT, Modbus over RS485 or Ethernet/IP) or (2) by communicating with information servers that have special APIs for accessing data.

BRIG is equipped with a specific module for the configuration of the radio network and bi-directional communication with sensors and is able to support the MQTT broker function through an Eclipse Mosquitto daemon with authentication via username / password.

MQTT has a client/server model, where every sensor is a client and connects to a server, known as a broker, over TCP. MQTT is message-oriented. Every message is a discrete chunk of data, opaque to the broker. Within the model, the publisher's task is to collect the data and send information to subscribers via the mediation layer which is the broker. The role of the broker, on the other hand, is to ensure security by cross-checking the authorization of publishers and subscribers.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

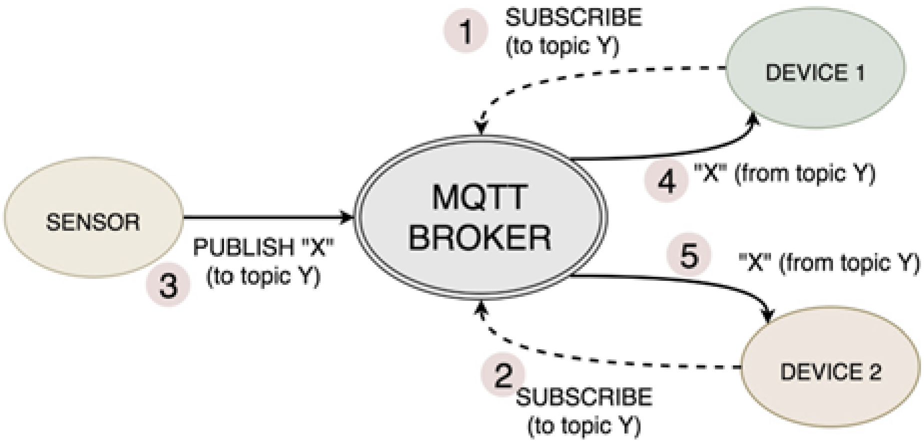


Figure 7 MQTT Protocol Architectural Structure

MQTT offers three modes of Quality of Service (QoS) to achieve this, thanks to which the publisher and the subscriber of a message have the possibility to define the quality of its message guaranteeing the delivery for a specific message.

There are 3 QoS levels in MQTT:

- QoS 0 (At most once): the least reliable mode but also the fastest. The publication is sent but confirmation is not received;
- QoS 1 (At least once): ensures that the message is delivered at least once, but duplicates may be received;
- QoS 2 (Exactly once): the most reliable mode while the most bandwidth-consuming. Duplicates are controlled to ensure that the message is delivered only once.

The role of the BRIG MQTT broker (QoS 2 level) is central in all communications concerning:

- The gathering of data by the Sphensor™ network, both relating to environmental measurements and diagnostic information.
- The configuration of the operating parameters of the Sphensor™ network and of the individual sensors.
- The gathering of information from the energy meters, whether they come from physical devices or from information systems accessible via the network.
- The sending of actuation commands to on/off switching devices and to proportional regulation devices.

The MQTT broker, therefore, represents the link between the control section of the field equipment (measurement and control) and the software section relating to the BRIG role. Having the appropriate access credentials, the MQTT broker can also be used by systems external to BRiG, thus obtaining ample flexibility during system monitoring, diagnosis and testing activities.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

3.2.2 Energy meters calibration

Norwegian Pilots (case studies 1-7)

The smart meters (AMS meters) installed on site will be accessed through their Home Area Network (HAN) port. The meter will regularly send data to the BMS system and every 10 seconds update its current consumption. Every 1 hour it will update its accumulated consumption.

This data will be read from the BMS JSON/REST API.

All the AMS meters are already installed in the Norwegian pilots by the local power company. The interface to the BMS system will be done through applicable hardware and integrated into the BMS system for presentation, logging and used in other control mechanisms.

There is no need for continuous calibration of the AMS meters.

French Pilot (case study 8)

All measurement equipment is already installed in the G2Elab building.

At the installation and commissioning of all measurement equipment, functional checks have been run in order to ensure the correct operation of all meters and sensors. Due to the large number of sensors, no official calibration or correction has been carried out. However, due to the fact that all sensors and meters are based on bus communication and thus numerical transmission of data, the risk of low accuracy due to the whole measurement loop are low, except in case of failure.

Cypriot Pilots (case studies 9 -11)

The three Cypriot pilot buildings are equipped with smart meters (Ether meters) but currently monitored data is not available at the buildings. We are working with the Ether company to set a communication line to store data from the smart meter locally at the buildings.

After the creation of the communication channel, calibration will be performed by a qualified calibration facility independent of the parties involved. There will be no need for continuous calibration of the smart meters after their set-up.

Italian Pilots (case studies 12 - 14)

The existing control and monitoring devices will be used for the monitoring of the heating system variables. Their sensors and electronic components are periodically maintained and checked, since they are used also for the official distribution of the costs for heating between the apartments.

New smart valves and smart plugs will be installed within the project, with the quality and the accuracy assurances from the manufacturing company.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

3.2.3 IEQ sensors (Sphensor™) calibration

Accuracy at installation

Sensors are provided with accuracy of sensing cells certified by producers. The accuracy is indicated in the data sheet of Sphensor™ for every sensing element.

The accuracy values provided by the producers are usually maximum or typical values, so the performance of the sensing elements can be even better.

For sensing elements acquired digitally we don't add additional errors.

Re-calibration

In order to define the suggested re-calibration period, it is important to focus on the characteristics of the environments as well as the necessities of the application.

In the COLLECTiEF project the period of installation of Sphensor™ in the pilot sites is 3 years, the installation environment can be considered neuter, the required accuracy for the application of energy efficiency and air quality in moderate thermo-hygrometric environments is not extremely high.

To calculate the suggested re-calibration period, we used the temporal drift of the accuracy of the measurement indicated by the sensing cells' producers. We considered as acceptable an accuracy drift comparable with the native cell accuracy.

For all the sensing elements, the re-calibration period found is more than 3 years (5 years for CO_2), so the sensors don't need a re-calibration during the project. The VOC measurement is different from the other quantities: it's an estimation of the total VOCs in the air and is not possible to separate the different components. The re-calibration of the cell is not applicable or not feasible.

In the following table the suggested periods for re-calibration and the related temporal drifts of the different sensing cells are shown:

Table 6 Suggested periods for re-calibration and related temporal drifts for Sphensor™ units

Quantity	**Suggested period for re-calibration [months]**	**Notes**
T_{air}	36	Long term drift max <0.03 °C/yr
RH	36	Long term drift typ <0.25 %RH/yr max 0.5 %RH/yr
Illuminance	36	Important: keep the optics clean to maintain the accuracy
UV-A	36	
Atmospheric Pressure	36	Long term drift typ 1 hPa/yr

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

CO_2	60	Re-calibration period suggested by the producer
VOC	ND	The VOC measurement is an estimation of the total VOC and not an exact measurement of the single VOC components; the measured value should be use as a qualitative indication of the environment health
PM	36	It's an indirect measurement based on an algorithm, the comparison with other technologies is not possible

3.2.4 Commissioning

The monitoring system commissioning starts with the planning phase and continue with the set-up and tests of the hardware and software components of the system. Test of the operation includes check of the information gathered and transferred by the data acquisition system: availability of the data, values collected, metrics, time frequency, data storage.

Particularly, in the planning phase, the positioning of the different systems to gather data from the field and the communication points will be defined as follow:

a) Definition of the measurement points in the environments and rooms of interest; it may be convenient to use a building plan; data collection in a spreadsheet listing at least the following information:
   - Building section.
   - Location of the measurement point in the section.
   - Identification code of the position of the measuring point.
   - Sensor type and model used for the specific measurements.
   - Serial identification code of the sensor used for the specific measurements.
   - List of physical measurements to be implemented.

b) Preliminary definition of the physical positions relating to the points in which to install the radio signal repeaters of the radio signals on the basis of an indicative assessment of the characteristics of the building, the positions of the measurement points, of the distances to be covered, of the available power points. These positions have to be confirmed or modified on the basis of the necessity that could emerge during the installation phase which will be possible to have confirmation only during the instruments' installation phase.

c) Definition of the physical positions of the BRiGs, considering the same aspects of the previous point and also the availability of network connectivity.

d) Definition of communication systems and connection points that allow BRiG to connect to COLLECTiEF systems for data collection.

After that, the communication and network structure, as defined in section 3.2.1, has to be established by (1) installing and configuring the MQTT broker that will be used for the "publication" of the environmental data collected by Sphensor^{TM} and in the second stage for the "publication" of all the data collected from sensors and actuators installed on the field level and (2) by installing and preparing the router or the network access point for BRiG connectivity to the remote MQTT broker.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

At this point, a software to support the installation of the devices is needed. To this end, a portable PC will be used to configure the installations of the sensors.

Also, an instrumental installation of environmental measurement systems will be conducted by implementing the following activities:

a) BRiG activation by placing the device in the position foreseen for its final functioning;
b) starting the Sphensor™ management software on the portable PC to configure the connection with the nearest BRiG and/or the BRIG defined as an access point for the specific Sphensor™ among those detected in the local network;
c) configuration of the BRiG network parameters and of the MQTT server to which the data will be sent (IP addresses / host names, access credentials);
d) switching on all sensors in a close position to BRiG so that it is possible to immediately identify the measurement activity, comparing the data measured by the various sensors and making sure that they are comparable within the degree of uniformity allowed by the place in which they are placed. This already represents a first validation system, considering that the comparison between the quantities may present false differences due to the environment and the degree of the setting of the probes in the environment itself;
e) to implement for every single sensor: (1) movement to the final measurement position; (2) detection of the quality of the radio signal. If the radio quality is less than 10%, expect the addition of a repeater in an intermediate position and evaluate again the quality of the radio signal, both for the sensor and for the repeater;
f) repeat the activities defined in the previous point for each sensor until the measurement network defined for the specific BRiG is finalized;
g) repeat all the steps from a. to g. for all the BRiG devices.

At this point, the activities related to the test of the system have to be carried out by evaluating the measured data through an MQTT client and their regular publication on the MQTT broker (verification of the correct data transmission) and evaluating the continuity of the measurements and the quality of the radio signals. The percentage of battery charge of the sensors and devices installed in the field must also be controlled to avoid data loss due to the devices being switched off.

At the same time, the necessary activities for the storage and processing of the measured data must be carried out, such as the creation and maintenance of the database, the software for the management of the data received from the MQTT server, and the procedures for the registration, data selection and analysis.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

3.3 Operation

3.3.1 Data quality check procedures (storage)

At the level of data storage, procedures will be applied to ensure data quality throughout the entire data life cycle.

Control of incoming data: data quality can be ensured through strict control of incoming data. Data profiling techniques will be used to review the source data, and examine aspects such as data format and models, data consistency on each record, data value distributions and anomalies, and data completeness. In this way, data with serious or numerous quality problems can be identified, as well as the source of the problems. The main techniques that will be used concern the identification of missing or unknown data (e.g., NAN/empty/null), identify outliers in the data (e.g., frequency peaks), as well as the creation of rules and alerts to verify the correct incoming reception of data from the source.

Accurate data collection: a persistent data storage and management system will be structured to provide all the necessary tools for managing the context history and data that can be stored using relational DBMS technologies. The schema of logical-entity relations will be modelled considering its three main layers (internal, logical, external) Clear documentation of the requirements will be provided, with easy access and sharing. A description of the repository in terms of conceptual, logical and physical elements (entity-relationship schema; definition of entities and attributes; relations and their attributes; cardinality, candidate keys; etc.) will also be provided in order to allow access, reading and processing of the information needed to enable the evaluation of the system performance against the KPIs.

Data integrity: At the level of physical integrity (e.g., a natural disaster, power outage affecting the functionality of the database) the database is designed by default to safeguard the collected data against unauthorized use and to comply with all national and European regulations in data storage and backup methods. Data backups are expected to occur once a week, though this is subject will change based on the amount of data that will ultimately need to be backed up.

At the level of **logical data integrity**, techniques such as primary keys, foreign keys, control constraints and triggers will be used to ensure accuracy, completeness and consistency of the data as a whole. Specifically, **entity integrity** will be ensured by creating primary keys, i.e., unique values identifying each piece of data, to ensure that information is not listed more than once and that no field in a table has a value of null. **Referential integrity** will be ensured by integrating rules into the database structure that control how foreign keys are used and ensure that data is only subject to appropriate modifications, additions or deletions. **Domain integrity** will be implemented with constraints and other measures that make it possible to control whether a set of values can be acceptable according to the type of values a column can contain (e.g., the percentage of moisture cannot exceed the value 100). These activities are very important as the volume of data in the project increases and are necessary to guarantee data uniformity for each pilot building.

Finally, to ensure data traceability, clear documentation and modelling of each dataset will be provided from the beginning, including its fields (metadata) and structure (keys). At the metadata level, the database will provide access to its metadata with a set of tables or views

These procedures will be implemented to maintain good data quality from the beginning, ensuring **data precision** (accuracy of the data), **relevance** (they must meet the requirements for the intended use), **completeness** (they must not have missing values), timeliness (checking that the data must be updated), **consistency** (they must have the intended data format).

3.3.2 Data post-processing

After the data is acquired, during the operation phase, the post processing is dedicated to assess the impacts, calculating the KPIs as defined in following sections. Deliverables D5.2, D5.3 and D5.4 - *Ongoing performance evaluation of the COLLECTiEF system implemented in the pilot cases* (first, second and final version) will contain the specifications regarding the methods to calculate the indicators and the post-processing guidelines.

3.3.3 Maintenance

To guarantee that the monitoring system works properly during the monitoring campaign, it is necessary to plan maintenance activities (monitoring system continuous commissioning).
Special attention must be given to sensor calibration (see chapter 3.2.2 and 3.2.3) and malfunctioning but also to data storage and sensor power supply (e.g., external power or battery power).
Some of the indoor environmental sensors (Sphensor™, see chapter 6.6 for details) installed in the pilot buildings are powered by not-rechargeable batteries (PRMPB0401-02-04). The batteries' lifetime periods are reported in the table below, according to the sampling frequency set:

Table 7 Batteries' lifetime periods for Sphensor™ units

	Non-Rechargeable Battery* Life			
Sampling Rate	**PRMPB0401**	**PRMPB0402**	**PRMPB0403**	**PRMPB0404**
30''	1 year e 3 months	1 year e 1 month		
1'	2 years e 1 month	1 year e 10 months		
2'	2 years e 9 months	2 years e 5 months		
5'	4 years e 2 months	3 years e 9 months		
10'	5 years	4 years e 6 months		

*Battery type: Lithium battery, 3.6 V 1.2 Ah, ½ AA size.

The selected sampling rate for the pilot buildings is 1 minute, so the battery lifetime will be 2 years and 1 month for the temperature, humidity and pressure sensor and 1 year and 10 months for the temperature, humidity, pressure and illuminance sensor.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

In order to plan maintenance activities, it is always advisable to be precautionary and consider changing the battery before the nominal lifetime, since the duration depends on several factors, such as the capacity of data transmitting to the receiver. In order to optimize the maintenance activities, it is advisable to change all the sensors' batteries at the middle of the monitoring period (after 1 year and 6 months).

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

4 Assessing smart readiness in COLLECTiEF

The smart readiness of buildings is the capability of buildings (or building units) to adapt their operation to the needs of the occupant, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility).

The 2018 revision of the European Energy Performance of Buildings Directive (EPBD) [6] has underlined the potential of smart technologies and has introduced the Smart Readiness Indicator (SRI) to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings. The SRI can be considered a top-level KPI, thus able to simplify complex information and point to the general state of a phenomenon [22].

The SRI should raise awareness amongst building owners and occupants of the value behind building automation and electronic monitoring of technical building systems and should give confidence to occupants about the actual savings of those new enhanced-functionalities [23].

4.1 Objectives

The COLLECTiEF system aims at upgrading the existing pilot buildings with at least one level of smartness according to SRI scoring methods, independently from the starting smart readiness level. COLLECTiEF in fact, will cover a portfolio of legacy equipment with different functionality levels that will be upgraded during the project to higher level and as a result will increase the overall SRI of the building.

4.2 Methodology

The assessment procedure is based on an inventory of “smart ready services” that could be available in buildings, which are categorized by 9 domains (heating, cooling, domestic heat water (DHW), controlled ventilation, lighting, dynamic building envelope, electricity, electrical vehicle charging, monitoring and control). The services within a building can be operated with various degrees of smartness, referred to as “functionality levels”. For each of the services, 5 functionality levels are defined. A higher functionality level indicates a “smarter” service, which therefore has higher beneficial impacts to building users and/or to the grid compared to the same service implemented at lower functionality level. COLLECTiEF system will increase the functionality level depending on the presence of services and their existing functionality level.

Two methods are currently available in literature: a detailed and a simplified assessment method. To support this, two catalogues of smart ready services are available. Each catalogue lists the relevant services and describes their main expected impacts towards building users and the energy grid.

To perform the SRI assessment, an SRI assessment package has been provided by SRI support team. The Pilots’ responsibles are currently doing visual inspections and are collecting technical data and information to complete properly the assessment (Figure 8), which will be available by the end of the baseline period (M24). The SRI evaluation is inspection-based and no measured data are necessary, therefore no specific plan for monitoring has to be defined.

5	SMART READINESS If available, please highlight in red the cell and provide additional infor									
	Domain	Service group	Smart ready service	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4	Standard used	COMMENTS (Please provide more information)
1	Heating	Heat control - demand side	Heat emission control	No automatic control	Central automatic control (e.g. central thermostat)	Individual room control (e.g. thermostatic valves, or electronic controller)	Individual room control with communication between controllers and to BACS	Individual room control with communication and occupancy detection	EN 15232	thermostatic valve on each radiators
2	Heating	Heat control - demand side	Emission control for TABS (heating mode)	No automatic control	Central automatic control	Advanced central automatic control	Advanced central automatic control with intermittent operation and/or room temperature feedback control		EN 15232	no TABS installed
3	Heating	Heat control - demand side	Control of distribution fluid temperature (supply	No automatic control	Outside temperature compensated control	Demand based control			EN 15232	
4	Heating	Heat control - demand side	Control of distribution pumps in networks	No automatic control	On off control	Multi-Stage control	Variable speed pump control (pump unit (internal)	Variable speed pump control (external demand	EN 15232	electronic pump at the base on each building (secondary loop)
5	Heating	Heat control - demand side	Thermal Energy Storage (TES) for building heating	Continuous storage operation	Time-scheduled storage operation	Load prediction based storage operation	Heat storage capable of flexible control through grid			no storage for heating
6	Heating	Control heat production facilities	Heat generator control (all except heat pumps)	Constant temperature control	Variable temperature control depending on	Variable temperature control depending on the			EN 15232	
7	Heating	Control heat production facilities	Heat generator control (for heat pumps)	On/Off-control of heat generator	Multi-stage control of heat generator capacity depending	Variable control of heat generator capacity depending	Variable control of heat generator capacity depending		EN 15232 + expanded	no heat pump installed
8	Heating	Control heat production facilities	Sequencing in case of different heat generators	Priorities only based on running time	Control according to fixed priority list: e.g. based on rated	Control according to dynamic priority list (based on	Control according to dynamic priority list (based on	Control according to dynamic priority list (based on	EN 15232 + expanded	
9	Heating	Information to occupants and facility managers	Report information regarding HEATING system	None	Central or remote reporting of current performance KPIs	Central or remote reporting of current performance KPIs	Central or remote reporting of performance	Central or remote reporting of performance	No standards available	annual report on energy uses for the ripartion of the energy costs
10	Heating	Flexibility and grid interaction	Flexibility and grid interaction	No automatic control	Scheduled operation of heating system	Self-learning optimal control of heating system	Heating system capable of flexible control through grid	Optimized control of heating system based on local	None	
11	Domestic hot water	Control DHW production facilities	Control of DHW storage charging (with direct electric	Automatic control on / off	Automatic control on / off and scheduled charging	Automatic control on / off and scheduled charging	Automatic charging control based on local availability of		EN 15232, except level 3	not present
12	Domestic hot water	Control DHW production facilities	Control of DHW storage charging (using hot water	Automatic control on / off	Automatic control on / off and scheduled charging	Automatic on/off control, scheduled charging enable and	DHW production system capable of automatic charging		EN 15232, except level 3	
13	Domestic hot water	Control DHW production facilities	Control of DHW storage charging (with solar collector	Manual selected control of solar energy or heat	Automatic control of solar storage charge (Prio. 1) and	Automatic control of solar storage charge (Prio. 1) and	Automatic control of solar storage charge (Prio. 1) and		EN 15232	not present
14	Domestic hot water	Control DHW production facilities	Sequencing in case of different DHW generators	Priorities only based on running time	Control according to fixed priority list: e.g. based on rated	Control according to dynamic priority list (based on	Control according to dynamic priority list (based on	Control according to dynamic priority list (based on		not present
15	Domestic hot water	Information to occupants and facility managers	Report information regarding domestic hot water	None	Indication of actual values (e.g. temperatures,	Actual values and historical data	Performance evaluation including forecasting and/or	Performance evaluation including forecasting and/or	No standards available	simple decentralized system in each apartment for the DHW preparation

Figure 8 – Smart readiness assessment: example of collection of technical data in one of the pilot buildings

4.3 Key Performance Indicator

The smart readiness score of a building or building unit is expressed as a percentage which represents the ratio between the smart readiness of the building or building unit compared to the maximum smart readiness that it could reach.

In COLLECTiEF the SRI will be calculated in each pilot building before and after the implementation of the systems.

The resulting **total SRI score** will be expressed in terms of percentage and SRI class and will take into account domain weightings and impact weightings. Moreover, the following results will be available through the “results” tab [24]:

- **Impact scores**: the impact scores for each impact criterion, taking into account domain weightings.
- **Domain scores**: the domain scores for each domain, taking into account impact weightings.
- **Detailed scores**: the detailed scores for each domain and each impact criterion, which results in a matrix for 9 domains and 7 criteria.
- **Aggregated scores**: the aggregated scores for 3 key functionalities.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

5 Monitoring energy in COLLECTiEF

When upgrading a building by one level of smartness, impacts on energy savings, related cost savings and improvements in the use of on-site renewables can be assessed.

The energy savings depend on the original energy demand of the building prior to installing the smart ready technology, on the uses influenced by the implementation of the system, on the algorithms developed and tested.

Regarding costs, it’s worth noting that several EU countries have introduced dynamic pricing, such as time-of-use pricing, direct linkage to wholesale pricing in the retail tariff and other forms of dynamic pricing. The availability of such tariff structures is largely defined by the national regulator and the structure of the power system. In 2017, consumers in 13 member states had access to time-of-use contracts with intraday/weekdays/ weekend energy price differentiation, and in 8 member states they could opt for real-time or hourly energy pricing.

Smart meters are a key enabler for dynamic pricing. Their functionalities should allow the reliable reading of consumption in specific time intervals that match electricity markets intervals.

According to the Electricity Directive, member states have been obliged to roll out electricity smart meters to 80% of consumers by 2020, unless the result of a cost-benefit analysis is negative. In the EU, 16 member states committed themselves to installing smart meters by 2020. Several do not intend a wide scale roll-out of smart meters (Belgium, the Czech Republic, Germany, Hungary and Lithuania). By the end of 2017, the roll-out of smart meters had reached more than 50% of the household customers in only nine member states.

Member States are required to ensure the implementation of smart metering under EU energy market legislation in the Third Energy Package. This implementation may be subject to a long-term cost-benefit analysis (CBA). To date, Member States have committed to rolling out close to 200 million smart meters for electricity and 45 million for gas by 2020 at a total potential investment of €45 billion. By 2020, it is expected that almost 72% of European consumers will have a smart meter for electricity while 40% will have one for gas.

While cost estimates vary, the cost of a smart metering system averages between €200 and €250 per customer, while delivering benefits per metering point of €160 for gas and €309 for electricity along with, on average, 3% energy savings.

The overall successful roll-out of smart meters across the EU is dependent on criteria largely decided by Member States. This includes regulatory arrangements, and the extent to which the systems to be deployed will be technically and commercial interoperable, as well as guaranteed data privacy and security [24].

Smart Metering in Norway

Since 1st of January 2019, smart meters have been installed by DSOs throughout entire electricity consumers in Norway. With AMS (Advanced Metering System), consumers receive advanced information about their electricity consumption, a more accurate meter reading and better opportunities to engage in demand response. Smart meters register electricity consumption every hour, and automatically send information about the consumption to the DSO [25].

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

About 65% (80TWh/year) of the electricity delivered in the Norwegian market is on dynamic pricing based on spot prices with hourly metering. This is mainly due to the industrial customers using 100.000 kWh/year or more already apply spot pricing with hourly metering.

Dynamic prices for households without smart meters are calculated based on different models:

- Average monthly spot price.
- Average spot prices for shorter periods.
- Dynamic prices based on spot as well as the traded short-term products in the futures market, e.g., a mix of spot, weekly and monthly contracts. This product is comparable to banking markets' competition in the market for interests. Suppliers offering these contracts are obliged to give the customer one to two weeks of warning before changing their prices [26].

Smart Metering in Italy

Italy is a pioneer country for digital electricity metering and more than 99 percent in Italian households have equipped with smart meters. Italy has successfully deployed the smart meter installation across the country. The Italian regulatory authority AEEG recognised the benefits of smart metering and made the installation of smart meters mandatory in 2006. According to a report by the European Commission, the Italian smart metering system, with the replacement of traditional meters since 2001, has been the most efficient in Europe [27].

Smart Metering in Cyprus

Introduction of dynamic-pricing retail contracts. Subject to the final provisions of the recast Electricity Directive, dynamic pricing retail contracts will be introduced gradually as the installation of smart meters is roll out and the competitive electricity market becomes operational. Cyprus shall provide the necessary regulatory framework to ensure that final customers who have a smart meter installed can request to conclude a dynamic electricity contract from a supplier that has more than 200 000 final customers. Suppliers with less than 200 000 final customers will not be obliged to offer dynamic-pricing retail contracts. Preliminary timeframe for this Target is 2024-2025. Electricity Authority of Cyprus (EAC) has implemented an automatic meter management (AMM) system (pilot project of 3,600 smart meters) [28].

Smart Metering in France

The complete roll-out of smart meters in France presents an opportunity to reward flexibility, even at the residential level through the introduction of dynamic prices, offers for smart charging or grid dispatch of EVs, week-end tariffs, and super off-peak hour products. Hitherto, 35 million smart meters has been installed by Energi across France [29].

5.1 Objectives

In COLLECTiEF monitoring energy flows is necessary to evaluate the impacts reported in Table 8. Moreover, the measurements will be exploited to calibrate the energy models that will be used for testing the algorithms and extend the impact assessment from the zone to the building/cluster of buildings level.

Table 8 Description of COLLECTiEF expected impacts which require energy monitoring

2	Depending on building thermal quality and climate zone, **9%-27% relative energy reduction and 0.2-3 €/m² annual energy cost savings** are estimated for buildings after installation of COLLECTiEF system and upgrading by one level of smartness.
3	An average of 16% **reduction in primary energy use** of the pilot buildings is estimated, equivalent of 0.93 (GWh/year).
4	Up to 52% increase in **self-consumption rate** can be achieved due to optimal operation provided by the COLLECTiEF system, which can bring up to 364 **EUR per year** additional income for a typical four-person family household with PV system.

5.2 Methodology

To evaluate the impacts related to energy quantities, it is necessary at first to identify the energy level to be considered for the assessment. Section 2.2 reports the operative definition of each energy level. For each pilot, the energy uses and the energy carriers have been identified and are reported in the specific building template, available in the repository. In each pilot, only a certain number of zones (e.g. flats or offices) will be interested by the implementation of the systems. For example, in Italy, the solutions will be implemented in 12 apartments out of 109 apartments in the three building blocks. The impact of the intervention, measured at the flat level, will then be scaled-up to the whole building block using calibrated simulation. Therefore, the final impact assessment will be provided at the building level. These site-specifics will be elaborated in details in deliverables *D5.2, D5.3 and D5.4 - Ongoing performance evaluation of the COLLECTiEF system implemented in the pilot cases (first, second and final version).*

5.2.1 Impact 2.a: energy

According to IPMVP [2], energy savings cannot be directly measured, because savings represent the absence of energy consumption or demand. Instead, savings are determined by comparing measured energy use before and after implementation of a system, making suitable adjustments for changes in conditions. The comparison of before and after energy consumption or demand should be made on a consistent basis, using the following general M&V equation, which is schematized in Figure 9:

$$\text{Savings} = (\text{Baseline Energy} - \text{Reporting Period Energy}) \pm \text{Adjustments}$$

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

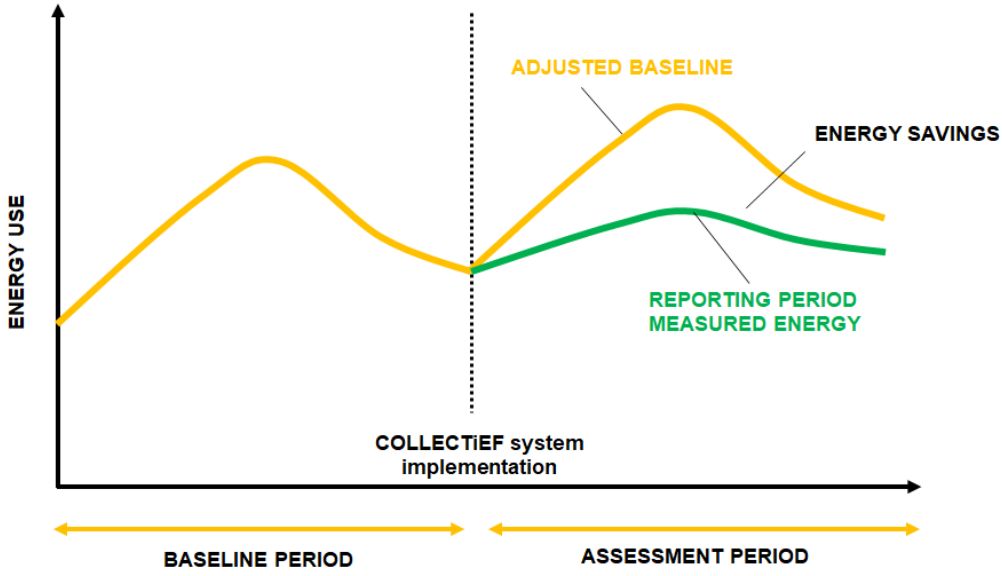


Figure 9 Energy savings representation, adapted figure from IPMVP [2]

The assessment of energy savings can be done at different levels and a series of metrics is available in section 5.3.1.

The energy data will be analyzed against accumulated temperature differences (degree days) according to ISO 15927-6:2007 [10]. In the case of heating, when hourly data are available, heating degree-days (HDD) shall be calculated according to the following equation:

HDD = $\sum_{h=1}^{n} \Delta T_h\,(T_b)/24$ where:

$\Delta T_h (T_b) = (T_b - T_{hm})$ if $T_{hm} < T_b$

$\Delta T_h (T_b) = 0$ if $T_{hm} > T_b$

with:

- T_b: base temperature [°C]
- ΔT_h: hourly temperature difference [°C]
- T_{hm} = hourly mean temperature [°C]

When hourly data are not available, the approximate method given in 4.5 of ISO 15927-6:2007 [10], based on the maximum and minimum temperatures each day, may be used.

NOTE: since calculating using daily or hourly data, or different choices of a conventional base temperature, brings to different values of HDD, the exact definition of HDD used in every calculation/project will be made explicit. Cooling Degree Days (CDD) are defined in a similar manner. In this case, it is especially important to specify the chosen base temperature since the potential range for the choice is broader.

The absolute energy savings will be calculated from measured data collected at the level of the zone (e.g. flat/office) for each energy carrier, where available, and from calibrated models, providing the assessment at the level of the entire building. Later they will be transformed into relative energy saving and linked to the corresponding improvement in the level of smartness. A description of the steps

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

necessary for the calculation of the relative energy saving is reported in Figure 10. The process will be detailed and adapted to the specific case study in deliverables *D5.2, D5.3 and D5.4*.

		SRI CLASS						
		G	F	E	D	C	B	A
1	**Delivered energy (per energy carrier) Ed**				*Pre installation*	*Post installation*		
	Energy use for space heating				kWh/year	kWh/year		
	Energy use for space cooling				kWh/year	kWh/year		
	Energy use for ventilation				kWh/year	kWh/year		
	Energy use for lighting				kWh/year	kWh/year		
	Energy use for DHW				kWh/year	kWh/year		
2	**Adjustments (e.g. HDD, CDD) Ed***							
	Energy use for space heating				kWh/(HDD* year)	kWh/(HDD* year)		
	Energy use for space cooling				kWh/(CDD* year)	kWh/(CDD* year)		
	Energy use for ventilation				kWh/year	kWh/year		
	Energy use for lighting				kWh/year	kWh/year		
	Energy use for DHW				kWh/year	kWh/year		
	Total							
3	**Absolute energy saving**				**D > C**			
					kWh			
					Ed*,D - Ed*,C			
4	**Relative energy saving**				**D > C**			
					%			
					(Ed*,D - Ed,C)/Ed*,D			

Figure 10 Calculation tool for relative energy saving (example of upgrading from D to C)

5.2.2 Impact 2.b: costs

Annual energy cost savings resulting from energy efficiency gains from smart ready technologies uptake will be calculated based on current energy prices. In the following, we report a synthesis of the analysis on the energy pricing system developed for the pilot countries. During the project duration, the trends of the prices for the different energy carriers will be considered, in order to take into account the variation of the prices according to the actual international context.

<u>Electricity prices</u>

The information about electricity prices is provided by Eurostat [30]. Table 9 and Table 11 report the electricity prices in €/kWh for household consumers in the pilot countries considering an annual consumption between 2500 and 5000 kWh, excluding and including taxes and levies respectively. Table 10 and Table 12 report the electricity prices in €/kWh for non-household consumers in the pilot countries considering an annual consumption between 500 and 2000 MWh, excluding and including taxes and levies respectively.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 9 Electricity prices [€/kWh] for household consumers considering an annual consumption between 2500 and 5000 kWh, excluding taxes and levies, in the pilot countries - bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.1089	0.1132	0.1134	0.1168	0.1148	0.1260	0.1242	0.1292	0.1289	0.1356
Italy	0.1322	0.1326	0.1285	0.1416	0.1432	0.1427	0.1382	0.1331	0.1432	0.1760
Cyprus	0.1454	0.1420	0.1445	0.1745	0.1545	0.1576	0.1497	0.1184	0.1276	0.1451
Norway	0.1163	0.1137	0.1254	0.1382	0.1360	0.1264	0.0954	0.0927	0.1326	0.1752

Table 10 Electricity prices [€/kWh] for non-household consumers considering an annual consumption between 500 and 2000 MWh, excluding taxes and levies, in the pilot countries – bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.0733	0.0666	0.0736	0.0669	0.0812	0.0737	0.0847	0.0754	0.0850	0.0810
Italy	0.0829	0.0813	0.0892	0.0885	0.0952	0.0930	0.0856	0.0878	0.0939	0.1403
Cyprus	0.1275	0.1258	0.1241	0.1703	0.1291	0.1479	0.1178	0.1095	0.1091	0.1412
Norway	0.0605	0.0601	0.0677	0.0771	0.0729	0.0661	0.0417	0.0392	0.0715	0.1104

Table 11 Electricity prices for household consumers considering an annual consumption between 2500 and 5000 kWh, including taxes and levies, in the pilot countries - bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.1704	0.1756	0.1748	0.1799	0.1778	0.1913	0.1893	0.1958	0.1946	0.2022
Italy	0.2132	0.2080	0.2067	0.2161	0.2301	0.2341	0.2226	0.2153	0.2259	0.2360
Cyprus	0.1863	0.1826	0.1893	0.2183	0.2203	0.2236	0.2133	0.1698	0.1976	0.2304
Norway	0.1642	0.1605	0.1751	0.1907	0.1867	0.1744	0.1355	0.1322	0.1826	0.2206

Table 12 Electricity prices for non-household consumers considering an annual consumption between 500 and 2000 MWh, including taxes and levies, in the pilot countries - bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.1180	0.1102	0.1175	0.1053	0.1225	0.1136	0.1265	0.1142	0.1255	0.1207
Italy	0.1712	0.1675	0.1642	0.1662	0.1895	0.1870	0.1738	0.1753	0.1837	0.2142
Cyprus	0.1664	0.1637	0.1653	0.2137	0.1901	0.2115	0.1706	0.1608	0.1786	0.2298
Norway	0.0888	0.0879	0.0973	0.1090	0.1036	0.0948	0.0634	0.0603	0.1013	0.1500

Taxes and levies remain by far the most important source of differences in retail prices across Member States (MS). This is due to the differences in MS policies and fiscal instruments affecting the taxation of electricity consumption.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Gas prices

The information about gas prices is provided by Eurostat [30]. Table 13 and Table 14 report the gas prices in €/kWh for household consumers in the pilot countries considering an annual consumption between 20 and 200 GJ, excluding and including taxes and levies respectively. Table 14 and Table 16 report the gas prices in €/kWh for non-household consumers in the pilot countries considering an annual consumption between 10000 and 100000 GJ, excluding and including taxes and levies respectively.

Table 13 Gas prices [€/kWh] for household consumers considering an annual consumption between 20 and 200 GJ, excluding taxes and levies, in the pilot countries - bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.0479	0.0521	0.0481	0.0553	0.0527	0.0606	0.0511	0.0536	0.0489	0.0569
Italy	0.0449	0.0558	0.0459	0.0621	0.0477	0.0610	0.0440	0.0570	0.0414	0.0737

Table 14 Gas prices [€/kWh] for non-household consumers considering an annual consumption between 10000 and 100000 GJ, excluding taxes and levies, in the pilot countries - bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.0277	0.0288	0.0281	0.0315	0.0306	0.0298	0.0268	0.0280	0.0271	0.0432
Italy	0.0248	0.0237	0.0263	0.0277	0.0298	0.0264	0.0261	0.0228	0.0227	0.0374

Table 15 Gas prices [€/kWh] for household consumers considering an annual consumption between 20 and 200 GJ, including taxes and levies, in the pilot countries - bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.0639	0.0695	0.0665	0.0763	0.0738	0.0839	0.0720	0.0751	0.0691	0.0788
Italy	0.0704	0.0874	0.0714	0.0951	0.0769	0.0934	0.0728	0.0897	0.0703	0.1005

Table 16 Gas prices [€/kWh] for non-household consumers considering an annual consumption between 10000 and 100000 GJ, including taxes and levies, in the pilot countries - bi-annual data (2017-2021)

TIME	2017-S1	2017-S2	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2	2021-S1	2021-S2
France	0.0391	0.0404	0.0414	0.0456	0.0443	0.0431	0.0400	0.0409	0.0405	0.0590
Italy	0.0303	0.0281	0.0320	0.0325	0.0391	0.0331	0.0349	0.0291	0.0308	0.0432

Energy pricing system in Norway

In Norway, the electricity bill is calculated based on grid rent (by grid companies) and electricity consumption (by power suppliers) prices including taxes namely electricity tax, Enova tax and VAT [31].

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Nettleie (grid rent)

Grid rent (Nettleie) includes the cost for emergency preparedness, development, maintenance and operation of the power grid. In Norway, Norwegian Water Resources and Energy Directorate (NVE) is responsible for regulation of the revenues of all grid companies. The consumers from business side, are categorized into three groups based on the consumption time, annual consumption, and grid level. According to recent regulation, amount of 80€ /year as government surcharge to Enova, is incorporated in the fix contract. In addition, there is a state electricity tax of 0.891 €/ kWh for January-March and 1.541€/kWh for April-December. The business consumers with power capacity over 250kW, can have flexible agreement [32] (see Annex 3 – Electricity Tariff and Grid Rent Pricing in Norway).

Spotpris (spot price)

Each day, the Nord Pool power exchange calculates the system price for the following day. The system price is theoretical and is based on the assumption that there is no congestion in the Nordic transmission grid. The system price is the same for the entire Nordic market, and functions as a reference price for price setting in the financial power market in the Nordic region [33].

Producers submit stating how much they are willing to produce at a specified price. The bids reflect the value producers put on their production, closely linked to running costs at power plants. End users submit bids indicating how much they wish to consume at different prices. The price is determined at the level that results in equilibrium between supply and demand in the day-ahead market [34].

Grid customers pay point tariffs for the transmission and distribution of electricity. This means that the amount they pay depends on where their connection point is in the system. The tariffs consumers pay are intended to cover a share of the costs that accrue at the relevant grid level and higher levels.

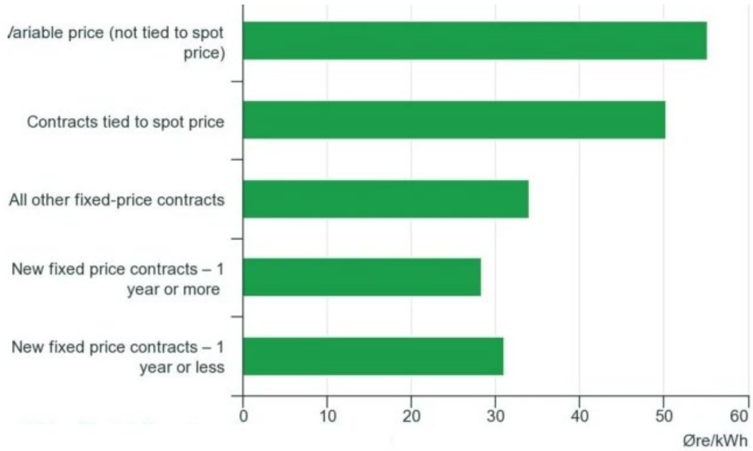


Figure 11 Electricity price for households, taxes and grid rent [35]

Nord Pool sets area prices, which take into account congestion in the grid. Area prices create a balance between the purchase and sales bids from participants in the different bidding zones in the Nordic region. In recent years, Norway has five bidding zones, Sweden four and Denmark two, while Finland constitutes one bidding zone.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

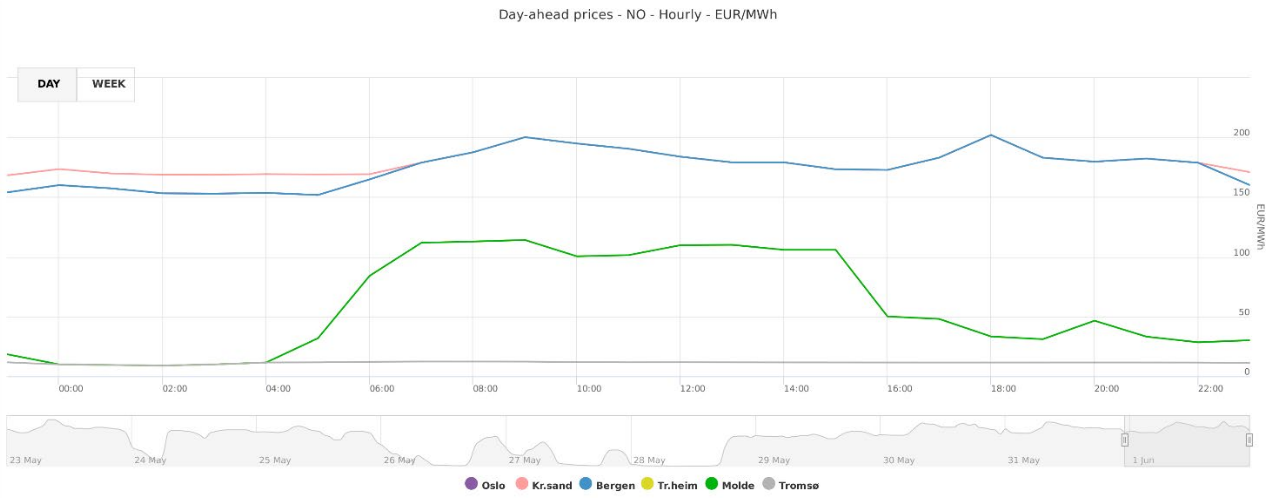


Figure 12 Day-ahead prices in Norway [36]

Energy pricing scheme in France

Since 2007 the choice of electricity supplier is free in France. There are yet two kinds of pricing:

- Price regulated by government: such option is yet possible for historical supplier mainly EDF and 3 others. (62% of end users, T1 2021). These offers are framed by the Code of Energy.
- Market offer: this option is possible for any historical provider (8% of end users, T1 2021). and any alternative supplier (about 40) (30% of end users, T1 2021). These offers can be fixed or indexed according to the regulated price or according to the wholesale market.

Regulated prices consider either a flat price independent of day/night or a price differentiated during key periods, in a simplified way this corresponds mainly to day and night. Dynamic prices do not exist in France for particular clients.

They are many determinants for the regulated price. It is partially at the end of government. Because it is yet dominant among the no professional, it should be considered that this kind of pricing determines the others at first order (people look at it carefully before to subscribe a market offer)

If power subscribed is less than 36 kVA (max power), customer can change supplier at no cost and no loss of service. Since 1 January 2019 the social energy (gas or electricity) tariff system is for households with an income of less than 10 700 €. They can benefit from an “energy cheque” to pay the energy bill.

There are always two components for the pricing: the cost to access to the electrical network which is the same for all suppliers, and the cost of electricity (cost of production or supply of electricity, commercial costs, margin or remuneration retained by the supplier). *This last component makes the difference between two suppliers*. Additionally, there are 3 taxes that are applied *identically* for all suppliers (CTA, CSPE, TCFE). The first is in relation with the funding for the retirement of electrical system workers while the second finances the expenses in relation to the public service missions of electricity (some cost in relation of PV for example). The last one is related to the cost of *distribution* network development (and thus is not applicable for big consumers). The latter one is variable, according to the location. Finally, the VAT is applied: VAT of 5.5% is applied only to the subscription component and to the CTA (a tax on the tax…), VAT of 20% is applied to the energy and the CSPE and TCFE for sites with a subscribed power of less than 36 kVA. For a contracted power of above 36

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

kVA, the system is simpler as 20% is applied onto the whole electricity bill. At the end, for a particular and a regulated price, about 34 % of the total cost is the energy.

To give some examples, applicable for private clients:

Table 17 Example of energy pricing in France (forth quarter 2021)

Regulated price				**Free price fixed**	**Free price variable**	**Free price variable + green**
Power kVA	kWh/year	€	€/kWh	Variation / regulated		
6	2400	512	0,21333333	-3% | +65%	-3% | +51%	
9	8500	1553	0,18270588		-3% | +78%	-3% | +50%

<u>Energy pricing scheme in Cyprus</u>

Consumers in Cyprus rely mostly on electricity, generated and supplied by the only provider of the island: the Electricity Authority of Cyprus (EAC), a state-owned entity. Power plants of the EAC consume heavy fuel oil to generate electricity (EAC 2019), therefore the price of electricity is highly influenced by global oil prices. The monopoly of supply, the dependence on oil and the fact that Cyprus is an isolated energy island, create conditions of very narrow margins for consumers without private photovoltaic panels installed, who are essentially left with no energy options. Actions to liberalise the electricity market have been underway in the past two decades, however no competition has been introduced yet. Nevertheless, several companies have obtained permits to generate and supply electricity, using conventional fuel (oil) or solar technologies [37]. A number of key projects were expected to materialize up to 2021, however, the global pandemic has contributed towards further delays of this prospect. Considering the fact that no national infrastructure exists for domestic distribution of natural gas, the only modern source of energy in this island is electricity, still being offered in a monopoly energy system. Several agents exist to regulate and operate the electricity transmission system, including the Cyprus Energy Regulatory Authority (CERA), which determines pricing and network usage fees, also controlling review processes as deemed necessary to the Transmission rules. The Transmission System Operator (TSO) is effectively the EAC, as owners of the grid, and the Cyprus Transmission System Operator (CTSO) is the entity managing the transmission system as stipulated by relevant legislation [38].

In relation to the tariffs offered by the EAC, consumers of electricity are billed as either domestic or industrial users, using pre-defined costs per unit energy. For example, the industrial tariff with code 40 is observed in Table 18, and the hours considered to be peak or off-peak are further explained in Table 19. This specific tariff is introduced here it refers to the billing method of the pilot buildings of this project for the case of Cyprus. However, although tariff schemes are predefined, price adjustments and further costs are incurred in the final bill [39]. Since the onset of the pandemic crisis, periodic discounted energy prices have also been applied to the final electricity bills, therefore electricity prices post-2020 are not representative and are susceptible to further fluctuations.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 18 Industrial tariff code 40 charges for the winter and summer seasons, further distinguished in peak and off-peak hours

		Tariff code 40 charge per unit (cent/kWh)				**Monthly charge (euro)**
		October-May		June-September		
	Periods	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays	
Energy charge	Peak	8.72	8.40	13.56	8.42	-
	Off-peak	7.50	7.17	8.34	8.13	-
Network Charge	Peak	1.80	1.80	1.80	1.80	-
	Off-peak	1.80	1.80	1.80	1.80	-
Ancillary services charge	Peak	0.64	0.64	0.64	0.64	-
	Off-peak	0.64	0.64	0.64	0.64	-
Meter reading charge		-	-	-	-	0.49
Supply charge		-	-	-	-	2.39

Table 19 Explanation of peak and off-peak hours

Periods	**October-May**		**June-September**	
	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays
Peak	16:00-23:00	16:00-23:00	09:00-23:00	09:00-23:00
Off-peak	23:00-16:00	23:00-16:00	23:00-09:00	23:00-09:00

The total pricing for household and non-household consumers for the first half of 2021 is presented in Table 20 and Table 21, indicating the cost of energy prior and after taxation.

Table 20 Electricity prices for household consumers, first half 2021 (EUR per kWh)

Include taxes and VAT	**Without VAT**	**Without taxes**	**Other taxes**	**VAT**	**Share of taxes (%)**
0.1976	0.1668	0.1276	0.0392	0.0308	35.43%

Table 21 Electricity prices for non-household consumers, first half 2021 (EUR per kWh)

Include taxes (no VAT)	**Without taxes**	**Non-recoverable taxes**	**Share of taxes (%)**
0.1515	0.1091	0.0424	27.99%

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

In terms of autonomous energy systems, household and non-household consumers can benefit from a net metering scheme from photovoltaic systems up to 10 kW. Moreover, net metering is also available for public school buildings with photovoltaic systems greater than 5.2 kW and up to 20 kW. Subsidies exist to support uptake of such solar technologies; however the fact still remains that Cyprus is an isolated island completely reliant on electricity generated through oil combustion. However, there are current attempts to connect Cyprus to Europe and Israel through the EuroAsia Interconnector, the world's longest submarine power cable of 1,208 km long. But, currently, the vulnerability of prices is evident in Figure 13, where the mean EU price for non-household consumers in the EU fluctuates between 0.14-0.16 €/kWh, whereas for Cyprus the range is between 0.16-0.21 €/kWh [40] .

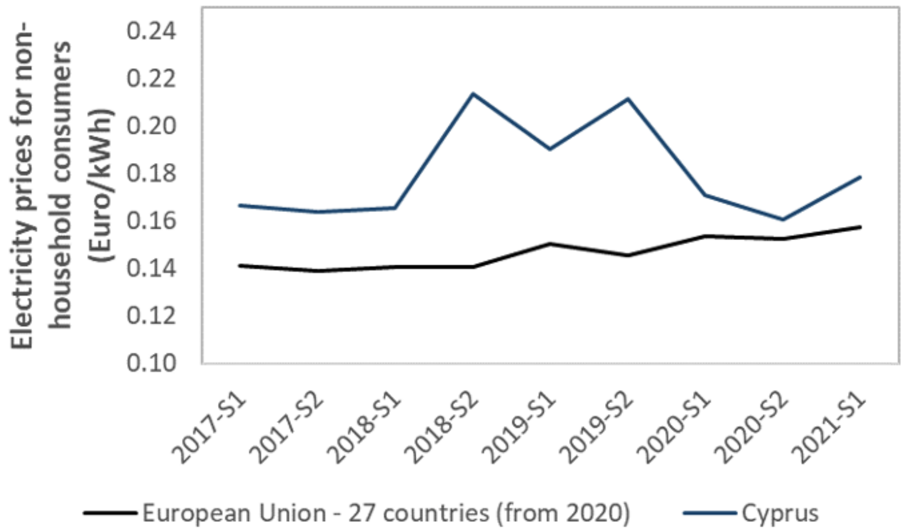


Figure 13 Bi-annual electricity prices for non-household consumers from 2017 up to the first half of 2021. Source: (Eurostat 2022).

Energy pricing scheme in Italy

In Italy, a free market is in place, in which each consumer can decide with which company selling electricity or gas have a contract with. The regulation foresees also that consumers, who have not yet decided for a specific utility, can continue with particular contracts defined by the energy authority, until they opt for a specific utility company. The energy prices for the final users are based on a variable reference price, to which the energy selling companies applies additional terms, according to their costs and commercial offers, and the taxes foreseen by the regulation. Different kind of contracts are in places and can be chosen by the consumers: some contracts offer energy tariffs that vary according to 3 or 2 time periods during the day and the weekends, so considerations about costs related to energy flexibility and to needs for the management of the grid are generally taken into account, while some other contracts present tariff not dependent on the time period of the day.

5.2.3 Impact 3: primary energy

For the evaluation of primary energy savings, the same methodology based on comparing energy use before and after implementing the system, as reported in section 5.2.1 will be used. In this case, primary energy factors (PEF) will be considered for the calculation of primary energy. The key

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

performance indicators necessary for calculating primary energy savings are described in section 5.3.3.

Particular attention should be put on PEF since primary energy consumption as reported through the EPBD is not directly comparable between Member States (MS). However, the objective of COLLECTiEF is to assess the impacts with reference to the case study (and thus the specific country) before and after the implementation of the systems and not the differences between the primary energy use between the countries.

In the following, the values of the total primary energy factors in each pilot countries for the relevant energy carriers in each pilot have been reported. The full breakdown for other energy carriers including renewable and non-renewable primary energy factors, is provided in *Annex 2 – Primary Energy Factors (PEF) in the Pilots' countries*. The PEF will be reviewed at the time of assessment, considering the most updated reference values available in literature.

Italy

The total primary energy factor for natural gas is 1.05 and for electric energy from the grid is 2.42, as chosen by the Italian Legislator (DM 26/6/15, Ann. 1, Art.1.1 [41]). Further details are provided in the annex.

France

The total primary energy factor for electric energy from the grid is 2.3, for district heating and district cooling is 1, for electric energy produced by photovoltaic is 2.58 if self-consumed while is 1 if exported to the grid. Further details are provided in the annex.

Norway

The total primary energy factors in Norway are considered 1.3 for electricity and 1.5 for district heating, according to ref. [42].

Cyprus

The total primary energy factor for electric energy from the grid is 2.7, for electric energy produced by photovoltaic is 1. Further details are provided in the annex.

5.2.4 Impact 4: self-consumption

The COLLECTiEF system is not oriented directly towards increasing the capacity of renewable energy production on site but it enables an optimal use of on-site renewable energy production. Therefore, the project aims to assess the ability of smart ready services to improve self-consumption of on-site or nearby renewable energy production. To quantify the measurement of self-consumption, the supply cover-factor method (γs) is commonly used in literature [43]. In section 5.3.4 the related key performance indicators is described.

5.3 Metrics/KPIs and relevant parameters

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

5.3.1 Impact 2.a: energy

To assess the reduction in energy consumption the **delivered energy** for each energy carrier in kWh/m² will be measured. In addition, according to ISO 52000-1:2017 [9], the indicators reported in Table 22 will be taken into account to detail the savings in relation to the specific energy uses.

Table 22 reports also the energy needs for heating, cooling and DHW. They can be useful to assess the impact of comfort control on the reduction of the energy needs and can be calculated easily via energy simulations.

Table 22 KPIs for energy assessments

ENERGY	Energy need for heating*	kWh/m²
	Energy need for cooling*	kWh/m²
	Energy need for DHW	kWh/m²
	Energy use for space heating*	kWh/m²
	Energy use for space cooling*	kWh/m²
	Energy use for DHW	kWh/m²
	Energy use for lighting	kWh/m²
	Energy use for ventilation	kWh/m²
	Energy use for other services	kWh/m²
	Auxiliary energy	kWh/m²

5.3.2 Impact 2.b: costs

For each pilot site, based on the local energy pricing scheme described in section 5.2.2, a cost function will be defined which can be used as an objective/reward function in the algorithm developed for cluster node to maximize energy cost savings. The function will be the base for a price-based signal communication from the cluster nodes to the edge nodes.

The comparison of before and after energy cost will be made on a consistent basis, considering the defined cost function for the baseline and the assessment period.

On the base of the annual energy savings, provided by higher energy efficiency and avoiding peak prices, the annual energy costs savings will be evaluated in euro/m².

5.3.3 Impact 3: primary energy

To evaluate primary energy savings the **total primary energy use** in kWh/m² will be calculated. The total primary energy use includes non-renewable energy and renewable energy and is calculated by multiplying the delivered energy, which is expressed per energy carrier, times the specific total primary energy factor, as reported in section 5.2.3.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

5.3.4 Impact 4: self-consumption

To quantify the measurement of self-consumption – renewable uptake, the **supply cover-factor index (γs)** will be considered in the analysis. This indicator can be defined as representing the percentage of on-site generation that is used directly on-site [43]. Mathematically, it could be defined as:

$$\gamma_s = \frac{\int_{t1}^{t2} \min[g(t) - S(t) - \zeta(t), l(t)]dt}{\int_{t1}^{t2}[g(t) - S(t) - \zeta(t)]dt}$$

where:
g = the on-site generation
S = the storage energy balance
ζ = energy losses, and
l = the system load

5.4 Monitoring equipment before and after the implementation of the COLLECTiEF system

On the basis of the information collected in each pilot, Table 23 reports the specifications of the monitoring equipment currently installed to measure the energy quantities. Existing meters and, where necessary, additional monitoring equipment will be used to collect the data before and after the implementation of the COLLECTiEF systems for the impacts assessment. In particular, smart plugs and smart valves will be used in the Italian pilot to monitor energy uses during the baseline period.

Table 23 – Existing energy meters in each pilot building

	Name	Location	Thermal energy metering	Electric energy metering	Fuel metering	RES metering
B1	Eidet Omsorgsenter	Norway	Building level. Smart meters and BMS. Interval data: 1 minute.	Building level. Smart meters and BMS. Interval data: 1 minute.	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 1 hour
B2	Ellingsøy Idrettshall	Norway	Building level. Smart meters and BMS. Interval data: 1 minute.	Building level. Smart meters and BMS. Interval data: 1 minute.	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 1 hour
B3	Flisnes Barneskole	Norway	Building level. Smart meters and BMS. Interval data: 1 minute.	Building level. Smart meters and BMS. Interval data: 1 minute.	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 1 hour
B4	Hatlane Omsorgsenter	Norway	Building level. Smart meters and BMS. Interval data: 1 minute.	Building level. Smart meters and BMS. Interval data: 1 minute.	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 1 hour
B5	Moa Helsehus	Norway	Building level. Smart meters and BMS. Interval data: 1 minute.	Building level. Smart meters and BMS. Interval data: 1 minute.	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 1 hour

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

B6	Spjelkavik Ungdomskole	Norway	Building level. Smart meters and BMS. Interval data: 1 minute.	Building level. Smart meters and BMS. Interval data: 1 minute.	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 1 hour
B7	Tennfjord Barneskole	Norway	Building level. Smart meters and BMS. Interval data: 1 minute.	Building level. Smart meters and BMS. Interval data: 1 minute.	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 1 hour
B8	GreEn'Er	France	Living lab level Smart meters and BMS. Interval data 10 minutes	Consumption data (electricity consumption and production, heat delivered from district heating network) for the complete building. Heat delivered in Living-lab (Predis)	No fuel used	Generated onsite. Smart meters and BMS. Interval data: 10 minutes
B9	Guy Ourisson Building (GOB)	Cyprus	No, all electric	Building level: Energy bills. Interval data: bimonthly Smart meter: The tuning of installed smart metering systems is ongoing (M13)	No fuel used	No
B10	Graduate School (GS)	Cyprus	No, all electric	Building level: Energy bills. Interval data: bimonthly Smart meter: The tuning of installed smart metering systems is ongoing (M13)	No fuel used	No
B11	Novel Technologies Laboratory (NTL)	Cyprus	No, all electric	Building level: Energy bills. Interval data: bimonthly Smart meter: The tuning of installed smart metering systems is ongoing (M13)	No fuel used	Generated onsite from PV panels. Smart meters and BMS. Interval data: customizable. Smart metering systems under tuning
B12	Valsesia Tower C2	Italy	Building level: heat meter (15 min). Flat level: heat cost allocators (daily)	Flat level. Energy bills. Interval data: monthly	Gas consumption	No RES available
B13	Valsesia Tower C3	Italy	Building level: heat meter (15 min). Flat level: heat cost allocators (daily)	Flat level. Energy bills. Interval data: monthly	Gas consumption	No RES available
B14	Valsesia Tower C4	Italy	Building level: heat meter (15 min). Flat level: heat cost allocators (daily)	Flat level. Energy bills. Interval data: monthly	Gas consumption	No RES available

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Smart Plug

In the project, Smart Plugs will be installed to monitor and control the single loads. In particular, Shelly Plug has been chosen for the installations in the project pilots. Shelly Plug is able to send data to the COLLECTiEF BRIG device by using a Wi-Fi connection and it is able also to act as Access Point. Shelly Plug has an integrated precise power meter to monitor the overall consumption of the electric devices connected to it and is possible to turn it on/off via the */settings* endpoint. Particularly, it is possible to control the Shelly Plugs by using the following resources: (1) */settings/relay/*0 to configure the behaviour of the plug in case of application of specific device control policies (e.g. switching on or off depending on consumption thresholds or time slots) and (2) */relay/0* to control and monitor the plug. These models of smart plugs have been selected between the common devices available on the market and to ensure adequate quality, reliability and compatibility with the solutions developed within COLLECTiEF. The MQTT[1] messaging protocol is used for the communication between the Smart Plugs and the BRIG device. On the latter's side, it is implemented by using the Eclipse Paho[2], integrated as a Python programming language script.

In Table 24 are reported the specifications of the Shelly Plug:

Table 24 Shelly Plug specifications

POWER	
Power supply AC	110-230V ±10%, 50/60Hz
Maximum load	16A
Power supply DC	No
SPECIAL FUNCTIONS	
Device temperature protection	No
Overload protection	Yes
Power measurement	Yes
FEATURES	
Operational temperature	-10°C to +50°C
Device power consumption	< 1 W
Intelligent On/Off	Yes
Local and remote control	Yes
Sunrise/Sunset	Yes
Weekly Schedule	Yes
CONNECTIVITY	
Wireless	Yes
Wi-Fi Protocol	802.11 b/g/n
Wi-Fi Radio frequency	2412 - 2484 MHz
Wi-Fi Radio signal power	1mW
Wi-Fi Range	up to 50 m outdoors and up to 30 m indoors (depending on the building materials)
DIMENSIONS	
Size	85mm x 57mm x 98mm

1 https://mqtt.org

2 https://www.eclipse.org/paho

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Smart Valve

In the project, Smart thermostatic radiator valves will be installed to monitor and control the temperature of the radiators. In particular, Shelly TRV has been chosen for the installations in the project pilots. Shelly TRV is able to send data to the COLLECTiEF BRIG device by using a Wi-Fi connection. Shelly TRV has an integrated precise temperature sensor to monitor the temperature of the radiator, giving the possibility to control the temperature by setting the room temperature in the range of 5°C to 30°C. It is possible to close and open the valve via the */settings/actions* topic by setting the following two types of actions: (1) *valve_close* to invoke when valve is closed and (2) *valve_open* to invoke when valve is opened.

The MQTT messaging protocol is used for the communication between the Shelly TRV smart valve and the BRIG device. When configured for MQTT, Shelly TRV sends values from its internal sensors on specific MQTT topic by publishing a JSON payload with the content of HTTP /status endpoint. Shelly TRV supports a set of commands published on a specific topic for the setting of the actuators, for instance, to set the target temperature in a range of 5°C to 30°C.

In Table 25 are reported the specifications of the Shelly TRV:

Table 25 Shelly TRV specification

POWER	
Battery life	Up to 2 years of battery life, based on 5 months heating season.
Battery type	3.6V 6500mAh NCR18650BD Panasonic rechargeable battery
Power supply AC	No
Charger requirements	USB type C (>2A)
Power supply DC	USB type C (>2A), charger not included
Power consumption	< 500 mA
SPECIAL FUNCTIONS	
CPU	SiLabs
FEATURES	
Working temperature:	0°C up to 30°C
Temperature control range	5°C - 30°C
Sunrise/Sunset	Yes
Weekly Schedule	Yes
CONNECTIVITY	
Wi-Fi Protocol	WiFi 802.11 b/g/n
Wi-Fi Radio frequency	2412 - 2472 MHz (Max. 2495 MHz)
Wi-Fi Radio signal power	1mW
Wi-Fi Range	up to 30 m indoors (depending on the building materials)
DIMENSIONS	
Size	94/62/53 mm

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

6 Monitoring and assessing IEQ in COLLECTiEF

The development of the occupant-centric fusion sensor network will focus on the needs of users for collecting data required for a real-time and longitudinal verification of their health, comfort and satisfaction.

6.1 Objectives

5	We aim at **increasing user satisfaction** with respect to some of the components of the indoor physical environments **by at least 15%** thanks to the implementation of smart occupant-centric sensoring and self-learning control algorithms.

The aim of the COLLECTiEF project is to upgrade the smartness of existing buildings and create a collaborative network of a large number of facilities providing grid flexibility while ensuring a reduction of energy consumption and comfortable conditions for the building occupants.

To cover diversity in energy use and users' needs, different types of buildings were included in the project demonstration: offices, residences, health care center for the elders, sports arena, elementary school, high school.

In all these building types, users interact with building systems and devices and the COLLECTiEF solution will develop hardware and software solutions to integrate individual buildings into local neighborhood networks, increase neighborhood energy flexibility, reduce overall energy consumption, offer new services and control possibilities to the building users, thereby improving their comfort and increasing their satisfaction.

Furthermore, smart control algorithms will be designed, developed and validated to testing the overall occupants' satisfaction with respect to the indoor physical environment.

To this purpose, Post-Occupancy Evaluation (POE) is used to assess the interactions between objective data (spot-measured, monitored) and subjective data (questionnaires, interviews, surveys). These data types are used to draw a comprehensive picture of the actual use and usability of the buildings, perceived as complex and interactive systems, including the physical building attributes, incorporated mechanical and other systems and equipment, and the actual use by their occupants.

POE is based on specifically designed questionnaires to evaluate the feedback from building occupants about their experience into their built environments, together with environmental monitoring and, within the COLLECTiEF project, it will provide data used for:

1. **Obj1:** Algorithm development, training and evaluation through Brief questionnaires.
2. **Obj2:** Overall users' satisfaction assessment through Satisfaction questionnaires.

Research questions

Diversity in building users was indicated to tackle different open gaps in knowledge and practice about, mostly, the thermostatic control of building and requirements of different user types. The hypothesis at the base of the occupant-centric design and operation of the COLLECTiEF building

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

network is that excursions from thermal comfort zone can contribute to enabling energy flexibility of buildings.

Currently, the standards ISO 7730 [13], EN 16798 [12], ASHRAE 55 [11], recommend, for mechanically controlled buildings, steady thermal conditions to be kept within predefined thermal comfort categories. Also, thermal comfort standards tend to recommend stricter ranges of variation of indoor operative temperature for fragile and sensitive people, while some studies showed that people are not as sensitive to these small variations [44] and uncertainties in monitoring are larger than the stricter thermal comfort category [45]. Furthermore, a commonly accepted practice mentioned even in standards is to consider the same reference thermal condition for both offices and residential buildings, while it is renown that metabolic activity may be different, adaptability options are diverse, the movement between spaces is higher in houses.

In COLLECTiEF, we design, develop and evaluate more complex strategies based on a dynamic modulation of indoor environmental variables using thermal cycles and ramps to increase thermal flexibility without causing any discomfort and, in the remote case they may create any nuisances, all necessary adjustments will promptly be made to remove any disturbances. Furthermore, recent studies in human comfort and physiology have proved that ”mild cold and warm environments increase metabolism” and “(mild) temperature excursions outside the thermal neutral zone affect people’s energy metabolism, but also our glucose metabolism” contributing to reduce the risk of obesity and diabetes [46]. Also, a recent study highlighted that cognitive performance can be affected by air temperature [47] but other studies did not find such relationship [48][49].

Another domain of investigation is the management of sport facilities that are wide and height spaces whose thermal management is typically controlled at a global level trying to find a trade-off between overall energy consumption and acceptable thermo-hygrometric conditions in the hall.

Moreover, advanced methods based on machine learning and reinforcement learning can be used to develop self-learning algorithms that personalize the adjustment of the indoor temperature minimizing the discomfort occurrences and thus increasing user satisfaction with respect to the indoor environment.

One of the objectives of the COLLECTiEF project is to prove that *self-learning and precisely-controlled dynamic environmental conditions can effectively increase buildings’ energy flexibility and reduce energy consumption*, while resulting a healthier practice by stimulating human metabolism and increasing users’ overall satisfaction.

To address this matter and provide data for **Obj1**, the data gathered with the *Brief questionnaires* and environmental monitoring are used to investigate six research questions:

1. **RQ1:** *Do collective thermal feedback in shared offices (thermal sensation, acceptability, preference) deviate from individual responses in offices?*
   Description: This RQ is tested only on office spaces and investigates whether social interaction may affect the thermal management of shared spaces. It can provide insights to identify ranges of variation of indoor temperature that will reduce the probability of conflicts and energy wasteful behaviors (e.g., windows open with space heating system on)
2. **RQ2:** *Are children more sensitive and vulnerable to temperature excursions outside thermal comfort zone than older kids and adults?*

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Description: This RQ investigates whether there is any significant difference in thermal response of children (primary school) with respect to kids (high school) and adults (working in offices). This will provide insights on the appropriateness of adoption of reference temperature setpoint values identified for adults and reported in standards also for children and on a more tailored thermal management of classrooms that currently is commonly led by the teacher (an adult).

3. **RQ3:** *Are fragile people more sensitive and vulnerable to temperature excursions outside thermal comfort zone than adults?*

   Description: This knowledge is important to understand if the assumption that fragile and sensitive people require stricter conditions and referred in standards if we can move within comfort limits from Class I to Class II (or from Class A to Class B) to provide higher energy flexibility potential and energy savings.
4. **RQ4:** *Is user thermal feedback (thermal sensation, acceptability, preference) in houses different from that in (shared) offices?*

   Description: This is tested comparing the POE of adults in the houses and in offices. More adaptive opportunities in houses and the movement between different spaces could lead to a broader range of accepted temperatures, that would result in a higher potential for energy flexibility.
5. **RQ5:** *Do dynamic thermal conditions reduce users' satisfaction in sport facilities?*

   Description: Due to the users' high metabolic rates, the expansion of the range of acceptable temperatures, for example based on evolution of outdoor temperature, would provide a significant source of energy flexibility for the neighborhood network. At the same time, workers supervising the users' activities may be exposed to uncomfortable conditions.

Finally, to address **Obj2**, a *Satisfaction questionnaire* will be designed and validated to respond to the research question:

6. **RQ6:** *Can user thermal feedbacks* (thermal sensation, acceptability, preference) *be explained by variations of the environmental variables* (air temperature, relative humidity, CO_2 concentration, VOC concentration, PMx concentration)*?*

   Description: This is tested in all building types. Understanding these relationships will offer insights on how to plan excursions outside the typical comfort setpoints enabling the energy flexibility potential.
7. **RQ7:** *Are user feedbacks (thermal sensation, acceptability, preference) in single and shared offices explained by variations of the environmental variables (air temperature, relative humidity, CO2 concentration, VOC concentration, PMx concentration, illuminance)?*

   Description: The aim is to investigate whether given indoor environmental conditions can explain differences in individual or shared spaces.
8. **RQ8:** *Does the COLLECTiEF solution increase users' overall satisfaction?*

   Description: This is tested by comparing the result of questionnaires administered before (M13-M24) and after (M25-M48) the installation of the COLLECTiEF solution in all the pilot buildings for type of users/buildings/countries.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

6.2 Methodology for experimental design

6.2.1 Description of sample size for hypothesis testing

A very important concept in experimental design is the formation and testing of a hypothesis, related to the different research questions elaborated in the experimental design [50]. The null hypothesis usually corresponds to a "status quo" and will be expressed with an equality concerning a specific population parameter (e.g., = 0) while the alternative hypothesis, being the opposite of the null hypothesis, will never contain an equality concerning a specific value of the population parameter (e.g., ≠ 0).

To test the null hypothesis, the following hypothesis formalization is used, expressed in different forms depending on whether tests are based on a single sample selected from a reference population, and tests based on two samples drawn from two or more populations. Depending on the type of evaluation, one can perform a one-tailed test: if there is a relationship between the variables in one direction, one looks for a deviation from H0 in one direction only, which can be either right (i.e., greater) or left (i.e., less). The other type of test is a two-tailed test: if there is a relationship between the variables in both directions, we look for a deviation from H0 in both directions, right (major) and left (minor).

Table 26 One-tailed hypothesis testing for one sample and two samples

One-tailed hypothesis testing (one sample)	One-tailed hypothesis testing (two sample)
H0: $\mu \leq 0$	H0: $\mu_1 \leq \mu_2$
H1: $\mu > 0$	H1: $\mu_1 > \mu_2$

Table 27 Two-tailed hypothesis test for one sample and two samples

Two-tailed hypothesis test (one sample)	Two-tailed hypothesis test (two sample)
H0: $\mu = 0$	H0: $\mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
H1: $\mu \neq 0$	H1: $\mu_1 \neq \mu_2$ or $\mu_1 - \mu_2 \neq 0$

One of the main assumptions in these tests (t test) is that the sample or sample pairs are drawn from normally distributed populations. However, the test does not lose power if the distribution of the population deviates from normal, especially when the sample size is large enough to use the central limit theorem for such a test statistic. However, it is possible to reach incorrect conclusions or to incur a loss of power if the test is used inappropriately. In particular, when the sample size is small (less than 30) and the assumption of normality of the reference population is not possible in any way. In this case it becomes more appropriate to use the procedure of the hypotheses which are called non-parametric.

In the case of hypothesis testing between two samples, it will be important to assess the independence or dependence of the samples. In the case of samples that are extracted from independent populations, this evaluation will be based on the presence of homoscedasticity and heteroscedasticity, with the relative implication on the type of test to be carried out (e.g., t-test for independent samples from homoscedastic populations or t-test with separated variances). The verification of this hypothesis is carried out by means of an F-test. In the case of samples that are

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

drawn from dependent populations (repeated or paired samples), it is possible to use the t-test for mean difference between two dependent populations (paired samples t test) to verify whether the populations differ significantly with respect to the parameter of interest.

In case we have to analyze the differences between two or more populations (or groups), the procedure that allows the simultaneous analysis of the differences between the averages of the groups is the analysis of variance (ANOVA), in its different forms, such as one or two (or more) independent factors, which is basically a generalization of the t-test for the difference of the averages. Or the one- or two-factor (or more) ANOVA for repeated measures (measuring the same cases several times), which is an extension of the t-test for paired samples. ANOVA can be performed with or without replication (where replication implies performing the same study on different subjects but identical conditions). In general, the hypotheses of interest in an ANOVA are the following:

Table 28 Hypothesis testing for Anova one way

Null hypothesis	Alternative hypothesis
H0: $\mu 1 = \mu 2 = \mu 3 \ldots = \mu k$	H1: Means are not all equal.

Table 29 Hypothesis testing for Anova two way (example without Replication)

Test desire	**Null hypothesis**	**Alternative hypothesis**
Effect of factor A	**H0**: $\mu_1 = \mu_2 = \mu_3 \ldots = \mu_k$	H_1: Means are not all equal.
Effect of factor B	**H0**: $\mu_1 = \mu_2 = \mu_3 \ldots = \mu_c$	H_1: Means are not all equal.

Table 30 Hypothesis testing for Anova two way (example with Replication)

Test desire	**Null hypothesis**	**Alternative hypothesis**
Effect of factor A	**H0**: $\mu_1 = \mu_2 = \mu_3 \ldots = \mu_k$	H_1: Means are not all equal.
Effect of factor B	**H0**: $\mu_1 = \mu_2 = \mu_3 \ldots = \mu_c$	H_1: Means are not all equal.
Effect of interaction of A and B	**H0**: an interaction is absent	H_1: an interaction is present

6.2.2 Sample size

When we perform a statistical test, we can reject or not reject the null hypothesis, depending on whether or not we find an effect. Finding an effect can be considered positive, while not finding an effect can be considered negative. Consequently, the conclusion will be correct or incorrect. In the case of an error, we can have a false positive or a false negative [51]:

- A false positive (type I error) is equivalent to finding a difference where in fact no difference exists.
- A false negative (type II error) is the same as failing to find a difference that actually exists.

When we talk about avoiding Type I errors, we must bear in mind that statistical tests are probabilistic. They quantify the probability of seeing a set of results under the null hypothesis. When this probability

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

is sufficiently low, i.e., the p-value is small, we reject the null hypothesis. However, there is always a non-zero chance that our results arrived by chance. We can therefore never eliminate the risk of type II errors; even when we do not find a significant effect, it may still exist.

However, **a larger sample size can help to avoid false negatives**. The larger our sample, the more sensitive our methods become, allowing us to avoid type II errors. **For this reason, calculating the sample size is particularly important, as with a larger sample size, we can draw better conclusions about the data**. The question this methodological section attempts to answer is what sample size we need to find an effect. Answering this requires looking at other parameters: Alpha, Power, Effect size. These parameters each influence the sample size calculation. When we increase the sample size, we increase our statistical power, decrease the usable alpha value and make it possible to detect smaller effects. In effect, we are asking what sample size is needed to detect effect size x at statistical power y and significance level z.

6.2.3 Key elements of sample size calculation

Directly related to hypothesis testing is the idea of power. Power is the probability that the test will correctly reject the null hypothesis when the alternative hypothesis is true. A "golden rule" in statistics is to have 80% power in the experiment, which means that will need an adequate sample size. Another parameter is effect size, which in the context of power analysis, is a standardized measure of the difference you are trying to detect, which can be calculated as the difference between the averages of H1 and H0 and divided by the overall standard deviation of the data. Finally, there is the significance level, which consists of the probability of incorrectly rejecting the null hypothesis even if it is true. While the power and significance level are usually set independently of the data, the effect size is a property of the sample data.

Given the following three inputs (Power, Effect size, Significance level), and other information based on the specific design, it is possible to calculate the sample size for most statistical tests [51]:

- **Power:** probability of correctly rejecting the null hypothesis if it is false (type II error)
  - 'Power = 1-β, where β is the probability of a type II error (false negative)
  - The higher the power, the higher the probability of detecting an effect if it is present, and the more statistical units are needed
  - The standard setting for power is 0.80
- **Significance level (α):** probability of wrongly rejecting the null hypothesis even if it is true
  - It is the probability of committing a type I error (false positive).
  - The lower the significance level, the higher the probability of avoiding a false positive and the more samples are needed
  - The standard setting for α is 0.05
- **Effect size:** effect size under the alternative hypothesis (this is how far we get from the null hypothesis)
  - The larger the effect size, the easier it is to detect and the smaller the sample size required.
  - For the effect size, we can use Cohen's d (standardized effect size), which is the difference between the two averages divided by the aggregate standard deviation. But also, a correlation coefficient is an effect size, a regression coefficient is an effect size, a relative risk is an effect size; an Odds Ratio is an effect size.

Finally, in the presence of two samples, we give a ratio of the samples (Ratio) in each group. A ratio of 1 means that the experiment is balanced. The ratio will be the number of observations belonging to a specific group divided by the observations belonging to another group.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

The objective will be to compare different groups of hypotheses by asking how many statistical observations we should sample to detect an effect, and we want to achieve at least an 80% probability of detecting a large effect with standard significance.

Type of observations per building use:

- Individual offices: paired observations/sample
- Health care centers: paired observations/sample
- Shared offices: paired observations/sample
- Sport halls:
    - Users: unpaired observations/sample
    - Workers: paired observations/sample
- Residences: paired observations/sample

6.3 Methodology for survey design

POE is a multi-purpose methodology for the documentation, analysis and study of the actual interaction between users and their built environment (namely a district, a building, or just a technical building system). It uses different tools like questionnaires, surveys and monitoring data, whose results are cross-analyzed to allow the understanding of subjective human reactions to objective conditions.

POE can help to (1) identify potential barriers, either technical or behavioral, (2) identify users' specific attributes and how they affect their overall satisfaction with a building and its technical systems (3) characterize the Indoor Environment Quality (IEQ) from the building occupant perspective; and (4) point at potential corrective measures and improvements toward the specific building-user interaction.

To reach such understandings, the surveyors need to identify the physical, cultural and behavioral attributes and peculiarities of building users, among them age, gender, health, education, occupation, attire and even the hours of the day a specific tenant uses the specific building unit, and the tasks they perform there and then. All these may affect the individual's perception of their indoor environment, and need to be considered under changing conditions: for example, hours of the day, sunny or cloudy conditions, seasons etc.

Therefore, these needs prescribe a rather intrusive and long-term relationship between interviewers and interviewees, which presumes a certain commitment on the building user's side. This requires the building occupants/users to collaborate by allocating time for surveys at different hours of the day, time and go through a repetitious process of questions and answers. Such a commitment can only be secured if the users understand fully and clearly the importance of the survey, the purpose of the different questions and, not least, the potential benefits for the end-users embodied in the process such as identifying potential problems and barriers, improving indoor conditions and satisfaction with the building and its systems, securing lower costs for climatizing the building etc.

The POE used in the COLLECTiEF project leverages (i) a preliminary interview with the participants during with the informed consent form is signed and few personal information are collected, (ii) questionnaires, and (iii) monitoring data.

6.3.1 Questionnaire design

In order to properly formulate a statistical problem, care has to be put to scale development and statistical significance.

Measurement scale

In this section we present the methodology that will be used in COLLECTiEF for the development of the measurement scale of the POE questionnaire. A measurement scale consists of a series of functional items to detect a variable that is not directly observable (e.g., user satisfaction and well-being, thermal comfort, etc.). Even if it is impossible to quantify a latent variable directly, a measurement scale can be developed to assess its intensity. The measurement scale, therefore, constitutes the main tool for being able to analyse the construct of interest and, as such, it is important to ensure that it is adequately constructed in measuring what it is designed for, and in providing statistically significant answers to the relevant research questions. The adequate measurement of abstract constructs is in fact one of the biggest challenges to be faced when proceeding with questionnaire-based surveys, where the main point is that it must ensure accuracy in the measurement of the constructs under consideration.

To develop a measurement scale, eight steps can be followed [52]. The first five steps aim at constructing the questionnaire:

1. **Definition of what is to be measured**: the starting point for the development of a measurement scale is a clear formulation of the construct of interest.
2. **Generating the item set:** the second step is to generate the items, generally a multi-item approach is used, whereby it is important to formulate an adequate number of items that can capture different aspects of the same phenomenon.
3. **Determining the structure of the measurement scale:** in this step, the structure underlying the items is chosen. Common forms of measurement scales include, for example, Likert scales, semantic differential scales etc.
4. **Review of the item set by a group of experts:** in this phase, the item set is reviewed by a group of people who are well informed about the phenomenon under investigation. The review conducted by the experts can, in fact, confirm or invalidate the definition of the construct of interest. This allows items that are judged irrelevant to be eliminated, while those that are unclear can be reformulated, as well as the possibility of including aspects of the phenomenon previously ignored.
5. **Evaluate the introduction of validation items:** validation items consist of additional questions to the main set of items and are intended to help determine the validity of the scale. There are two types of validation items. The first type is used to assess the presence of flaws in the questionnaire (e.g., in the face of biased responses related to social desirability issues, by including a scale that measures "social desirability", it is possible to assess in advance how much the responses to the items are characterised by these biases). The second class includes all items necessary to assess construct validity. Since construct validity represents a coherence of the measured object with the different dimensions of the phenomenon, validation items are included in the questionnaire which, according to the reference theory, can be causes or consequences of the investigated construct.

The remaining three steps serve to finalise the measurement scale, ensuring that it enjoys the property of reliability:

6. **Administration of the items to a sample of subjects**: once the questionnaire has been constructed, it must be administered to a group of respondents. The sample should preferably be large (at least 300 people).
7. **Assessment of Item Reliability:** this phase consists of assessing the reliability of the measurement scale. The first property desired in a set of items is a high level of inter-correlation. That is, the items that make up a scale are assumed to be strongly correlated with the underlying construct, and therefore also closely related to each other, i.e., manifesting a high degree of internal consistency. To this end, the correlation matrix is used, where high values of inter-correlation between items correspond to high levels of reliability. While a general index to check internal consistency is Cronbach's Alpha. This indicator represents the proportion of variance shared by the items that is attributable to the investigated construct. It takes values between 0 and 1, where values close to zero indicate a low degree of item reliability, while values close to 1 indicate a high degree of scale consistency.
8. **Optimizing the length of the scale:** item reliability checks must confirm that all items in the questionnaire are consistent and form a reliable scale (with an alpha level around 0.90). It is

well known that respondents prefer to complete short questionnaires; therefore, it is important to optimise the length of the scale. A problem here is the trade-off between brevity and reliability. Since longer scales tend to be more reliable, care must be taken to reduce the number of items. A useful method to perform this check is Cronbach's Alpha. Typically, this index is between 0 and 1, values between 0.70 and 0.80 are considered respectable, between 0.80 and 0.90 very good values, finally, in the case of values above 0.90 the scale is very reliable and there may be repetitive and redundant items. Therefore, the optimisation of its length can be evaluated. Another control method consists in calculating Cronbach's Alpha by excluding the item to be analysed. If the value of this index exceeds the value of the Alpha calculated on the scale as a whole, then, by eliminating that item, the overall reliability of the scale would increase.

Reliability

Reliability is defined as the degree to which a measurement is free of errors (e.g., responses influenced by the respondent's mood, or level of tiredness etc.) and thus, able to produce statistically significant results. A measurement scale can be said to be perfectly reliable when causal error is absent. There are three popular forms for measuring scale reliability.

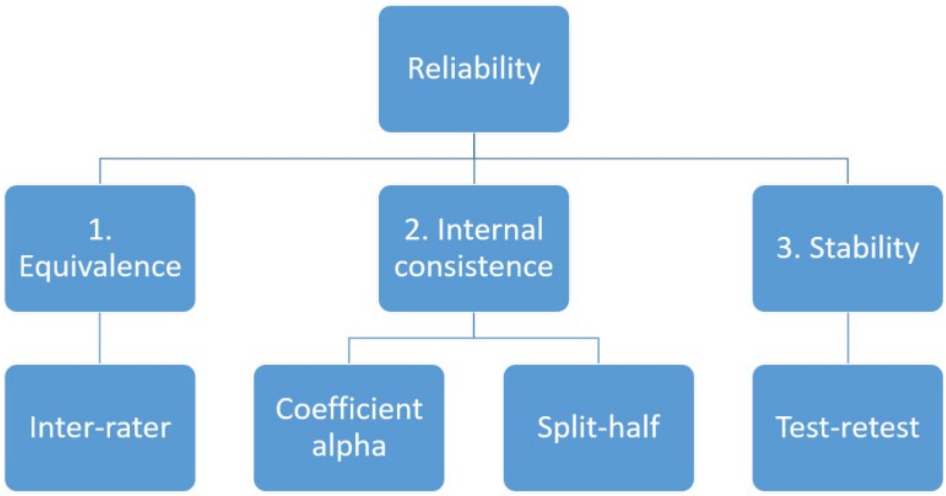


Figure 14 Measuring scale reliability

1. **Equivalence:** the degree of agreement between assessors/examiners on the same measurement. As mentioned above it is examined using the following statistical tests: percentage of agreement between examiners, Cohen's Kappa coefficient, Pearson correlation coefficient, intraclass correlation coefficient. A coefficient with a value ≥ 0.80 indicates acceptable examiner-to-examiner reliability.
2. **Internal consistency:** the degree to which the items of a scale are related and the ability to measure a single concept or concept domain/scale with minimum error. In general, it is assumed that there is a correlation between the items that make up a scale and the underlying latent variable. If this relationship is strong, then the items will also be highly correlated with each other. Internal consistency is assessed with Cronbach's alpha coefficient, which is given by the common variance (due to the latent variable X, as X varies so do the items related to it), the unique variance (specific to each item and due to its error term) and the total variance (a combination of total variance and unique variance). Cronbach's alpha is thus a function of the ratio of common (or shared) variance to total variance. In addition to the alpha coefficient there is another method of assessing internal consistency, which is the split-half item technique, i.e., the division of the scale into two homogeneous groups of items. It is assumed that a scale can be considered reliable, if the item groups provide similar results in terms of internal consistency. The division can be carried out using various methods. The first method

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

consists in separating the first half of the items from the second half. This type of division is problematic (e.g., the second group of items may be characterised by a higher random error, e.g., due to the respondent's tiredness). To avoid this problem, the scale should be divided into items coded with even numbers and items coded with odd numbers. Once the division into groups is obtained, three indices are calculated: the split-half R index, the Spearman-Brown index and finally the Guttman coefficient. Values of these indices close to 1 indicate high levels of reliability. The second method is called split-half sample and consists of dividing the overall sample into two random and homogeneous subsamples to allow comparison between them. These two subgroups are evaluated according to the internal consistency indices shown so far (Cronbach's alpha - split-half indices). If the value of the indices is similar in the two subsamples, then it can be said that the scale is reliable as it is able to measure the same construct on two different groups of subjects.

3. **Stability or test-retest:** the degree to which the instrument reproduces the same results for the same individual when measurements are made on different occasions. Stability is frequently assessed by the correlation coefficient with which the degree of association between pairs of items (inter-item correlation) and between an item and the rest of the items on the scale (item-total correlation) is tested. In general, an item with a high item-total correlation index is very consistent with the rest of the scale, vice versa, an item with a low item-total correlation index is not very consistent with the rest of the scale. The literature suggests a minimum threshold of 0.30 for item correlations, while item-total correlations should exceed 0.50; below these values the items are considered unreliable and inconsistent with the scale.

Exploratory and confirmatory factor analysis

When testing the reliability of a scale, it is important to check whether the scale produces data that satisfy the research hypothesis and appear to reflect the latent construct. For this purpose, factor analysis is used, i.e., a statistical technique that makes it possible to reduce the number of variables analysed by extracting factors that can explain unobservable aspects. Factor analysis helps to understand whether the questionnaire actually measures what it was designed for. Under the generic name of factor analysis, we have several statistical techniques [53]:

- **Principal component analysis (PCA):** is a mathematical technique underlying factor analysis that allows a small number of factors to explain variation among a large number of original variables.
- **Exploratory factor analysis (EFA):** is used during the development of measures and allows the factor structure to be explored from a set of observed variables. It is used to associate one or more latent variables with a group of observed variables that are assumed to have something in common. We can use EFA to explore how many dimensions of the latent construct might be reflected in the survey data.
- **Confirmatory factor analysis (CFA):** is used we already know a priori the structure of the variables and want to confirm whether this structure is present in the data collected from the survey. It is formally checked whether the number of factors reflected in the data corresponds to what has been assumed on the basis of the theory. Confirmatory factor analysis is used to validate a measure after item development.

Validity

Validity is the scale property that refers to the degree to which the latent construct is the cause of item correlation. A scale is valid if the item it measures coincides with the phenomenon of interest.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

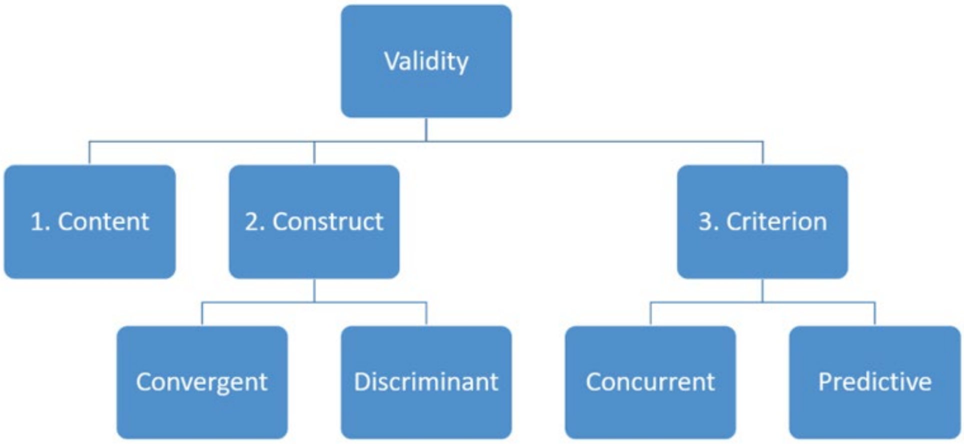


Figure 15 Measuring validity

There are three types of validity:

- **Content validity:** indicates the ability of a set of items to meaningfully represent the domain of interest, representing all its aspects and dimensions. Typically, the method of checking content validity consists in selecting a group of experts who can make judgements on the adequacy of the scale and can suggest possible aspects that are not included.
- **Construct validity:** indicates the ability of the measurement scale to actually measure the construct for which it was designed. It can be distinguished into convergent validity (high observed correlation between the measure to be validated and other measures of constructs theoretically related to the investigated construct) and discriminant validity (little or no correlation between the measure to be validated and other measures of other constructs not related to the measured construct). Based on the correlation coefficient, if converging, two or more items of theoretically related constructs should have a high correlation to be considered valid measures of that construct. Similarly, two or more measures of different constructs should not have a high correlation for the two constructs to be effectively different.
- **Criterion validity:** criterion validity refers to the degree to which a scale score is associated with another variable, called the criterion variable (Gold standard or validation item). To enjoy the property of criterion validity, a scale must vary in the same direction and with the same intensity as the criterion. A distinction is made between concurrent validity and predictive validity. If a scale score agrees with other valid measures (criterion variable) of the same construct, this is referred to as concurrent validity. If a scale score is used to get an estimate of the score in a criterion which is delayed in time, this is called predictive validity. Concurrent validity is generally established by the correlation coefficient between the overall scale score and the criterion variable score. High values of the correlation index indicate a high degree of criterion validity.

6.4 Experimental design

In order to investigate the mentioned research questions, the experiment is design specifically to identify the relevant study group and monitoring variable. In the following sections the study group design and the monitoring design are described in detail.

6.4.1 Study group design

Populations of interest

Given the diverse buildings' types included in the project pilot case studies, the population of interest is composed by:

- Adults (females and males) working in office annotated as adults;

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

- Clients (female and male) resident in a health care center annotated as elderly and fragile people;
- Non-athletes (females and males) training in sport facilities annotated as non-minors;
- Pupils (females and males) studying in primary school within the age range 6 to 11;
- Pupils (females and males) studying in high school within the age range 14 to 18;
- Tenants (females and males, adults and young) living in private apartments.

All participants are volunteers and will declare to be healthy, normotensive, non-obese, and not taking any medication that might have altered their cardiovascular system or thermoregulatory responses.

The participants are recommended to refrain alcoholic beverages and intensive physical exercise at least 5 hours before the experiment. The users of the sport centers, who might have executed a high metabolic rate activity before filling out the questionnaire, are excepted.

Experimental structure and design

The structure of the experiments is a **randomized block design** (aka stratified random design), where subjects are first grouped according to a characteristic they share (e.g., climate, type of building) and then randomly assigned to the different groups (single office versus shared office).

It follows a **within-subjects design** (also known as a repeated measures design) meaning that all participants are exposed to the different environmental conditions, and their responses to these conditions are measured.

Hypothesis testing and sample size

To address this matter and provide data for **Obj1**, the data gathered with the Brief questionnaires and environmental monitoring are used to investigate six research questions:

1. **RQ1:** *Do collective thermal feedback in shared offices (thermal sensation, acceptability, preference) deviate from individual responses in offices?*
   - **Description**: This RQ is tested only on office spaces and investigate whether social interaction may affect the thermal management of shared spaces. It can provide insights to identify ranges of variation of indoor temperature that will reduce the probability of conflicts and energy wasteful behaviors (e.g., windows open with space heating system on)
   - **H0**: There is no difference in the thermal sensation in individual and shared offices.
   - **H1**: There is a difference in thermal sensation (thermal sensation ≠ 0) in shared offices.
   - **Type of test for hypothesis testing**: 2-tailed test
   - **Groups**:
   - Individual offices
   - Shared offices
   - **Type of sample**: Paired observations
   - **Effect size**: Cohen's d [mean(TSV_{shared}) – mean($TSV_{individual}$)]/SD_{total}
   - **Power** = 0.8
   - **Alpha** = 0.05
2. **RQ2:** *Are children more sensitive and vulnerable to temperature excursions outside thermal comfort zone than older kids and adults?* This is tested comparing primary school children, high school kids and adults working in office (with similar sedentary activity).
   - **Description**: This RQ investigates whether there is any significant difference in thermal response of children with respect to adults. This will provide insights on the appropriateness of adoption of reference temperature setpoint values identified for adults and reported in standards also for children and on a more tailored thermal management of classrooms that currently is commonly led by the teacher (an adult).

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

- **Type of test**: Multiple comparisons on more than 2 groups (e.g., children, kids, adults, elderly) with ANOVA (for differences in mean among 2 or more groups)
- **Ratio issue**: Balanced or Unbalanced analysis

3. **RQ3:** *Are fragile people more sensitive and vulnerable to temperature excursions outside thermal comfort zone than adults?*
   - **Description**: This is tested comparing self-sufficient elderly and adults in residences and offices. This knowledge is important to understand if the assumption that fragile and sensitive people require stricter environmental conditions and, referring to standards, if we can move from the thermal comfort limits of Class I to Class II (or from Class A to Class B) to provide higher energy flexibility potential and energy savings.
   - **H0**: There is no difference in the thermal sensation of sensitive and vulnerable people (elderly / children) with respect to adults / (adults and kids).
   - **H1**: There is a difference in thermal sensation (thermal sensation ≠ 0) between sensitive and vulnerable people (elderly / children) and adults / (adults and kids).
   - **Type of test for hypothesis testing**: 2-tailed test
   - **Groups**:
   - Sensitive and vulnerable people
   - Adults
   - **Type of sample**: Paired observations
   - **Effect size**: Cohen's d_[mean(TSV_{shared}) – mean($TSV_{individual}$)]/SD_{total}
   - **Power** = 0.8
   - **Alpha** = 0.05
4. **RQ4:** *Is user thermal feedback (thermal sensation, acceptability, preference) in houses different from that in (shared) offices?*
   - **Description:** This is tested comparing the POE of adults in the houses and in offices. More adaptive opportunities in houses and the movement between different spaces could lead to a broader range of accepted temperatures, that would result in a higher potential for energy flexibility.
   - **H0**: There is no difference in the thermal sensation perceived by people in residences and shared offices.
   - **H1**: There is a difference in thermal sensation (thermal sensation ≠ 0) perceived by people in residences and shared offices.
   - **Type of test for hypothesis testing**: 2-tailed test
   - **Groups**:
   - Residences
   - Shared offices
   - **Type of sample**: Paired observations
   - **Effect size**: Cohen's d [mean(TSV_{shared}) – mean($TSV_{individual}$)]/SD_{total}
   - **Power** = 0.8
   - **Alpha** = 0.05
5. **RQ5:** *Do dynamic thermal conditions reduce users' satisfaction in sport facilities?*
   - **Description**: Due to the users' high metabolic rates, the expansion of the range of acceptable temperatures, for example based on evolution of outdoor temperature, would provide a significant source of energy flexibility for the neighborhood network. At the same time, workers supervising the users' activities may be exposed to uncomfortable conditions.
   - **H0**: there is no difference in the thermal sensation between fixed and dynamic temperature setpoint (users and workers)
   - **H1**: there is a difference in the thermal sensation between fixed and dynamic temperature setpoint (users and workers)

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

- **Type of test for hypothesis testing**: 2-tailed test
- **Groups**:
- Observation collected when typical fixed setpoint temperature are used
- Observation collected when dynamic setpoint temperature are implemented
- **Type of samples**:
- end users: unpaired samples
- workers: pared samples
- **Effect size**: Cohen's d [mean(TSVshared) – mean(TSVindividual)]/SDtotal
- **Power** = 0.8
- **Alpha** = 0.05
- **Additional**: Sub analyses for the two groups users and workers if enough responses are collected

Finally, to address **Obj2**, a Satisfaction questionnaire will be designed and validated to respond to the research question:

6. **RQ6:** *Can user thermal feedbacks* (thermal sensation, acceptability, preference) *be explained by variations of the environmental variables* (air temperature, relative humidity, CO_2 concentration, VOC concentration, PMx concentration)*?*
   - **Description:** This is tested in all building types. Understanding these relationships will offer insights on how to plan excursions outside the typical comfort setpoints enabling the energy flexibility potential.
7. **RQ7:** and *Are user feedbacks (thermal sensation, acceptability, preference) in single and shared offices explained by variations of the environmental variables (air temperature, relative humidity, CO2 concentration, VOC concentration, PMx concentration, illuminance)?*
   - **Description:** the aim is to investigate whether given indoor environmental conditions can explain differences in individual or shared spaces.
8. **RQ8:** *Does the COLLECTiEF solution increase users' overall satisfaction?*
   - **Description:** This is tested by comparing the result of questionnaires administered before (M12-M23) and after (M24-M40) the installation of the COLLECTiEF solution in all the pilot buildings for type of users/buildings/countries.

Estimated number of survey responses

Preliminary estimation of the number of Brief and Satisfaction questionnaires filled out for one year according to the assumptions reported in the table and considering 100% response rate, optimistic estimation and pessimistic estimation.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 31 Requirements for survey filling per building use for all the pilot buildings

Country	Building number	Building name	Building type and description	Zones to be monitored	Occupancy info	Floor number	Number of zones to be monitored	Zone area (m2)	Nominal number of people	Monitoring parameters	Type of Sphensors to be installed	Total number of Sphensors	Assumptions	Brief POE per week	randomization	POE per month	POE per season (Response rate)	POE per year MAX (100%)	POE per year OPTIMISTIC (60%)	POE per year PESSIMISTIC (40%)	Assumptions	Satisfaction POE per month	POE per season (Response rate)	POE per year MAX (100%)	POE per year OPTIMISTIC (50%)	POE per year PESSIMISTIC (30%)
Norway	B1	Eidet Omsorgsenter	Health care center, elders, 70 flats	flats	1 patient	2	4	21.7	4	CO2, VOC, PM1,2.5,4,10 T_air, RU	423 401	4 4	1 POE/day for the 4 rooms	7	Repeted	28	84	336	201.6	134.4	1 POE/person/every2months	2	6	24	12	7.2
				Shared office I (large one 1st floor - 1074)	N/A	2	1	?	3	T_air, RU, illuminance CO2, VOC, PM1,2.5,4,10	402 423	1 1	1 POE/day filled by different people	7	Random	28	84	336	201.6	134.4	1 POE/person/every2month	1.5	4.5	18	9	5.4
	B2	Ellingsøy Idrettshall	Sport center, main hall, 1 dance room, 1 meeting room and 1 cafeteria	Main Hall (25m* 45m)	futsal, badminton, basketball, handbal, etc.	1	1	1167.3	10	CO2, VOC, PM1,2.5,4,10 T_air, RU	423 401	3 3	3 POE/day	21	Random	84	252	1008	604.8	403.2	1 POE/person/every2month	5	15	60	30	18
				Dance room (98.9 m2) + social room (39.9 m2). They are	Aerobic, trim, dance	1	1	138.8	10	CO2, VOC, PM1,2.5,4,10 T_air, RU	423 401	2 2	3POE/day	21	Random	84	252	1008	604.8	403.2	1 POE/person/every2month	5	15	60	30	18
	B3	Flisnes Barneskole	Elementary school	Classroom 1	N/A	N/A	1	?	20	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/week/classroom			0	0	0	0	0	1 POE/person/every2month		0	0	0	0
				Classroom 2	N/A	N/A	1	?	20	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/week/classroom			0	0	0	0	0	1 POE/person/every2month		0	0	0	0
	B4	Hatlane Omsorgsenter	Health care center, elders, 70 flats	flats	1 patient	2	4	23	4	CO2, VOC, PM1,2.5,4,10 T_air, RU	423 401	4 4	1 POE/day for the 4 rooms	7	Repeted	28	84	336	201.6	134.4	1 POE/person/every2month	2	6	24	12	7.2
				Shared office	N/A	2	1	29.4	3	T_air, RU, illuminance CO2, VOC, PM1,2.5,4,10	402 423	1 1	1 POE/day filled by different people	7	Random	28	84	336	201.6	134.4	1 POE/person/every2month	1.5	4.5	18	9	5.4
	B5	Moa Helsehus	Medical center	Individual offices (nurse room, doctor office, phsychologist office,...)	1 person	N/A	2	15	2	T_air, RU, illuminance	402	2	2 POE/week/room	8	Repeted	32	96	384	230.4	153.6	1 POE/person/every2month	1	3	12	6	3.6
				Break room (checking SBS hypothesis)	N/A	N/A	1	?	3	CO2, VOC, PM1,2.5,4,10 T_air, RU	423 401	1 1	3 POE/week	3	Random	12	36	144	86.4	57.6	1 POE/person/every2month	1.5	4.5	18	9	5.4
				Shared offices	N/A	N/A	3	?	9	T_air, RU, illuminance CO2, VOC, PM1,2.5,4,10	402 423	3 3	1 POE/day filled by different people	21	Random	84	252	1008	604.8	403.2	1 POE/person/every2month	4.5	13.5	54	27	16.2
	B6	Spjelkavik Ungdomsskole	High School	Classroom 1 & 2	28 students + 1 teacher	1	2	75	58	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	2 2	1 POE/week/classroom	58	Random	232	696	2784	1670.4	1113.6	1 POE/person/every2month	29	87	348	174	104.4
				Classroom 3 & 4	28 students + 1 teacher	2	2	75	58	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	2 2	1 POE/week/classroom	58	Random	232	696	2784	1670.4	1113.6	1 POE/person/every2month	29	87	348	174	104.4
				Shared office	9 Teachers	2	1	15	9	T_air, RU, illuminance CO2, VOC, PM1,2.5,4,10	402 423	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	4.5	13.5	54	27	16.2
	B7	Tennfjord Barneskole	Elementary school	Classroom 1-6	13-25 students + 1 teacher	1	6	?	90	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	6 6	1 POE/week/classroom	174	Random	696	2088	8352	5011.2	3340.8	1 POE/person/every2month	45	135	540	270	162
				Shared office	10 Teachers	1	1	61	15	T_air, RU, illuminance CO2, VOC, PM1,2.5,4,10	402 423	2 2	1 POE/day filled by different people	10	Random	40	120	480	288	192	1 POE/person/every2month	7.5	22.5	90	45	27
France	B8	Green'ER building (G2Elab)	Campus building	classrooms/Labs	N/A	N/A	N/A	N/A	5	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	2 8	5 POE/week	5	Random	20	60	240	144	96	1 POE/person/every2month	2.5	7.5	30	15	9
	B9	Guy Ourisson Building (GOB)	Campus building	Individual office 201b	40 y	2	1	21.67	1	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Individual office 207	40 y	2	1	15,13	1	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Individual office 211	40 y	2	1	20,18	1	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Shared office 115	Post-docs (30-40 y)	1	1	21.99	6	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	3	9	36	18	10.8
				Shared office 112	Post-docs (30-40 y)	1	1	20.18	2	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	1	3	12	6	3.6
				Individual office 109	40 y	1	1	20.37	1	T_air, RU, illuminance	402	1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Individual office 010	40 y	G	1	19.33	1	T_air, RU, illuminance	402	1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Individual office 014	40 y	G	1	16.96	1	T_air, RU, illuminance	402	1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Individual office 016	40 y	G	1	14.43	1	T_air, RU, illuminance	402	1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Individual office 009	50 y	G	1	20.36	1	T_air, RU, illuminance	402	1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Shared office 001	Post-docs (30-40 y)	G	1	45.24	3	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	1.5	4.5	18	9	5.4
	B10	Graduate School (GS)	Campus building	Classroom 007	Graduate studenst and teachers	G	1	44.64	12	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	2 POE/week/room	2	Random	8	24	96	57.6	38.4	1 POE/person/every2month	6	18	72	36	21.6
				Classroom 006	Meeting room	1	1	28.88	1	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	0.9
				Individual office 002	Adult - F	G	1	13.87	1	T_air, RU, illuminance	402	1	2 POE/week/room	2	Repeated	8	24	96	57.6	38.4	1 POE/person/every2month	0.5	1.5	6	3	1.8
				Shared office 102	PhD students (23-30 y)	1	1	79.75	16	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	8	24	96	48	28.8
				Shared office 101	PhD Students (23-30 y)	1	1	24.32	5	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	2.5	7.5	30	15	9
	B11	Novel Technologies Laboratory (NTL)	Campus building	Shared office 102	office work	1	1	44.14	9	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	4.5	13.5	54	27	16.2
				Shared offices 002	office work	G	1	16.31	3	CO2, VOC, PM1,2.5,4,10 T_air, RU, illuminance	423 402	1 1	1 POE/day filled by different people	5	Random	20	60	240	144	96	1 POE/person/every2month	1.5	4.5	18	9	5.4
Italy	B12	C2 Tower	Residential Apartments	Private apartments	N/A	N/A	4	90	12	T_air, RU	401	10	3 POE/week filled by different people	15	Random	60	180	720	432	288	1 POE/person/every2month	6	18	72	36	21.6
	B13	C3 Tower	Residential Apartments	Private apartments	N/A	N/A	4	90	12	T_air, RU	401	10	3 POE/week filled by different people	15	Random	60	180	720	432	288	1 POE/person/every2month	6	18	72	36	21.6
	B14	C4 Tower	Residential Apartments	Private apartments	N/A	N/A	4	90	12	T_air, RU	401	10	3 POE/week filled by different people	15	Random	60	180	720	432	288	1 POE/person/every2month	6	18	72	36	21.6

Table 32 Estimated number of the survey per building use

Type of building	Randomization	Brief questionnaires: POE per year MAX	Brief questionnaires: POE per year OPTIMISTIC 0.6	Brief questionnaires: POE per year PESSIMISTIC 0.4	Satisfaction questionnaires: POE per year MAX	Satisfaction questionnaires: POE per year OPTIMISTIC 0.5	Satisfaction questionnaires: POE per year PESSIMISTIC 0.3
Client rooms	Random	672	403	269	48	24	14
Individual offices	Repeated	1440	806	422	144	72	21
Shared offices	Random	4224	2534	1690	516	249	155
Classrooms (primary school)	Random	8832	5299	3533	630	315	189
Classrooms (secondary school)	Random	5568	3340.8	2227.2	696	348	208.8
Classroom (tertiary education)	Random	336	201.6	134.4	102	51	30.6
Apartments	Random	2160	1296	864	216	108	65
Sport halls	Random	2016	1210	806	120	60	36
TOTALS		25248	15091	9946	2472	1227	719

In order to properly design the experimental research, an *a priori* power analysis is used to estimate the minimum sample size (number of participants or observations) for each the RQs. Basic assumptions are reported in the following.

6.4.2 Monitoring design

Beyond the subjective data gathered through questionnaires, interviews and surveys, the collection of objective environmental data is of paramount importance to assess the interactions between users and their buildings and answer the identified research questions.

As such, it is important to identify the physical variables to collect, the most appropriate sensors to install indoors and outdoors, their location, the datalogging, the data transmission protocol and the data storage solution. Within the COLLECTiEF project, industrial partners provide the sensors fusion devices (Sphensor^{TM} units) with different monitoring capabilities, the data logging, transmission and storage solutions (BRIGs, and NTNU database for the development phase). All descriptions, protocols and responsibilities are reported in the COLLECTiEF Data Management Plan.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

In the following subsections the Sphensor™ features are reported, and rules for their localization.

6.5 Metrics/KPIs and relevant parameters

Numerous contextual factors can also influence occupants' thermal comfort perception, including behavioral and cultural aspects, individual preferences, demographic and anthropometric characteristics (e.g., age, gender, weight), space layout, architectural features, and adaptive opportunities available [54]. For these reasons, the following variable are identified:

- **Background variables:** identified and measured but not controlled:
    - Ambient temperature, temperature, Outdoor relative humidity, Solar radiation, Ethnicity, Height, Weight.
- **Constant variables**: controlled or measured but held/considered constant:
    - Atmospheric pressure, Metabolic rate, BMI (Body Max Index), Space layout and architectural features (it is assumed that no change in the room layout will occur during the experimental period).
- **Uncontrollable variables**: variables known to exist, but some conditions prevent them from being manipulated or they are very difficult to measure:
    - Radiant temperature, Acoustic pressure, Glare probability, Wind speed and direction, Atmospheric pressure.
- **Primary variables:** variable of interest:
    - **Indoors:** Air temperature, Operative temperature, Relative humidity, Illuminance, CO_2, VOC, PMx, Time of the day (morning vs afternoon), Age, Sex.

Table 33 and

Table 34 report the main variables and key performance indicators to assess thermal comfort in indoor environments available in literature.

Table 35 reports the main indicators for indoor air quality assessments and Table 36 reports variables and KPIs for visual comfort assessments.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 33 Relevant variables to be measured/calculated or surveyed for thermal comfort assessment

		Main variables to be Measured (M) /Calculated (C) /Surveyed (S)	Type	S.I. units	Description	Formula	Reference
INDOOR	1	Air temperature	M	°C	The air temperature is the temperature of the air around the human body		EN ISO 7726:2002 [14]
	2	Mean radiant temperature	M	°C	The mean radiant temperature is the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure.	The mean radiant temperature is given by: $\overline{T}_r = \sqrt[4]{T_g^4 + \frac{h_{cg}}{\varepsilon_g \sigma}(T_g - T_a)}$ where: Ɛg is the emissivity of the black globe (without dimension); σ is the Stefan-Boltzmann constant, in watts per square metre kelvin to the fourth power; [σ = 5,67 × 10^-8 W/(m2 · K4)]; Tr is the mean radiant temperature, in kelvins; Tg is the temperature of the black globe, in kelvins. In the case of natural convection: $h_{cg} = 1{,}4 \left(\frac{\Delta T}{D}\right)^{1/4}$ and in the case of forced convection: $h_{cg} = 6{,}3 \frac{v_a^{0{,}6}}{D^{0{,}4}}$ where D is the diameter of the globe, in metres; Va is the air velocity at the level of the globe, in metres per second.	EN ISO 7726:2002 [14]

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

	3	Globe temperature	M	°C	The mean radiant temperature can be measured by instruments which allow the generally heterogeneous radiation from the walls of an actual enclosure to be "integrated" into a mean value (see annex B). The black globe thermometer is a device frequently used in order to derive an approximate value of the mean radiant temperature from the observed simultaneous values of the globe temperature, tg, and the temperature and the velocity of the air surrounding the globe.		EN ISO 7726:2002 [14]
	4	Operative temperature	C	°C	Operative temperature (to) is defined as the uniform temperature of an enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the existing non-uniform environment.	$t_o = \frac{h_c \cdot t_a + \bar{h}_r \cdot \bar{t}_r}{h_c + h_r}$ where: ta is the air temperature; tr is the mean radiant temperature; hc is the heat-transfer coefficient by convection; hr is the heat-transfer coefficient by radiation.	EN ISO 7726:2002 [14]
	5	Surface temperatures	M	°C	Surface temperature is the temperature of a given surface. This is used to evaluate the radiant heat exchange between the human body by means of the mean radiant and/or the plane radiant temperature. It is also used to evaluate the effect of direct contact between the body and a given surface.		EN ISO 7726:2002 [14]

<table>
<tr><td></td><td>6</td><td>Air velocity</td><td>M/C</td><td>m/s</td><td>The air velocity is a quantity defined by its magnitude and direction. The quantity to be considered in the case of thermal environments is the speed of the air, i.e. the magnitude of the velocity vector of the flow at the measuring point considered</td><td>The air velocity, va, at any point in a space fluctuates with time and it is recommended that the velocity fluctuations be recorded. An air flow can be described by the mean velocity, Va, which is defined as the average of the velocity over an interval of time (measuring period) and by the standard deviation of the velocity, SD, given by the equation:

$$SD = \sqrt{\frac{1}{n-1}} \sum_{i=1}^{n} \left(v_{a_i} - v_a\right)^2$$

where
vai is the velocity at the time "i" of the measuring period.</td><td>EN ISO 7726:2002 [14]</td></tr>
<tr><td></td><td>7</td><td>Metabolic rate</td><td>S</td><td>met</td><td>The metabolic rate, as a conversion of chemical into mechanical and thermal energy, measures the energetic cost of mucular load and gives a numerical index of activity. Metabolic rate is an important determinant of the comfort or the strain resulting from exposure to a thermal environment. In particular, in hot climates, the high level of metabolic heat production associated with muscular work aggravate heat stress, as large amounts of heat need to be dissipated, mostly by sweat evaporation.</td><td>Table 1 — Levels for the determination of the metabolic rate
<table>
<tr><th>Level</th><th>Method</th><th>Accuracy</th><th>Inspection of the work place</th></tr>
<tr><td rowspan="2">1
Screening</td><td>1A: Classification according to occupation</td><td rowspan="2">Rough information
Very great risk of error</td><td>Not necessary, but information needed on technical equipment, work organization</td></tr>
<tr><td>1B: Classification according to activity</td><td></td></tr>
<tr><td rowspan="2">2
Observation</td><td>2A: Group assessment tables</td><td rowspan="2">High error risk
Accuracy: ± 20 %</td><td>Time and motion study necessary</td></tr>
<tr><td>2B: Tables for specific activities</td><td></td></tr>
<tr><td>3
Analysis</td><td>Heart rate measurement under defined conditions</td><td>Medium error risk
Accuracy: ± 10 %</td><td>Study required to determine a representative period</td></tr>
<tr><td rowspan="3">4
Expertise</td><td>4A: Measurement of oxygen consumption</td><td rowspan="3">Errors within the limits of the accuracy of the measurement or of the time and motion study
Accuracy: ± 5 %</td><td>Time and motion study necessary</td></tr>
<tr><td>4B: Doubly labelled water method</td><td>Inspection of work place not necessary, but leisure activities must be evaluated.</td></tr>
<tr><td>4C: Direct calorimetry</td><td>Inspection of work place not necessary</td></tr>
</table></td><td>EN ISO 8996:2004 [55]</td></tr>
</table>

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

	8	Clothing insulation	S	clo	the resistance to sensible heat transfer provided by a clothing ensemble, expressed in units of clo. (Informative Note: The definition of clothing insulation relates to heat transfer from the whole body and, thus, also includes the uncovered parts of the body, such as head and hands.)	4 methods available in the standard ASHRAE 55. • **Method 1:** Table 5-2 of this standard lists the insulation provided by a variety of common clothing ensembles. If the ensemble in question matches reasonably well with one of the ensembles in this table, then the indicated value of I_{cl} should be used. • **Method 2:** Table 5-3 of this standard presents the thermal insulation of a variety of individual garments. It is acceptable to add or subtract these garments from the ensembles in Table 5-2 to estimate the insulation of ensembles that differ in garment composition from those in Table 5-2. For example, if long underwear bottoms are added to Ensemble 5 in Table 5-2, the insulation of the resulting ensemble is estimated as $I_{cl} = 1.01 + 0.15 = 1.16$ clo • **Method 3:** It is acceptable to define a complete clothing ensemble using a combination of the garments listed in Table 5-3 of this standard. The insulation of the ensemble is estimated as the sum of the individual values listed in Table 5-3. For example, the estimated insulation of an ensemble consisting of overalls worn with a flannel shirt, t-shirt, briefs, boots, and calf-length socks is $I_{cl} = 0.30 + 0.34 + 0.08 + 0.04 + 0.10 + 0.03 = 0.89$ clo • **Method 4:** It is acceptable to determine the clothing insulation I_{cl} with Figure 5-1 in mechanically conditioned buildings. When people select their clothing as a function of outdoor and indoor climate variables, the most influential variable is outdoor air temperature. Figure 5-1 can be used to calculate the clothing insulation for each day of the year or for representative days. The curve in Figure 5-1 is an approximation for typical (or average) clothing. The model is based on field study and may not be appropriate for all cultures and occupancy types. The model represented in Figure 5-1 is suited to be implemented in building performance simulation software or building control systems. The model graphed in Figure 5-1 is described by the following equations: For $t_{a(out,6)} < -5°C$ $I_{cl} = 1.00$ For $-5°C \le t_{a(out,6)} < 5°C$ $I_{cl} = 0.818 - 0.0364 \times t_{a(out,6)}$ For $5°C \le t_{a(out,6)} < 26°C$ $I_{cl} = 10^{(-0.1635 - 0.0066 \times ta(out,6))}$ or $t_{a(out,6)} \ge 26°C$ $I_{cl} = 0.46$	ASHRAE 55:2020 [11]
	9	Absolute humidity of the air	M		The absolute humidity of the air characterizes any quantity related to the actual amount of water vapour contained in the air.		EN ISO 7726:2002 [14]
	10	Relative humidity	C	%	The relative humidity gives the amount of water vapour in the air in relation to the maximum amount that it can contain at a given temperature and pressure.		EN ISO 7726:2002 [14]

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

OUTDOOR	1	Outdoor air temperature	M	°C			
	2	Outdoor running mean temperature	C	°C	exponentially weighted running mean of the daily mean external air temperature Θed is such a series	$\Theta_{rm} = (1-\alpha).\{\Theta_{ed\,-1} + \alpha.\ \Theta_{ed\,-2} + \alpha^2\ \Theta_{ed\,-3}.....\}$ (1) This equation can be simplified to $\Theta_{rm} = (1-\alpha)\Theta_{ed\,-1} + \alpha.\ \Theta_{rm-1}$ (2) Where Θ_{rm} = Running mean temperature for today Θ_{rm-1} = Running mean temperature for previous day Θ_{ed-1} is the daily mean external temperature for the previous day $\Theta_{ed\,-2}$ is the daily mean external temperature for the day before and so on. α is a constant between 0 and 1. Recommended to use 0,8 The following approximate equation can be used where records of daily mean external temperature are not available: $\Theta_{rm} = (\Theta_{ed\,-1} + 0{,}8\ \Theta_{ed\,-2} + 0{,}6\ \Theta_{ed\,-3} + 0{,}5\ \Theta_{ed\,-4} + 0{,}4\ \Theta_{ed\,-5} + 0{,}3\ \Theta_{ed\,-6} + 0{,}2\ \Theta_{ed\,-7})/3{,}8$ (3)	EN 16798-1:2019 [12]
	3	Prevailing mean outdoor air temperature	C	°C	when used as an input variable in Figure 5-8 for the adaptive model, this temperature is based on the arithmetic average of the mean daily outdoor temperatures over some period of days as permitted in Section 5.4.2.1.	* It shall be based on no fewer than seven and no more than 30 sequential days prior to the day in question. * It shall be a simple arithmetic mean of all of the mean daily outdoor air temperatures tmda(out) of all the sequential days in Section 5.4.2.1.1. * Exception to 5.4.2.1.2: Weighting methods are permitted, provided that the weighting curve continually decreases toward the more distant days such that the weight applied to a day is between 0.6 and 0.9 of that applied to the subsequent day. For this option, the upper limit on the number of days in the sequence does not apply. (See Informative Appendix J for example calculation.) Mean daily outdoor air temperature tmda(out) for each of the sequential days in Section 5.4.2.1.1 shall be the simple arithmetic mean of all the outdoor dry-bulb temperature observa- tions for the 24-hour day. The quantity of measurements shall be no less than two, and, in that case, shall be the minimum and maximum for the day. When using three or more measure- ments, the time periods shall be evenly spaced. *5.4.2.1.3 Observations in Section 5.4.2.1 shall be from the nearest approved meteorological station, public or private, or Typical Meteorological Year (TMY) weather file. *Exception to 5.4.2.1.3: When weather data to calculate the prevailing mean outdoor air temperature tpma(out) are not available, it is permitted to use as the prevailing mean the published meteorological monthly means for each calendar month. It is permitted to interpolate between monthly means.	ASHRAE 55:2020 [11]
	4	Global horizontal solar irradiance	M	W/m^2			
	5	Global horizontal solar irradiation	M	kWh/m^2			

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 34 KPI for thermal comfort assessment

KPI	1	PMV - Predicted Mean Vote	C	%	The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale (see Table 1), based on the heat balance of the human body. Thermal balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment. In a moderate environment, the human thermoregulatory system will automatically attempt to modify skin temperature and sweat secretion to maintain heat balance.	Calculate the PMV using Equations (1) to (4): $PMV = \left[0{,}303 \cdot \exp(-0{,}036 \cdot M) + 0{,}028\right] \cdot \left\{ \begin{array}{l} (M-W) - 3{,}05 \cdot 10^{-3} \cdot \left[5\,733 - 6{,}99 \cdot (M-W) - p_a\right] - 0{,}42 \cdot \left[(M-W) - 58{,}15\right] \\ -1{,}7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_a) - 0{,}001\,4 \cdot M \cdot (34 - t_a) \\ -3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl}+273)^4 - (\bar{t}_r + 273)^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{array} \right\} \quad (1)$ $t_{cl} = 35{,}7 - 0{,}028 \cdot (M-W) - I_{cl} \cdot \left\{3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\right\} \quad (2)$ $h_c = \begin{cases} 2{,}38 \cdot \lvert t_{cl} - t_a \rvert^{0{,}25} & \text{for} \quad 2{,}38 \cdot \lvert t_{cl} - t_a \rvert^{0{,}25} > 12{,}1 \cdot \sqrt{v_{ar}} \\ 12{,}1 \cdot \sqrt{v_{ar}} & \text{for} \quad 2{,}38 \cdot \lvert t_{cl} - t_a \rvert^{0{,}25} < 12{,}1 \cdot \sqrt{v_{ar}} \end{cases} \quad (3)$ $f_{cl} = \begin{cases} 1{,}00 + 1{,}290\, l_{cl} & \text{for } l_{cl} \leqslant 0{,}078\ \text{m}^2 \cdot \text{K/W} \\ 1{,}05 + 0{,}645\, l_{cl} & \text{for } l_{cl} > 0{,}078\ \text{m}^2 \cdot \text{K/W} \end{cases} \quad (4)$ where M is the metabolic rate, in watts per square metre (W/m²); W is the effective mechanical power, in watts per square metre (W/m²); I_{cl} is the clothing insulation, in square metres kelvin per watt (m² · K/W); f_{cl} is the clothing surface area factor; t_a is the air temperature, in degrees Celsius (°C); $\bar{t}_r$ is the mean radiant temperature, in degrees Celsius (°C); v_{ar} is the relative air velocity, in metres per second (m/s); p_a is the water vapour partial pressure, in pascals (Pa); h_c is the convective heat transfer coefficient, in watts per square metre kelvin [W/(m² · K)]; t_{cl} is the clothing surface temperature, in degrees Celsius (°C). NOTE 1 metabolic unit = 1 met = 58,2 W/m²; 1 clothing unit = 1 clo = 0,155 m² · °C/W.	EN ISO 7730:2005 [13]

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Calculate the PMV using Equations (1) to (4):

	2	PPD - Predicted Percentage of Dissatisfied	C	-	The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. For the purposes of this International Standard, thermally dissatisfied people are those who will vote hot, warm, cool or cold on the 7-point thermal sensation scale given in Table 1.	$PPD = 100 - 95 \cdot \exp(-0{,}033\,53 \cdot PMV^4 - 0{,}217\,9 \cdot PMV^2)$	EN ISO 7730:2005 [13]
	3	ALD - ASHRAE Likelihood of Dissatisfaction	C	%	The ALD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm, i.e. voting hot, warm, cool or cold on the 7-point thermal sensation scale according to the ASHRAE adaptive comfort model	$ALD(\Delta T_{op}) = PPD(\Delta T_{op}) = \frac{e^{-3.057+0.419\Delta T_{op}+0.007\Delta T_{op}^2}}{1+e^{-3.057+0.419\Delta T_{op}+0.007\Delta T_{op}^2}}$	Carlucci at al. 2021 [56]
	4	NaOR - Nicol's et a.'s Overheating Risk	C	%	The likelihood of overheating is derived from a logistic regression analysis based on comfort surveys in European office buildings. It gives the proportion P of subjects voting 'warm' or 'hot' on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) comfort scale (which is the accepted definition of discomfort from heat)	$P = \frac{e^{(0.4734*\Delta T - 2.607)}}{\{1+e^{(0.4734*\Delta T - 2.607)}\}}$	Nicol et al. 2009 [57]
	5	Percentage of time outside a PMV range	C	%	Method A Calculate the number or percentage of hours during the hours the building is occupied, the PMV or the operative temperature is outside a specified range.		EN ISO 7730:2005 [13]

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

	6	Percentage of time outside an operative temperature range	C	%	Method A Calculate the number or percentage of hours during the hours the building is occupied, the PMV or the operative temperature is outside a specified range.		EN ISO 7730:2005 [13]
	7	Degree-hours	C	h	Method B The time during which the actual operative temperature exceeds the specified range during the occupied hours is weighted with a factor which is a function of how many degrees the range has been exceeded.	1) The weighting factor, wf, equals 1 for $t_o = t_{o,limit}$ where $t_{o,limit}$ is the lower or upper temperature limit of the comfort range specified (e.g. 23,5 °C < t_o < 25,5 °C corresponding to –0,2 < PMV < 0,2, as specified in Annex A for single offices, category A, summer). 2) The weighting factor, wf, is calculated as $wf = 1 + \frac{\lvert t_o - t_{o,limit} \rvert}{\lvert t_{o,optimal} - t_{o,limit} \rvert}$ for $\lvert t_o \rvert > \lvert t_{o,limit} \rvert$ 3) For a characteristic period during a year, the product of the weighting factor, wf, and the time, t, is summed and the result expressed in hours. i) Warm period: $\sum wf \cdot t$ for $t_o > t_{o,limit}$ ii) Cold period: $\sum wf \cdot t$ for $t_o < t_{o,limit}$	EN ISO 7730:2005 [13]

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

	8	PPD-weighted criterion	C	%	Method C The time during which the actual PMV exceeds the comfort boundaries is weighted with a factor which is a function of the PPD. Starting from a PMV distribution on a yearly basis and the relation between PMV and PPD (see Clause 5), the following is calculated:	1) The weighting factor, wf, equals 1 for $PMV = PMV_{\text{limit}}$ where PMV_{limit} is determined by the comfort range calculated according to this International Standard. 2) The weighting factor, wf, is calculated as $wf = \frac{PPD_{\text{actualPMV}}}{PPD_{\text{PMVlimit}}}$ for $\lvert PMV \rvert > \lvert PMV_{\text{limit}} \rvert$ where $PPD_{\text{actualPMV}}$ is the PPD corresponding to the actual PMV; PPD_{PMVlimit} is PPD corresponding to PMV_{limit}. 3) For a characteristic period during a year, the product of the weighting factor, wf, and the time, t, is summed and the result expressed in hours. i) Warm period: $\sum wf \cdot t$ for $PMV > PMV_{\text{limit}}$ ii) Cold period: $\sum wf \cdot t$ for $PMV < PMV_{\text{limit}}$	EN ISO 7730:2005 [13]
	9	Average PPD	C	%	Method D The average PPD over time during the occupied hours is calculated.		EN ISO 7730:2005 [13]
	10	Sum PPD	C	%	Method E The PPD over time during the occupied hours is summed.		EN ISO 7730:2005 [13]

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Table 35 Main variables for IAQ assessment

1	Carbon dioxide (CO_2)	M	ppm	Carbon dioxide (chemical formula CO_2) is a chemical compound occurring as a colorless gas with a density about 53% higher than that of dry air.
3	Total volatic compounds (TVOCs)	M	ppm	Volatile organic compounds are compounds that have a high vapor pressure and low water solubility. Many VOCs are human-made chemicals emitted as gases from certain solids or liquids.
4	Particulate matter (PM10, PM2.5)	M	ppm	It is used to refer to a mixture of solid particles and liquid droplets found in the air. Particle pollution includes: PM10 : inhalable particles, with diameters that are generally 10 micrometers and smaller; and PM2.5 : fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller.

Table 36 Variables and KPIs for visual comfort

AMOUNT OF LIGHT	1	Illuminance	M	lx	Illuminance at a point P of a given surface is a physical quantity, measured in lux and defined as the ratio between the luminous flux incident on an infinitesimal surface in the neighborhood of P and the area (Arec) of that surface.	$E_p = \frac{d\phi}{dA_{rec}} \quad [lx].$	Carlucci et al. 2015 **[58]**
	2	Daylight Autonomy (DA)	C	%	It is defined as the percentage of the occupied hours of the year when a minimum illuminance threshold is met by the sole daylight.	$DA = \frac{\sum_i (wf_i \cdot t_i)}{\sum_i t_i} \in [0,\ 1]$ with $wf_i = \begin{cases} 1 & \text{if} \quad E_{Daylight} \geq E_{limit} \\ 0 & \text{if} \quad E_{Daylight} < E_{limit} \end{cases},$	Carlucci et al. 2015 **[58]**
	3	Continuous Daylight Autonomy (DA_CON)	C	%	IT is an amelioration of DA proposed by Rogers and Goldman. In contrast to earlier definitions of DA, partial credit is attributed to time-steps when the measured daylight illuminance (Edaylight) lies below the limit (Elimit).	$DA_{CON} = \frac{\sum_i (wf_i \cdot t_i)}{\sum_i t_i} \in [0,\ 1]$ with $wf_i = \begin{cases} 1 & \text{if} \quad E_{Daylight} \geq E_{limit} \\ \frac{E_{Daylight}}{E_{limit}} & \text{if} \quad E_{Daylight} < E_{limit} \end{cases}.$	Carlucci et al. 2015 **[58]**

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

<table>
<tr>
<td></td>
<td>4</td>
<td>Useful Daylight Illuminance (UDI)</td>
<td>C</td>
<td>%</td>
<td>It is the fraction of the time in a year when indoor horizontal daylight illuminance at a given point falls in a given range. A lower and an upper illuminance limit values are proposed in order to split the analyzed period into three bins: the upper bin is meant to represent the percentage of the time when an oversupply of daylight might lead to visual discomfort, the lower bin represents the percentage of the time when there is too little daylight, and the intermediate bin represents the percentage of the time with appropriate illuminance level.</td>
<td>

$$UDI=\frac{\sum_i wf_i\cdot t_i}{\sum_i t_i}\in[0,\ 1]\begin{cases} UDI_{Overlit} \quad \text{with} \quad wf_i=\begin{cases}1 & \text{if} \quad E_{Daylight}>E_{Upper\ \ limit}\\ 0 & \text{if} \quad E_{Daylight}\le E_{Upper\ \ limit}\end{cases}\\ UDI_{Useful} \quad \text{with} \quad wf_i=\begin{cases}1 & \text{if} \quad E_{Lower\ \ limit}\le E_{Daylight}\le E_{Upper\ \ limit}\\ 0 & \text{if} \quad E_{Daylight}<E_{Lower\ \ limit}\vee E_{Daylight}>E_{Upper\ \ limit}\end{cases}\\ UDI_{Underlit} \quad \text{with} \quad wf_i=\begin{cases}1 & \text{if} \quad E_{Daylight}<E_{Lower\ \ limit}\\ 0 & \text{if} \quad E_{Daylight}\ge E_{Lower\ \ limit}\end{cases}\end{cases}$$

Illuminance limit values of UDI.

<table>
<tr><th>Source</th><th>Lower illuminance limit</th><th>Upper illuminance limit</th></tr>
<tr><td>Nabil and Mardaljevic [32]</td><td>100</td><td>2000</td></tr>
<tr><td>Mardaljevic and Heschong [30]</td><td>100</td><td>2500</td></tr>
<tr><td>Olbina and Beliveau [89]</td><td>500</td><td>2000</td></tr>
<tr><td>David and Donn [82]</td><td>300</td><td>8000</td></tr>
</table>

</td>
<td>Carlucci et al. 2015 [58]</td>
</tr>
</table>

<table>
<tr>
<td>LIGHT UNIFORMITY</td>
<td>5</td>
<td>Illuminance Uniformity (U_0)</td>
<td>C</td>
<td>%</td>
<td>Illuminance Uniformity (UO) of a given plane is defined as the ratio, in a given moment, between the minimum value of the illuminance on the plane (E_min) and the average illuminance on that plane (E_average). It is also possible to use the ratio between the minimum and the maximum (E_max) values of illuminance on the given plane, but this has to be specified [77].</td>
<td>

$$U_{O,average}=\frac{E_{min}}{E_{average}}$$

$$U_{O,max}=\frac{E_{min}}{E_{max}}.$$

</td>
<td>Carlucci et al. 2015 [58]</td>
</tr>
</table>

<table>
<tr>
<td>GLARE</td>
<td>6</td>
<td>Wienold et al.'s simplification of Discomfort Glare Probability</td>
<td>C</td>
<td>%</td>
<td>It is a simplified version of DGP (DGPs) where the logarithmic term depending on the local quantities (luminance and solid angle of the source seen from the observation point) is neglected. Discomfort Glare Probability (DGP) is a short-term, local, one-tailed index assessing glare.</td>
<td>

$$DGPs\big|_{Wienold}=6.22\cdot 10^{-5}\cdot E_V+0.184.$$

</td>
<td>Carlucci et al. 2015 [58]</td>
</tr>
</table>

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

	7	Hviid et al.'s simplification of Discomfort Glare Probability	C	%	It is a simplified version of DGP (DGPs) where the logarithmic term depending on the local quantities (luminance and solid angle of the source seen from the observation point) is neglected. Discomfort Glare Probability (DGP) is a short-term, local, one-tailed index assessing glare.	$DGPs\|_{Hviid} = 5.87 \cdot 10^{-5} \cdot E_V + 0.16.$	Carlucci et al. 2015 [58]

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

6.6 IEQ Sensors

In the project, we will install and use the sensor fusion units developed by LSI LASTEM and identified with the name Sphensor™, which allows to simultaneously measure thermo-hygrometric parameters such as air temperature and relative humidity, environmental parameters such as atmospheric pressure, illuminance for five different orientations, UV-A radiation and air quality in terms of concentration of VOCs, CO_2 and PM1, 2.5, 4, 10.

The Sphensor™ data logger sensors, using the Thread protocol, are able to send the information acquired to the Sphensor Gateway through a robust mesh radio network. The Sphensor™ Gateway, in addition to acting as a buffer memory, has been integrated with the BRIG module developed by ENERGY@WORK.

Three units with different monitoring capabilities are used during the implementation of the COLLECTiEF project. They are identified with the codes:

- **PRMPB0401**: measuring air temperature, relative humidity and atmospheric pressure;
- **PRMPB0402**: measuring air temperature, relative humidity, atmospheric pressure and illuminance in five orientations;
- **PRMPA0423**: measuring the concentration of CO_2, VOC, PM1, 2.5, 4, 10.

In Table 37 there are the specifications of the sensors installed in the three typologies of Sphensor™.

Table 37 Sphensor™ units specifications

Temperature	Principle	RTD Pt100 1/3 DIN B (Class AA EN60751)
	Measure range	-30...60°C
	Accuracy	0.1°C (@ 0°C)
	Resolution	0,015°C
	Response time (T63)	> 2 sec
	Long term stability	<0.03 °C/yr
Relative Humidity	Principle	Capacitive
	Measure range	0...100%
	Accuracy	±1.5% (@5...95%); max 2%
	Resolution	0,01%
	Response time (T63)	8 sec
	Long term stability	<0.25 %RH/yr
Atmospheric Pressure	Principle	Piezoresistive
	Measure range	600...1100 hPa
	Accuracy	0.18 hPa (@ 25 °C); ±0.6 hPa (@ -40...85 °C)
	Resolution	0.1 hPa

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Temperature	Principle	RTD Pt100 1/3 DIN B (Class AA EN60751)
	Measure range	-30...60°C
	Accuracy	0.1°C (@ 0°C)
	Resolution	0,015°C
	Response time (T63)	> 2 sec
	Long term stability	<0.03 °C/yr
Relative Humidity	Principle	Capacitive
	Measure range	0...100%
	Accuracy	±1.5% (@5...95%); max 2%
	Resolution	0,01%
	Response time (T63)	8 sec
	Long term stability	<0.25 %RH/yr
Atmospheric Pressure	Principle	Piezoresistive
	Measure range	600...1100 hPa
	Accuracy	0.18 hPa (@ 25 °C); ±0.6 hPa (@ -40...85 °C)
	Resolution	0.1 hPa

Lux (PRMPB0402-3)	Principle	Ambient Light Photodiode Sensor
	Measure direction	• 0°, 90°, 180°, 270° with elevation of 45° with respect to the sensor plane • 1 measure on the normal of the sensor plane
	Measure Range	0,1...90 klx
	Accuracy	2% (@ lux > 40); 5% (@ lux < 40)
	Resolution	0.01 lx
	Cosine response	2% (for incidence angle < 50°)

UV-A (PRMPB0403)	Principle	Indium Gallium Nitride Photodiode
	Measure direction	On the normal of the sensor plane
	Measure Range	0...200 μW/cm^2
	Accuracy	±5% VL
	Resolution	0.05 μW/cm^2
VOC and equivalent CO_2 (PRMPA0423)	Range (ethanol, H_2)	0...1000 ppm
	Accuracy	Ethanol: 15% of measured value
		H_2: 10% of measured value
	Resolution (ethanol, H_2)	0.2% of measured value
	Thermal drift (ethanol, H_2)	1.3% of measured value
	Operative temperature	-10...60 °C

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

PM (1, 2.5, 4, 10) (PRMPA0423)	Range	0…1000 µg/m3
	Precision	PM1 and PM2.5: • 0…100 µg/m^3 ±10 µg/m^3 • 100…1000 µg/m^3 ±10 % of measured value
		PM4 and PM10: • 0…100 µg/m^3 ±25 µg/m^3 • 100…1000 µg/m^3 ±25 % of measured value
	Temperature drift	• 0…100 µg/m^3 ±1.25 µg/m^3/year • 100…1000 µg/m^3 ±1.25 % of measured value/year
	Life time	24h/g > 10 years
	Acoustic emission level	25 dB
	Noise emission level drift	+0.5 dB
	Operative temperature	-10…60 °C
CO_2 (PRMPA0423)	Range	0…5000 ppm
	Accuracy	<± (50 ppm + 3% of measured value)
	Response time (T63)	140 s (with measured average), 75 s (without measured aver-age)
	Automatic calibration	Present: it does not require positioning of the sensor outdoors for recalibration.
	Periodic calibration	5 years
	Temperature influence	± (1+CO_2[ppm]/1000) ppm/°C (-20±45°C)

Internal Temperature (PRMPA0423)	Range	-40±60 °C
	Accuracy	±0.5 °C @ 25 °C
Internal Pressure (PRMPA0423)	Range	700…1100 mbar
	Accuracy	±2 mbar @ 20±80% RH @ 25 °C

PRMPB0401 and PRMPB0402 are used to collect data useful to investigate RQ1, RQ2, RQ3, RQ4, RQ5, and RQ6.

PRMPA0423 are used to collect data useful to investigate RQ1, RQ2, RQ3, and RQ4.

6.6.1 Sensor installation

Based on the aforementioned research questions, among the sensor fusion options provided by LSI LASTEM, it is suggested:

- The **PRMPB0401** (T_{air}, RU, P_{atm}) to be installed:
  - In the residences because:
    - these spaces accommodate several functions with different illuminance requirements and do not need a strict illuminance control. Furthermore, electric lighting is directly controlled by the occupants.
    - The residential units included in the COLLECTiEF pilot case studies, as the large majority of the existing building stock, do not have a mechanical ventilation system controlled by the concentrations of indoor pollutants like CO_2, VOC or PMx.
  - In the health care center patients' rooms because:
    - these spaces accommodate several functions with different illuminance requirements and do not need a strict illuminance control. Furthermore, electric lighting is directly controlled by the occupants.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

  - o In the sport center because
    - these spaces accommodate several functions with different illuminance requirements and do not need a strict illuminance control.
  - o For investigating RQ1.
- The **PRMPB0402** (T_{air}, RU, P_{atm}, illuminance) to be installed:
  - o In both single and shared offices (including the offices in the health care centers, medical center and educational institutes) because the illuminance level has an important role in the users' overall satisfaction with the indoor environment.
  - o In the classrooms in primary and high schools and in tertiary institute because the students' overall satisfaction with the indoor environment depends also on the amount of light.
  - o For investigating RQ1 and RQ
- The **PRMPB0423** (CO_2, VOC, PM1, 2.5, 4, 10) is installed ONLY in those rooms where we have either:
  - o **More than one occupant** (shared offices, classrooms, meeting rooms) to specifically investigate RQ2;
  - o **Fragile persons** (self-sufficient elderly and primary school pupils) to specifically investigate RQ3 and RQ4;
  - o **High metabolic activity** (sport halls) to specifically provide insights respect to RQ6.

Country	Building number	Building name	Building type and description	Zones to be monitored	Occupancy info	Floor number	Number of zones to be monitored	Zone area (m2)	Nominal number of people	Monitoring parameters	Type of Sphensors to be installed	Total number of Sphensors
Norway	B1	Eidet Omsorgsenter	Health care center, elders, 70 flats	flats	1 patient	2	4	21.7	4	CO2, VOC, PM1,2.5,4,10	423	4
										T_air, RU	401	4
				Shared office I (large one 1st floor - 1074)	N/A	2	1	?	3	T_air, RU, illuminance	402	1
										CO2, VOC, PM1,2.5,4,10	423	1
	B2	Ellingsøy Idrettshall	Sport center, main hall, 1 dance room, 1 meeting room and 1 cafeteria	Main Hall (25m* 45m)	futsal, badminton, basketball, handbal, etc.	1	1	1167.3	10	CO2, VOC, PM1,2.5,4,10	423	3
										T_air, RU	401	3
				Dance room (98.9 m2) + social room (39.9 m2). They are	Aerobic, trim, dance	1	1	138.8	10	CO2, VOC, PM1,2.5,4,10	423	2
										T_air, RU	401	2
	B3	Flisnes Barneskole	Elementary school	Classroom 1	N/A	N/A	1	?	20	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Classroom 2	N/A	N/A	1	?	20	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
	B4	Hatlane Omsorgsenter	Health care center, elders, 70 flats	flats	1 patient	2	4	23	4	CO2, VOC, PM1,2.5,4,10	423	4
										T_air, RU	401	4
				Shared office	N/A	2	1	29.4	3	T_air, RU, illuminance	402	1
										CO2, VOC, PM1,2.5,4,10	423	1
	B5	Moa Helsehus	Medical center	Individual offices (nurse room, doctor office, phsychologist office,...)	1 person	N/A	2	15	2	T_air, RU, illuminance	402	2
				Break room (checking SBS hypothesis)	N/A	N/A	1	?	3	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU	401	1
				Shared offices	N/A	N/A	3	?	9	T_air, RU, illuminance	402	3
										CO2, VOC, PM1,2.5,4,10	423	3
	B6	Spjelkavik Ungdomsskole	High School	Classroom 1 & 2	28 students + 1 teacher	1	2	75	58	CO2, VOC, PM1,2.5,4,10	423	2
										T_air, RU, illuminance	402	2
				Classroom 3 & 4	28 students + 1 teacher	2	2	75	58	CO2, VOC, PM1,2.5,4,10	423	2
										T_air, RU, illuminance	402	2
				Shared office	9 Teachers	2	1	15	9	T_air, RU, illuminance	402	1
										CO2, VOC, PM1,2.5,4,10	423	1
	B7	Tennfjord Barneskole	Elementary school	Classroom 1-6	13-25 students + 1 teacher	1	6	?	90	CO2, VOC, PM1,2.5,4,10	423	6
										T_air, RU, illuminance	402	6
				Shared office	10 Teachers	1	1	61	15	T_air, RU, illuminance	402	2
										CO2, VOC, PM1,2.5,4,10	423	2
France	B8	Green'ER building (G2Elab)	Campus building	classrooms/Labs	N/A	N/A	N/A	N/A	5	CO2, VOC, PM1,2.5,4,10	423	2
										T_air, RU, illuminance	402	8
	B9	Guy Ourisson Building (GOB)	Campus building	Individual office 201b	40 y	2	1	21.67	1	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Individual office 207	40 y	2	1	15,13	1	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Individual office 211	40 y	2	1	20,18	1	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Shared office 115	Post-docs (30-40 y)	1	1	21.99	6	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Shared office 112	Post-docs (30-40 y)	1	1	20.18	2	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Individual office 109	40 y	1	1	20.37	1	T_air, RU, illuminance	402	1
				Individual office 010	40 y	G	1	19.33	1	T_air, RU, illuminance	402	1
				Individual office 014	40 y	G	1	16.96	1	T_air, RU, illuminance	402	1
				Individual office 016	40 y	G	1	14.43	1	T_air, RU, illuminance	402	1
			-	Individual office 009	50 y	G	1	20.36	1	T_air, RU, illuminance	402	1
				Shared office 001	Post-docs (30-40 y)	G	1	45.24	3	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
	B10	Graduate School (GS)	Campus building	Classroom 007	Graduate studenst and teachers	G	1	44.64	12	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Classroom 006	Meeting room	1	1	28.88	1	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Individual office 002	Adult - F	G	1	13.87	1	T_air, RU, illuminance	402	1
				Shared office 102	PhD students (23-30 y)	1	1	79.75	16	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Shared office 101	PhD Students (23-30 y)	1	1	24.32	5	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
	B11	Novel Technologies Laboratory (NTL)	Campus building	Shared office 102	office work	1	1	44.14	9	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
				Shared offices 002	office work	G	1	16.31	3	CO2, VOC, PM1,2.5,4,10	423	1
										T_air, RU, illuminance	402	1
Italy	B12	C2 Tower	Residential Apartments	Private apartments	N/A	N/A	4	90	12	T_air, RU	401	10
	B13	C3 Tower	Residential Apartments	Private apartments	N/A	N/A	4	90	12	T_air, RU	401	10
	B14	C4 Tower	Residential Apartments	Private apartments	N/A	N/A	4	90	12	T_air, RU	401	10

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Finally, it is recommended to install the Sphensor™ units as close as possible to the work location of the participants to be capable to characterize the physical environment around the person but mounted in a manner that:

- does not cause any nuisances to the participants and auxiliary people during the execution of their typical activities,
- are away from heat sources (e.g., radiators, computers, lamps) and
- are not exposed to direct solar radiation.

Sensors should possibly be installed or localized in a position comprised between the standing and the seated heights of the hearth.

The air quality sensors (**PRMPA0423**) need a power supply; therefore, they need to be installed close to an electric socket. They will be supplied with a stainless-steel base

The temperature, humidity and pressure sensors (**PRMPB0401**) do not require a power supply and will be delivered with a stainless-steel base, so that they can be easily positioned on a horizontal plane (i.e., the workplane).

The air quality sensors (PRMPB0423) require power and will be supplied with a stainless-steel base, so that they can be easily positioned on a horizontal plane, close to an electric socket.

The repeaters can be installed by means of a screw in the wall in a raised position with respect to the passage of people.

6.6.2 Position of sensors

Total of 82 zones have been identified in the project to be monitored including 8 patient rooms, 14 classrooms, 1 student hall, 9 individual offices, 19 shared offices, 1 meeting room, 1 break room, 3 rooms for laboratory activities, 1 main hall, 1 dance room, 12 apartments (in each apartment two zones will be monitored: the living room and the bedroom). In the *Annex 4 – Pilot Installation: monitoring* specifications it is reported the complete overview of the zones (area, occupancy info, floor number, nominal number of people) and the type of sensors planned to be installed for monitoring. The exact location of the zones remains confidential only to pilots responsibles and the project leader.

The position of the sensors is as close as possible to the location of the participants to be capable to characterize the physical environment around the person. General guidelines have been followed, as described in section 6.6.1. In the engagement workshops in Italy and Norway, the placement of the sensors was directly discussed with the users and were identified according to their needs and preferences.

Norwegian pilots

There are seven pilots buildings in Norway including three schools, two healthcare centres for elderly, one sports center, one medical center. The total of 32 zones are identified for monitoring in these buildings, out of which 12 are classrooms, 8 are patients' rooms for elders, 6 are shared offices, 2 are individual offices, 1 is a break room and 2 are sports halls.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

In the classrooms, patients rooms, shared offices and sports hall, we will monitor both thermal comfort parameters and IAQ levels. In the individual offices only thermal comfort will be monitored.

The sensors will be located in the center of the room, not close to the air inlet and outlet, away from heat sources (e.g., radiators, computers, lamps) and not exposed to direct solar radiation. In the patients rooms they will be placed on a shelf, close to the bed, with access to electricity (not creating obstacles for nurses who are helping the patients). Figure 16 shows, as an example, one of the thermal zones in the healthcare center in Alesund where a shelf will be added to locate the sensor.

Figure 16 One of thermal zone monitored in the healthcare centre (Alesund)

In the largest sport hall we will place a total of 6 Sphensor™ units (3 monitoring IAQ and 3 thermal comfort) to cover the large floor area of the main hall (1167.3 m^2). In the smaller one (dance/social room) we will place 4 Sphensor™ (2 IAQ and 2 thermal comfort).

French pilot

The G2Elab pilot includes 8 thermal zones (mainly offices, 1 laboratory, 1 student hall and 1 classroom). Average occupation per office is about 3 persons; one office is occupied by just one person. The classroom is occupied by 25-34 persons. The laboratory and the student hall by three persons. The sensors will be located in the desk of offices and for meeting rooms, classrooms and labs at the center of the room.

Cyprus pilots

The Cyprus pilots involve 3 buildings located in the Athalassa campus of the Cyprus Institute with 18 zones included in the pilot. Specifically, the zones to be monitored are 1 classroom, 1 meeting room, and 16 offices. In the majority of them, a single Sphensor™ 402 will be installed while Sphensor 423 will be installed in rooms occupied with more than one person. The position of sensor will be located on the desk of offices and for meeting rooms, classrooms and labs at the center of the room hanged at the ceiling or on side walls at a height of 110 cm.

Italian pilots

A total of 12 apartments will be monitored in the project. In each flat will be placed two Sphensor™ to measure air temperature and relative humidity: one in the bedroom and one in the living room. The Sphensor™ for measuring air quality will be located in 6 of the flats, in the living room. In the bedroom the unit will be installed close to the bed at a high of around 70 cm. In the living room the

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Sphensor^{TM} will be placed at a height of 110 cm. The locations will slightly change between the flats according to the users' needs and preferences.

6.7 Survey design

6.7.1 Tentative draft of the Brief questionnaire

Objective

The Brief questionnaire provides feedback from building users useful to support algorithm development, training and evaluation.

Scope

It focuses on describing the right-here and right-now user's response to the thermal environment.

Structure

This questionnaire has three sections:

1. the first section intends to collect data on contextual factors [59], including few personal information, useful to understand potential differences in thermal comfort perception from different target groups,

2. the second section collects data on individual factors affecting the thermal response of a person,

3. the third section asks question of the assessment of some aspects of the thermal environment according to standardized and consolidated practices.

In *Annex 5 – Post Occupancy Evaluations: the Brief questionnaire (DRAFT)* a draft of the Brief questionnaire under development is reported.

In *Annex 6 – POE Brief questionnaire with designed graphics (DRAFT)* a preliminary version is presented.

6.7.2 Tentative draft of the Satisfaction questionnaire

Objective

The Satisfaction questionnaire provides feedback from building users useful to evaluate the overall users' satisfaction.

Scope

It focuses on describing the overall user's satisfaction with the building quality and different aspects of the indoor environment.

Structure

This questionnaire has two sections:

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

1. the first section intends to collect data on contextual factors [59], including few personal information, useful to understand potential differences in comfort perception from different target groups,

2. the third section asks question of the assessment of some aspects of the building quality and the indoor environment according to standardized and consolidated practices and their supposed impact on health and wellbeing.

In *Annex 7 – Post Occupancy Evaluations: the Satisfaction questionnaire (DRAFT)* a draft of the Satisfaction questionnaire under development is reported.

7 Assessing energy flexibility in COLLECTiEF

The concept of energy flexibility is broad, and can apply to anything from building and factories to larger swaths of society. As such, there is no single way to quantify energy flexibility, and it becomes necessary to choose scenarios and metrics.

A dedicated study on flexibility in buildings has been developed by the IEA EBC Annex 67 project "Energy Flexible Buildings" [15]. They propose a comprehensive definition, which states as follows: "the Energy Flexibility of a building is the ability to manage its demand and generation according to local climate conditions, user needs and grid requirements. Energy Flexibility of buildings will thus allow for demand-side management/load control and thereby demand response based on the requirements of the surrounding grids."

Within DSM, DR programs encourage customers to reduce (generally, in most cases) or increase (generally, in limited cases) demand in response to a price signal or financial incentive. Typically, the request to reduce or increase demand is made for a specific time period on a specific day, which is referred to as a Demand Response event (DR event).

In literature, demand response Measurement and Verification (M&V) refers to the application of appropriate statistical and load research techniques to measure and verify the load impact resulting from the utilization of a Demand Response program. Simply stated, M&V is a process to quantify, with statistical confidence, the value of a Demand Response load change throughout the duration of a Demand Response event. Events may last for one or more hours; the measurement typically quantifies the entire event period, and may also quantify the change during the peak hour. Measurement can be reported in MW, hourly kW, peak kW, etc. and may further be reported in a variety of intervals including 15, 30, 60 minute and total event duration. Measurement quantifies this load change and Verification provides evidence that the change is reliable.

The project will be developed in close collaboration with IEA EBC - Annex 82 - Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems using the knowledge and following the updates on the topic.

Demand response in EU

Demand response includes mainly industrial consumers that are ready to shift their demand (demand-side management) and active consumers in the residential sector and assumes electric vehicles and heat pumps for the future. France, Germany, Italy, Spain and the United Kingdom are the leading markets for demand response in the EU. The European Commission assumes the theoretical potential of demand response to amount to 100 GW and expects it to reach 160 GW in 2030 provided full digitalisation, technical availability and economic feasibility. In 2016, around 21 GW of demand response participated in the market; 15 GW come from large industry and 6 GW from residential customers which had dynamic pricing contracts [60].

Positive developments in demand-response regulation and implementation happened in 2020 and 2021. More countries removed barriers preventing demand-response from providing more services to the grid, and some also increased the amount of capacity awarded in electricity markets. Nevertheless, even faster progress is needed: 500 GW of demand response should be brought onto the market by 2030 to meet the pace of expansion required in the Net Zero Emissions by 2050 Scenario (NZE), a tenfold increase on deployment levels in 2020. In the NZE, the equivalent of 15% of average annual demand can be shifted to some extent by 2050 (shares are higher in many advanced economies with demand response markets in operation today). Demand response can be unlocked through actions taken in this decade to open markets to demand-side participation, encourage new business models and establish controllability standards for equipment and appliances [61].

After an uneven 2019, the European market appears to be reverting to strong growth in 2020 and 2021. In 2021, the United Kingdom secured 239 MW of demand-side resource capacity in its T-1 (one-year-ahead) auction – a considerable increase from the 84 MW awarded in 2020 – owing to a record clearing price of GBP 45/kW/year. In turn, there was a slight decline in the T-4 (four-year-ahead) auction, to 1 GW from the 1.2 GW awarded in 2020. In Italy, the system operator awarded total capacity of 4.4 GW of virtually aggregated mixed units in 2021. Meanwhile, the French market for demand-side flexibility has grown by ~0.6 GW in 2021 (to 1.5 GW), thanks to a subsidy ceiling increase to EUR 60 000/MW/year – double the previous year's level. New business models such as aggregation, virtual power plants and other distributed energy resource platforms offer great promise for enabling demand-side flexibility [61].

In the first part of 2020, the Covid-19 pandemic significantly reduced acquisitions and investment activity in demand-side flexibility businesses, but they returned to pre-pandemic levels in Q4 2020 [62].

Demand response in Norway

The Norwegian power supply system is flexible. The balance in the system is maintained largely by the large power plants with storage reservoirs. Large end-users also provide flexibility through direct participation in the day-ahead and intraday. Norway has extensive hydropower resources. It represents about 95% of its electricity consumption and fills most of its flexibility needs. An important share of residential heating is covered by electricity. Norway has taken important steps to allow wider Demand Response participation. In fact, Demand Response and aggregation can now legally bid in all balancing markets. In order to place bids on the market, aggregators must be BRPs themselves or co-operate with a BRP which takes on the balance responsibility for them. While this framework might be pervasive across the Nordics, this model makes the concept of aggregation less appealing to market actors and thus implemented less, and in cases in Norway, technically unfeasible [63].

Demand response in Italy

Enabling active consumers and demand response means that, in the coming years, Member States of the European Union shall complete an ambitious program of deployment of advanced-metering infrastructure, allowing demand resources to receive more precise market signals and to react to them. In other words, end consumers shall receive price signals with adequate locational and time granularity in tariffs, thus allowing them to take ownership of the way they use and consume their electricity.

Italy shows one of the most significant smart meter roll-out programs in Europe, a pioneer country in the installation of this kind of meters, starting it since 2001. Currently, more than 98% of customers is equipped with the 1st generation smart meters (1G). Starting from 2016 the Authority is leading the implementation of a second generation of smart meters (so-called 2G) based on new specific functionalities, able to bring benefits for all customers and electricity retailers more widely.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Relating to metering data collection, 2G smart meters allow data reading every quarter-hour for all customers compared to 1G smart meters which limited this option only to customers with contractual power higher than 55 kW. This information will help all customers to better know their consumption, making the introduction of new commercial offers based on real time prices set in the spot market possible for retailers. Moreover, prepaid contracts can be more effective, also as an instrument to contrast the risk of payment arrears which are a market entry barrier [64].

Demand response in France

France has strongly expanded demand response across the entire electricity market and is a leader in demand response in Europe. In 2019, France had demand-response capacity of 2.9 GW, with 2.3 GW from the capacity mechanism and 0.6 GW from suppliers which rely on dynamic pricing. Bigger electricity suppliers and flexibility operators can offer demand response in the energy market depending on wholesale market prices (the so-called NEBEF mechanism). Besides, RTE (administrator of national electricity transmission network) has in place interruptibility schemes with industry. The PPE (Programmations Pluriannuelles de l'Energie) plans for 6.5 GW of demand response by 2028 through tenders. A new network tariff regulation (TURPE 6) has come into force in August 2021, which will enable the system operator to offer differentiated network tariffs to suppliers (seasonal, hourly, voltage-specific). Traditionally, France had a diverse set of time-of-use pricing, which should rebound with the full roll-out of smart meters. Since 2015, France is in the process of rolling out smart meters and targets 35 million by the end of 2021. Enedis (electrical national distributor)'Linky technology is being deployed, which is also deployed by ELDs (Electrical Local Distributor) in their areas. As of 2019, more than 28 million smart meters had been installed. In France almost 50% of the expected demand response volume for 2022 is reserved for sites of 1 MW or less [29,61].

Demand response in Cyprus

The commitment of Cyprus to promote the transformation of the traditional vertically and centrally organised electricity system to an electricity system that will be able to accommodate non-dispatchable decentralised generation is reflected in the T-TYNDP financial commitment. A budget of ca. 112 million Euros will be dedicated to investing in modernisation projects up to the year 2027, which is equivalent to an expenditure of 130 Euros per capita. In particular:

Installation of Advanced Metering Infrastructure (AMI) and Smart Meters to enable optimization and control of the distribution system, increase the penetration of distributed renewable sources, enable aggregation of RES, demand response and storage, increase direct final customer participation in all market stages (active customers). The deployment of advanced metering infrastructure (AMI) includes the roll-out of 400 000 smart meters. The AMI contributes to increased system observability, load and generation forecasting accuracy, accurate system analysis and planning, load management alternative to ripple control, optimisation of the operation of the distribution system, supervisory control and data acquisition of PV systems and so forth. The major functionality of the AMI is the metering data requisition moreover, control through head end systems (no billing). The total budget of the project is estimated at 75-80 million euros and will be realised in 7 phases, each involving the installation of 57143 smart meters. Each phase ends in January starting from year 2021 (end of phase 1) to January 2027 (end of year 2027). The financing of this project will be through the national budget of the distribution system owner.

Amend Trade and Settlement Rules and Transmission and Distribution Rules to allow for Demand Response in the market according to Art. 15(8) Directive 2009/27/EU [65].

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

This PaM aims at creating the necessary conditions for the participation of Demand Response in the Day Ahead Market (directly or via Aggregator) and the Balancing and Ancillary Services Markets (via aggregator). Technical modalities should be defined in order for the national law, as harmonized with Article 15(8) of the Directive, to be applied in practice; in particular, the submission of DR Upward and Downward offers with priority over other participants i.e. should be cleared before offers of other sources with the same price. The DR Aggregator should be engaged in Bilateral Contracts with Suppliers, so as to secure the necessary capacity for participating in the Day Ahead Market and the Balancing Market.

7.1 Objectives

Among the expected impacts listed in the GA, there is no a direct assessment of energy flexibility. However, to guarantee the achievement of key functionality n.3 of smart readiness, i.e. to adapt in response to the situation of the energy grid by providing energy flexibility, in the project we will evaluate this aspect.

7.2 Methodology

The evaluation of KPIs related to energy flexibility will be done for each DR event and for each demonstration site. In all these cases, the determination of KPIs will be based on a comparison with a reference scenario where no energy flexibility is provided.

7.3 Metrics/KPIs and relevant parameters

To quantifying energy flexibility, indicators in literature have typically revolved around three metrics: (i) the quantity of energy that can be shifted, (ii) the temporal flexibility, i.e., how long the consumption can be shifted, and (iii) the cost of utilising this flexibility [66]. In all these cases, the determination is based on a comparison with a reference case where no energy flexibility is exploited.

In this section we present a selection of KPIs which are under evaluation at this stage of the project. Further indicators might be introduced following the development of the project.

Three KPIs in relation to the quantities of energy displaced will be calculated for each DR event:
- Change of electric load on the grid during the DR event in kW ($\Delta_{abs}\overline{P}_{elec,grid}$), in kWh ($\Delta_{abs}E_{elec,grid}$) and in % ($\Delta_{ref}\overline{P}_{elec,grid}$ or $\Delta_{ref}E_{elec,grid}$);
- Electric self-consumption change during the DR event in % ($\Delta_{ref}E_{elec,autoconsumed}$, in case of an electric local production);
- Primary energy balance during the DR event in kWh ($\Delta_{abs}E_{all\ energies}$) and in % ($\Delta_{ref}E_{all\ energies}$).

The calculation will be realized at the Edge Node level and at the Cluster Node level.

<u>Change of electric load on the grid:</u>

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

$$\Delta_{abs}\overline{P}_{elec,grid}(i) = \overline{P}_{elec,grid,DR}(i) - \overline{P}_{elec,grid,reference}(i)$$

$$\Delta_{abs}E_{elec,grid}(i) = E_{elec,grid,DR}(i) - E_{elec,grid,reference}(i)$$

$$\Delta_{ref}\overline{P}_{elec,grid}(i) = 100\times\frac{\overline{P}_{elec,grid,DR}(i) - \overline{P}_{elec,grid,reference}(i)}{\overline{P}_{elec,grid,reference}(i)}$$

$$\Delta_{ref}E_{elec,grid}(i) = 100\times\frac{E_{elec,grid,DR}(i) - E_{elec,grid,reference}(i)}{E_{elec,grid,reference}(i)}$$

$$\Delta_{ref}\overline{P}_{elec,grid}(i) = \Delta_{ref}E_{elec,grid}(i)$$

Where

$\overline{P}_{elec,grid,DR}(i)$ is the mean electrical power called on the grid during the DR event *i*, in kW (of final energy),

$\overline{P}_{elec,grid,reference}$ is the mean electrical power called on the grid in the reference scenario (without the DR event) over the same period as the DR event *i*, in kW (of final energy),

$E_{elec,grid,DR}(i)$ is the quantity of electrical energy consumed on the grid during the DR event *i*, in kWh (of final energy),

$E_{elec,grid,reference}$ is the quantity of electrical energy consumed on the grid in the reference scenario (without the DR event) over the same period as the DR event *i*, in kWh (of final energy),

i is the index for the DR event.

The calculation will be able to be realized at the level of all electrical uses and only at the level of electrical(s) use(s) subject to the DR events.

<u>Electric self-consumption change (in case of an electric local production):</u>

$$\Delta_{ref}E_{elec,autoconsumed}(i) = 100\times\frac{E_{elec,autoconsumed,DR}(i) - E_{elec,autoconsumed,reference}(i)}{E_{elec,autoconsumed,reference}(i)}$$

Where

$E_{elec,autoconsumed,DR}(i)$ is the quantity of auto-consumed electrical energy (from the electric local production and/or its associated storage system) during the DR event *i*, in kWh (of final energy),

$E_{elec,autoconsumed,reference}(i)$ is the quantity of auto-consumed electrical energy (from the electric local production and/or its associated storage system) in the reference scenario (without the DR event) over the same period as the DR event *i*, in kWh (of final energy),

i is the index for the DR event.

The calculation will be able to be realized at the level of all electrical uses (a priori, no possibility of knowing which uses are subject to self-consumption).

<u>Primary energy balance:</u>

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

$$\Delta_{abs} E_{all\ energies}\ (i) = E_{all\ energies,DR}\ (i) - E_{all\ energies,reference}(i)$$

$$\Delta_{ref} E_{all\ energies}(i) = 100 \times \frac{E_{all\ energies,DR}(i) - E_{all\ energies,reference}(i)}{E_{all\ energies,reference}(i)}$$

Where

$E_{all\ energies,DR}(i)$ is the quantity of primary energy consumed at the level of all energies during the DR event *i*, in kWh (of primary energy),

$E_{all\ energies,reference}$ is the quantity of primary energy consumed at the level of all energies in the reference scenario (without the DR event) over the same period as the DR event *i*, in kWh (of primary energy),

i is the index for the DR event.

The calculation will be able to be realized at the level of all uses and only at the level of use(s) subject to the DR events.

As these three KPIs in relation to the quantities of energy displaced will be calculated for each DR event, it will be possible to give some statistics on all DR events of one given year (e.g. distribution, mean, median, quartiles). The analysis will be done separately for the DR events corresponding to shedding order/incentive and for the DR events corresponding to shifting or rising order/incentive.

One KPI in relation to the duration of the event will be calculated for each DR event, $t_{DR}(i)$ in hour.

As for the three KPIs in relation to the quantities of energy displaced, for this KPI, the assessment will be realized at the Edge Node level and at the Cluster Node level. It will be able also to give some statistics for the KPI on all DR events of one given year (e.g. distribution, mean, median, quartiles). The analysis will be able also to be done separately for the DR events corresponding to shedding order/incentive and for the DR events corresponding to shifting or rising order/incentive.

7.4 Frequency and duration

For KPIs calculation, the time step of data collection on each demonstration site will be taken into account. If the available data are not enough to carry out the evaluation, calibrated models will be taken into account. Further, the time step of the reference scenario should not be higher than the minimum duration of the DR events.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

8 Assessing climate resilience and climate flexibility

Becoming climate resilient is not possible without knowing about probable future climate. This requires considering multiple future climate scenarios in the assessment. Meanwhile, there is no standard approach to assess and/or design a climate resilient system since the topic is quite new and developing, especially in connection to future climate scenarios. The COLLECTiEF project focuses on assessing the climate resilient of the novel energy management system through conducting simulations and using multiple future climate scenarios out of regional climate models (RCMs), including extreme weather events on an hourly temporal resolution. In this regard, some approaches have been developed by the team members, e.g. [67,68], which will be adopted and/or developed further for the purpose of the COLLECTiEF project.

8.1 Objectives

6 Based on our recent studies for Stockholm, depending on the season and considering heating or cooling demand, CI-based control can increase the **demand flexibility between 24% to 58%** and **the agility of the system between 27% to 40%** (agility is an indicator to assess climate resilience and the recovery speed after/during shocks). By counting for extreme climate in the energy system design we can increase the **renewable energy penetration above 30%**.

Many studies confirm that climate change increases the frequency and magnitude of extreme events, which can cause significant disruptions in the built environment. The COLLECTiEF project places emphasis on this theme investigating the potential of the COLLECTiEF solution in coping with climate variations and extreme events.

8.2 Methodology

There exist many flexibility indicators, meanwhile very few are specifically defined in relation to climate, since the concepts of climate-flexibility/resilience are quite new. The team members are among the pioneers in the field who have brought up the need for addressing climate change and extremes in energy system design and control, providing a comprehensive review of climate flexibility [69] and resilience [19] in their previous works. There exist strong similarities between the flexibility and resilience concepts when the focus is the performance of the energy system in relation to climate variations. More than flexibility, the concept of resilience also shares some characteristics with stability, reliability and robustness, each having long history and multiple assessment approaches in the energy sector. When it comes to climate-resilience (and -flexibility), the KPIs should be defined based on the considered problem, system characteristics, desired improvement and/or critical measures. For example, Two KPIs are defined as the following when the desired solution is moving back to normal/typical energy profiles as soon as possible (i.e. gradual peak shaving in a collaborative manner).

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

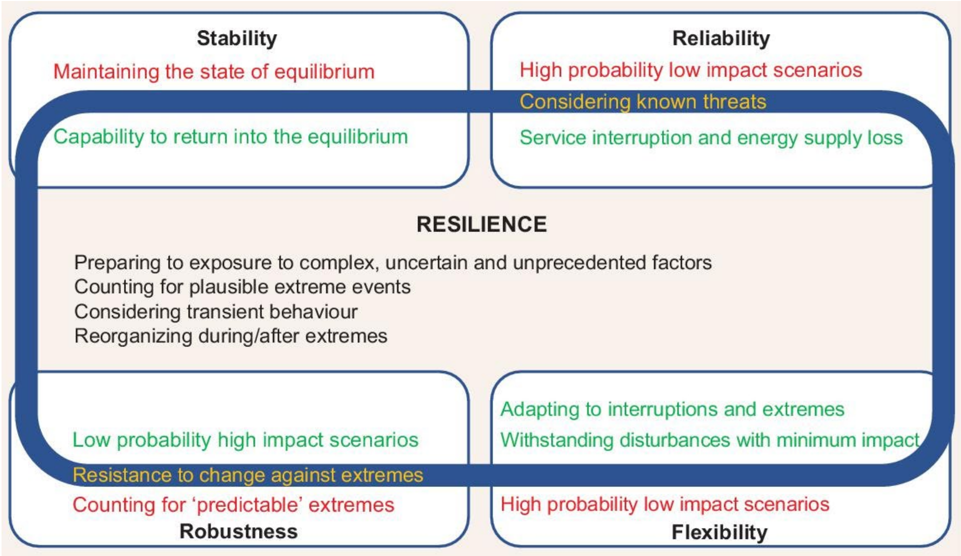


Figure 17 The specific characteristics of resilience (text in black) and its similarities (text in green and yellow) and differences (text in red) with stability, reliability, robustness and flexibility. The yellow texts on the border of resilience are not always considered in studying resilience (figure is from [19])

8.3 Metrics/KPIs and relevant parameters

Two main indicators have been identified to assess climate resilience and flexibility, namely, Demand Flexibility Factor (DFF) and Agility Factor (AF) [70].

Demand Flexibility Factor (DFF)

Demand flexibility is the potential of the CI-based system to reduce the energy demand (i.e. space heating and cooling demand) compared to the ordinary system (without CI control)

$$dff^t = \frac{E^t_{no\text{-}CI} - E^t_{CI}}{E^t_{no\text{-}CI}} = 1 - \frac{E^t_{CI}}{E^t_{no\text{-}CI}}$$

$$DFF = \sum_{t=1}^{t_{end}} \frac{dff^t}{t_{end}}$$

where dff^t [–] is the demand flexibility factor per time unit, $E^t_{no\text{-}CI}$ [kWh] is the energy demand at time t [h] when there is no CI-DSM and no adaptation measure is applied, and E^t_{CI} [kWh] is the demand at the same time when CI-DSM is working and applying the adaptation measures in the case of need. Energy demands are calculated for the same weather conditions which is the extreme weather scenario in this case. The maximum of dff^t, and DFF, can be one, which is the case when applying the adaptation measures results in zero energy demand.

The minimum should be zero when the adopted measures do not make any improvements, and the demand is at the same level of extreme conditions without any adaptation. However, if the adaptation measure is bad enough to work worse than the reference case (with no adaptation), dff^t can have negative values.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Agility Factor (AF)

Agility Factor (AF) is defined to assess how fast the adaptation measure helps the system to respond to extreme events and absorb the shock.

The agility factor is defined as the following:

$$af^{t+1} = 1 - \frac{abs\left(E^{t+1}_{extreme,CI} - E^{t+1}_{typical,no-CI}\right)}{abs\left(E^{t}_{extreme,CI} - E^{t}_{typical,no-CI}\right)}$$

$$AF = \sum_{t=2}^{t_{end}} \frac{af^t}{t_{end} - 1}$$

where af^{t+1} [–] is the agility factor per time unit, $E^{t+1}_{extreme,CI}$ [kWh] is the energy demand at time t + 1 [h] during extreme conditions when adaptation measures are applied using collective intelligence, and $E^{t+1}_{typical,no-CI}$ is the demand during typical conditions with no adaptation.

8.4 Frequency and duration

The frequency and duration depend on the assessed system, but in general the frequency in one hour and over one extreme cold/warm month (for different future climate scenarios).

8.5 Measurement of climate resilience before and after the implementation of the COLLECTiEF system

Since the focus is future climate resilience, most of the assessment will be performed on simulation basis. However, it is possible to investigate (and check with simulations) the resilience of the system during certain extreme cold/warm periods after implementation.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

9 Users' engagement

To support WP5 objectives, and its measurement and verification activities, procedures and methods, the stakeholder engagement activities planned under WP7 will provide a bottom up supporting system, making sure that building users (owners/managers, teachers, students, elderly, etc.) are well-aware of energy uses, the effectiveness of energy policies, the agile installation and maintenance of the COLLECTiEF system, as well as to capture their levels of comfort and satisfaction. In general, user engagement activities aim to **a)** in the first period, communicate the benefits and advantages compared to competitor/substitute technologies and provide evidence on its cost-effectiveness; **b)** gather participants and guarantee their involvement in the COLLECTiEF pilots; **c)** during and after the demonstration phase, communicate the benefits of the device in terms of energy efficiency and savings, its agile installation and maintenance to building users as well as decision makers and municipalities with the long-term ripple effect of having smarter and liveable communities; **d)** in the last phase, raise awareness on the benefits stemming from the CI-DSM system and providing user-friendly learning curricula on the maintenance and utilization of installations in each pilot.

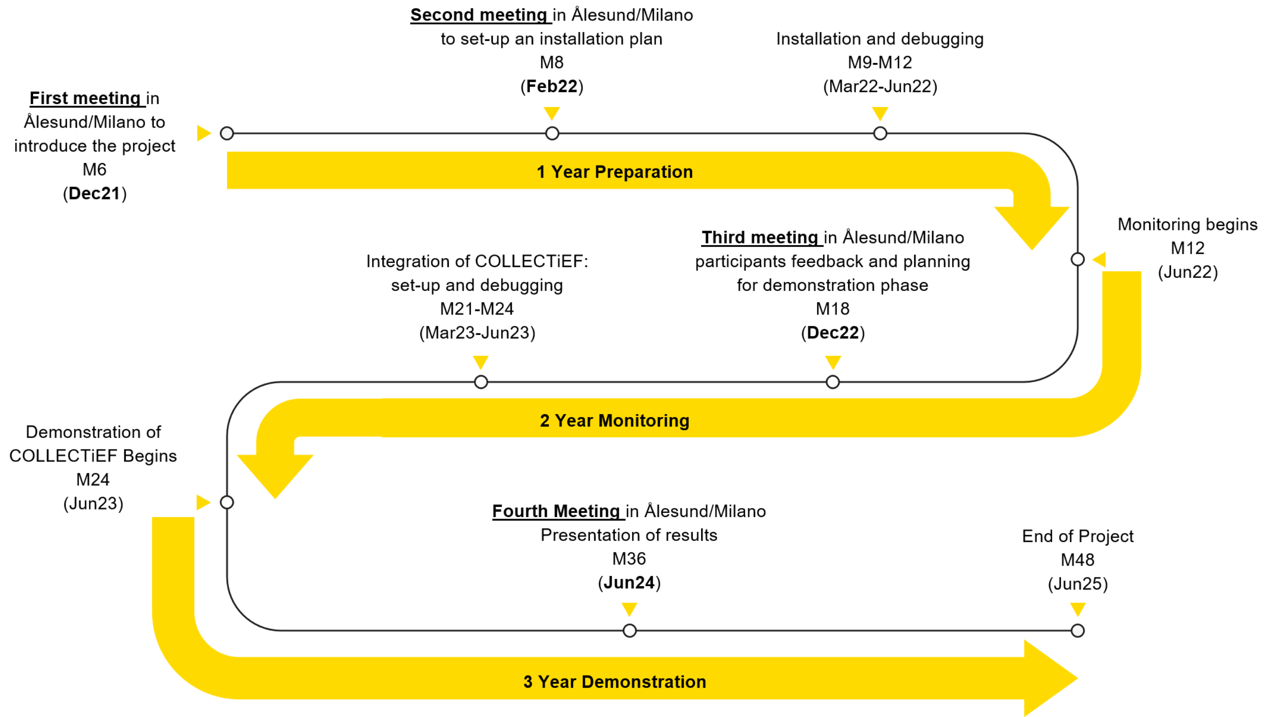


Figure 18 graphical representation of the path for users' engagement

Therefore, for phase 1 and 2, an important part plays the engagement of building users and flat owners in pilot sites. Relations between property and facilities managers and occupants contribute towards meeting compliance obligations and the achievement of wider project objectives. Our strategy involves a) clarifying the needs and expectations of occupants, b) explaining the functionality of our solutions, c) providing clear timelines for agile installation of the sensor and monitoring system, and d) explaining the benefits of COLLECTiEF solutions. It is also important to

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

establish communication and engagement methods that can be used to share information and evaluate the way in which these needs can be met. For instance, during the first meeting with building users and owners in Ålesund and Milan, a template of the feedback system (the survey) that will be used throughout the first year of the project was presented. The participants were encouraged to test the survey to get an idea of what it will entail once the system is implemented. Moreover, participants in the Italian pilot were engaged with an energy quiz, a nice icebreaker before opening the floor to questions.

In the first period, the building owner's engagement activities will consist of:

- Preparing printed communication materials – project materials have been translated in Norwegian and Italian by NTNU and TEICOS
- Preparing general presentation of the project (English, Norwegian and Italian)
- Preparing a project video to be displayed
- On-site meeting for presentation of the project - December 2021 in Milan and January 2022 Ålesund.
- Call for nomination – collecting interested flat owners to participate
- Setting up the installation plan

For the later stage, especially phase 3, a stakeholder database, which will be actively maintained and updated throughout the project, will support the scouting process of relevant stakeholders for the presentation of results. It will consist of relevant stakeholders and end-users such as public authorities, policy-makers, energy efficiency practitioners, smart energy storage companies, as well as umbrella and multiplier organizations. The stakeholder database will be compiled through: a) Partner contributions, b) "Associated Partners" and c) Newsletters.

As the piloting progresses, its achievements and results will be actively conveyed to the target groups through on-site activities and news articles. Future ad-hoc stakeholder engagement strategies will be similarly co-created with relevant partners, by also taking into consideration different target groups in pilot sites. For instance, building owners will be invited to COLLECTiEF exhibitions and stakeholder workshops and have access to e-Learning materials. Families, elderly, students, sport centre users will be engaged through eLearning materials, social media, gaming activities, and through local networks/platforms which will be used as multipliers.

The current strategy envisions a clear distribution of tasks:

- GEO will coordinate the tasks related to communication, such as preparation of communication materials, designing the printed consent form, post-engagement social media coverage, co-creation with TEICOS of engagement materials, translation of dissemination materials, update of stakeholder database;
- NTNU will coordinate scientific and bureaucratic tasks related to privacy issues and informed consent and coordinate building owner's engagement activities in Norway;

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

- TEICOS has a long-standing experience in engaging flat owners; therefore, TEICOS will share the methodology and best practices and coordinate building owner's engagement activities in Italy. The methodology will be adapted and replicated in Ålesund, Grenoble and Nicosia.

The engagement of users is being done in complete compliance with GDPR regulations. The Informed Consent Procedures that will be implemented for the participation of humans will be submitted as part of this deliverable. For more information, see chapter 9.1 where the Informed Consent Procedure is presented in detail.

9.1 Informed Consent Procedure

In the following it is reported the text of the Informed Consent Form to participate in the Post-Occupancy Evaluation survey and Building monitoring in COLLECTiEF. The underlined texts are the ones to be adjusted based on the case study.

Dear Madam/Sir,

We are conducting a European research project titled "*Collective Intelligence for Energy Flexibility*" (COLLECTiEF), Contract No. H2020-B4E-3-2020.101033683.
The Norwegian University of Science and Technology (Data Controller) is the institution coordinating the COLLECTiEF consortium that is composed of 14 partners from six European countries covering both academia and business. For the <u>Norwegian</u> pilot case studies, <u>Ålesund kommunale eigedom KF (ÅKE), as project partners (Data Processor)</u> is the local organization that provides support and is in charge of the project implementation and demonstration and interaction with the users.

This Informed Consent Form has two parts:

- **Information Sheet (to share information about the research with you)**
- **Certificate of Consent (for signatures if you agree to take part)**

You will receive a copy of the full Informed Consent Form.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Part I: Information Sheet

What is COLLECTiEF?

The COLLECTiEF project aims to upgrade the smartness of existing buildings and therefore reducing the annual energy cost, increasing user satisfaction. The COLLECTiEF methodology connects household appliances and energy systems in the building using the unique algorithms developed in the project.

We will test our solution and systems in 14 buildings across Europe to prove that they are efficient and adaptable to different climate zones. To achieve these goals, we need to monitor the case studies to collect data for energy consumption and production as well as the indoor environmental conditions. For this purpose, monitoring equipment (i.e., sensors) will be installed in selected spaces. The installed monitoring equipment is not expected to cause any discomfort and, in the remote case they may create any nuisances, we will promptly make all necessary adjustments to remove any disturbances. A survey called "Post Occupancy Evaluation (POE)" will further assist the suitability of designed and optimized solutions. This includes replying to standard questionnaires regarding how you feel about the indoor environmental conditions (e.g., thermal comfort, visual comfort etc.) and the usability of your building space. For monitoring purposes, a few environmental data will be collected: air temperature, relative humidity, CO_2 concentration, volatile organic compounds (VOC), particulate matter (PM), illuminance, and heating/cooling set point of specific rooms of the facility as well as the power consumption of lights, appliances, heating and cooling systems and the whole facility.

Why are you being asked to participate?

Being one of the occupants of the buildings participating in the project, we kindly ask you to fill out dedicated online surveys. Answers from the surveys and the data gathered from sensors will be used for the development and validation of smart control algorithms and for testing the overall occupants' satisfaction concerning the indoor physical environment. For this purpose, four patient rooms will be monitored at Eidet Omsorgsenteret. The rooms are selected based on the recommendations of the building management and nursing team.

What does your participation imply?

If you take part in the project, you are expected to fill out some online surveys. Your answers will be recorded electronically using a QR Code available in your space.
There will be **Brief surveys** that will take less than two minutes to be completed and **Satisfaction surveys** that will take about ten minutes to be completed. You should fill out the **Brief surveys twice a week at your convenient time**, not least because we need to establish the efficiency of the project at different times of the day and of the year. The **Satisfaction surveys need to be filled out once every second month**. What we are interested in are the subjective reactions of the participants while being in their living space to understand how to increase user experience. Replies to the questionnaires are administered and collected electronically and do not include any details which will identify a specific person and proper anonymization techniques are implemented to protect participant privacy according to the current regulations in force.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Participation is voluntary

Participation in the project is voluntary. At all times, you maintain the right to:

- access the personal data that is being processed about you,
- request that your personal data be deleted,
- request that incorrect personal data about you be corrected/rectified,
- receive a copy of your personal data (data portability)
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data.

We will ask your nurse to provide information and assist you in filling out the questionnaire on behalf of you. Your participation will not change your treatment at the care centre and your relationship with your nurse.

Your personal privacy is of a major importance

Although the data we collect focuses on energy performance and indoor environmental quality and, as such, does not fall under the category of sensitive data, there is nonetheless the potential for information to be derived from this data. Therefore, all necessary measures will be taken to ensure that any personal data or data which could be linked with individuals is adequately protected under data protection legislation (the General Data Protection Regulation and Personal Data Act). Concerning the collected data from POE and monitoring, these will be stored on a secured server at the Norwegian University of Science and Technology.

What will happen to your personal data at the end of the research project?

The project is scheduled to end on 31/05/2025. Only the project leader will know which room the data are linked to, and that other researchers in the project will only have access to anonymised data. The anonymous results of the project will be presented in scientific papers and conferences, or other non-commercial educational events. Any personally identifiable information will be removed, rewritten or categorized and the identification key will be deleted by the end of the project.

What gives us the right to process your personal data?

We will process your personal data based on your consent.

Based on an agreement with NTNU, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is following data protection legislation.

If you have questions about the project or want to exercise your rights, please, contact:

- The Data Controller: Norwegian University of Science and Technology via Amin Moazami, by email at amin.moazami@ntnu.no or by telephone at xxxxxx.
- The Data Processor: Ålesund kommunale eigedom KF (ÅKE)
- Our Data Protection Officer at the Norwegian University of Science and Technology:
- NSD – The Norwegian Centre for Research Data AS, by email:

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Part II: Certificate of Consent

I have received and understood information about the project COLLECTiEF through the Information Sheet and have been given the opportunity to ask questions. Any questions asked have been answered thoroughly and clearly.
I give freely and voluntarily consent:

- ☐ For participation, collection of data and data processing through POE survey and building monitoring.

By signing this document, I agree to participate in this project under the terms set out in the Information Sheet until the expected end date of the project, approx. 31/05/2025.

--------------------------------------- ---------------------------------------

(Signature of the participant) (date)

I also confirm that a copy of this Certificate of Consent and the Information Sheet has been provided.

(Signature of the participant)

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

10 Conclusions

The adoption of measurement and verification procedures allows to plan and properly execute all the activities which are necessary to verify that a building performs according to design expectations. The three phases of the protocol, namely, planning, installation and operation, have been detailed in the deliverable specifying the most relevant steps.

The COLLECTiEF M&V protocol requires to set a baseline period, i.e. a period of time selected as representative of the building before the implementation of the system. We chose to consider as baseline a full year (2nd year of the project) because of the weather-dependent loads affecting the results. After M24, it will be possible to evaluate the impacts twice (3rd and 4th year) and assess possible improvements after adapting and improving the algorithms developed during the project.

The information will be acquired through a measurement campaign at the flat level (edge node) while to assess the impacts at the building (or cluster of building) level, the Consortium plans to collect the data to calibrate the energy models of the pilots. Further, the simulation models will be exploited to test the algorithms at the edge and cluster node and assess the key performance indicators which cannot be calculated directly through measured data.

The deliverable describes the main features of the M&V plan in each pilot case, specifying the measurement equipment and its position in the buildings, the frequency and duration of the measurement campaign.

Also, it presents a set of key performance indicators and relevant metrics which need to be considered for the impact assessment.

Finally, the report highlights the central role of occupants and end-users in the development of the project presenting a section dedicated to users' engagement, where a clear path for their involvement and the informed consent procedure are described.

The plan of M&V for COLLECTiEF is particularly challenging since it affects different domains (building smartness, energy, indoor environmental quality, climate flexibility and resilience), which require different metrics, monitoring parameters, measurement equipment, frequency and duration of measurements. Moreover, the different intended use and end-users of the pilot buildings, require adjustments to address the specificity of each case study (from monitoring objectives to measurement instruments and post occupancy evaluations).

The phase of planning has been completed during the first year of the project and we are currently carrying out the installation of the measurement equipment necessary for monitoring the data during the baseline period.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

11 Annex 1 – Description of weather database for real weather conditions

Data sources

Mereen provides weather data from SYNOP and METAR weather reports from various source that archive theses reports defined by WMO (www.wmo.int). The main provider of these data is NOAA (https://www.ncdc.noaa.gov/cdo-web/datasets). Most other data source are mirroring NOAA.

Data Source	Description	Lien	Measured variables
MeteoFranceSynop	database of French weather institute MeteoFrance for a limited set of stations for SYNOP reports	Meteo France synop essentiel.	temp, dewpt, press_sta, wind_dir, wind_speed.
OgimetSynop	mirror base of NOAA operating from 2005 for SYNOP reports	www.ogimet.com	temp, dewpt, press_sta, wind_dir, wind_speed.
OgimetMetar	mirror base of NOAA operating from 2005 for METAR reports	www.ogimet.com	temp, dewpt, octa, press_sea, wind_dir, wind_speed.
IEMMetar	mirror base of NOAA operating from 2010 for METAR reports(IOWA university)	Metar IOWA university	temp, dewpt, octa, press_sea, wind_dir, wind_speed.
MERRA	NASA model of restrospective analysis on climate (used for solar radiation that are calculated from satellite observation)	gmao.gsfc.nasa.gov	GHI, GHIClearSky, TOA, ALBEDO.
SODA	solar radiation data from satellite observation provided by European Copernicus Atmosphere Monitoring Service. provides solar data for Europe/africa and asia	CAMS webservice site	TOA, GHIClearSky, BHIClearSky, DHIClearSky, BNIClearSky, GHI, BHI, DHI, BNI.
NOAASynopArchive	archive of NOAA from 1990 to today with both METAR and SYNOP weather reports.	NOAA archive	temp, dewpt, press_sta, wind_dir, wind_speed.

Services

Mereen can provide weather data with many options available. To simplify the user requests some of the configuration are preset in some "services" available below. If you desire to use more advanced features please use the API.

Name of the service	Description	API name
raw data	all raw data from mereen web service	raw_data_all
energy sim ready data	all data necessary for simulation including calculated variables from raw measured data	sim_ready_all
Degree Days	Degree days B21,B18,B26	dju
Degree hours	degree hours B21,B18,B26	dh
energy sim ready data EPW(EnergyPlus) format	all data necessary for simulation including calculated variables from raw measured data on EPW format	sim_ready_all_epw_format
energy sim ready data RAY format	all data necessary for simulation including calculated variables from raw measured data on ray format	sim_ready_all_ray_format
All results of Mereen	all data provided by mereen including epw and ray format files + calculation of extreme years.	sim_ready_all_post_processing

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Variables description

In this section there is a short description of all variables calculated in Mereen. The mention CALCULATED means the variable has been calculated from a model using some of the measured variables of Mereen but is not directly provided by any of the sources.

Sources	Description	
time	time in the format yyyy-mm-dd HH:MM:SS for the UTC timezone or local timezone if this option has been chosen.	
temp	outdoor temperature in °C	OgimetSynop, OgimetMetar, IEMMetar.
dewpt	dew point of the air in °C	OgimetSynop, OgimetMetar, IEMMetar.
octa	The fraction of the sky that is obscured by clouds, in eighths (one octa means that one eighth of the sky is obscured, two octas that one quarter is obscured, and so on)	OgimetMetar, IEMMetar.
press_sta	pression at station level in Pa	OgimetSynop.
press_sea	pression at sea level in Pa	OgimetMetar, IEMMetar.
wind_dir	direction of the wind in ° 0 is the true north and counting clockwise	OgimetSynop, OgimetMetar, IEMMetar.
wind_speed	wind speed in m/s	OgimetSynop, OgimetMetar, IEMMetar.
hr	relative humidity in % (can be calculated instead of direct measure)	calculated or measured.
ha	absolute humidity in g(water)/Kg(air) (always calculated)	
TOA	Top of Atmosphere global irradiance in W/m2	MERRA, SODA.
GHIClearSky	Global Horizontal Irradiance in clear sky conditions in W/m²	MERRA, SODA.
BHIClearSky	Direct Horizontal Irradiance in clear sky conditions in W/m²(can be calculated)	SODA, calculated or measured.
DHIClearSky	Diffuse Horizontal Irradiance in clear sky conditions in W/m²(can be calculated)	SODA, calculated or measured.
BNIClearSky	Direct Normal Irradiance in clear sky conditions in W/m²(can be calculated)	SODA, calculated or measured.
GHI	Global Horizontal Irradiance in W/m²	MERRA, SODA.
BHI	Direct Horizontal Irradiance in W/m²(can be calculated)	SODA, calculated or measured.
DHI	Diffuse Horizontal Irradiance in W/m²(can be calculated)	SODA, calculated or measured.
BNI	Direct Normal Irradiance in W/m²(can be calculated)	SODA, calculated or measured.
ALBEDO	albedo factor (SU)	MERRA.
sun_azimuth	azimuth of sun in degree (°)(CALCULATED)	CALCULATED.
sun_height	height of sun in degree (°)(CALCULATED)	CALCULATED.
KT	The Clearness Index Kt is defined as the ratio of the horizontal global irradiance to the corresponding irradiance available out of the atmosphere(CALCULATED)	CALCULATED.
BINorth	Direct Irradiance on an vertical plane on the North face (0°) in W/m2 (CALCULATED)	CALCULATED.
DINorth	Diffuse Irradiance on an vertical plane on the North face (0°) in W/m2 (CALCULATED)	CALCULATED.
BISouth	Direct Irradiance on an vertical plane on the South face (180°) in W/m2 (CALCULATED)	CALCULATED.
DISouth	Diffuse Irradiance on an vertical plane on the South face (180°) in W/m2 (CALCULATED)	CALCULATED.
BIWest	Direct Irradiance on an vertical plane on the West face (270°) in W/m2 (CALCULATED)	CALCULATED.
DIWest	Diffuse Irradiance on an vertical plane on the West face (270°) in W/m2 (CALCULATED)	CALCULATED.
BIEast	Direct Irradiance on an vertical plane on the East face (90°) in W/m2 (CALCULATED)	CALCULATED.
DIEast	Diffuse Irradiance on an vertical plane on the East face (90°) in W/m2 (CALCULATED)	CALCULATED.
GINorth	Global Irradiance on an vertical plane on the North face (0°) in W/m2 (CALCULATED)	CALCULATED.
GISouth	Global Irradiance on an vertical plane on the South face (180°) in W/m2 (CALCULATED)	CALCULATED.
GIWest	Global Irradiance on an vertical plane on the West face (270°) in W/m2 (CALCULATED)	CALCULATED.
GIEast	Global Irradiance on an vertical plane on the East face (90°) in W/m2 (CALCULATED)	CALCULATED.
RI	Reflective Irradiance in W/m2 (CALCULATED)	CALCULATED.
Tsky	temperature of the sky in °C (CALCULATED)	CALCULATED.
Tground100cm	temperature of the ground at 100cm of depth in °C (CALCULATED)	CALCULATED.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

12 Annex 2 – Primary Energy Factors (PEF) in the Pilots' countries

In this section are reported the primary energy factors for each energy carrier in the different pilots' countries.

Italy

Table 38 Primary energy factors chosen by the Italian Legislator [Source: DM 26/6/15, Ann. 1, Art.1.1]. $f_{P,TOT}$ = total primary energy factor, $f_{P,REN}$ = renewable primary energy factor, $f_{P,NREN}$ = non-renewable primary energy factor.

Energy carrier	$f_{P,NREN}$	$f_{P,REN}$	$f_{P,TOT}$
Natural gas	1.05	0	1.05
GPL	1.05	0	1.05
Fuel oil	1.07	0	1.07
Coal	1.1	0	1.1
Solid biomass	0.2	0.8	1
Liquid and gaseous biomass	0.4	0.6	1
Electric energy **from** the grid	1.95	0.47	2.42
District heating	1.5	0	1.5
Municipal solid waste	0.2	0.2	0.4
District cooling	0.5	0	0.5
Thermal energy from solar collectors	0	1	1
Electric energy produced by photovoltaic, small scale wind/hydro electricity (self-consumption)	0	1	1
Electric energy produced by photovoltaic, small scale wind/hydro electricity (export **to** the grid).	0	1 (only to counterbalance consumption in the same month, NOT in the entire year)	1 (only to counterbalance consumption in the same month, NOT in the entire year)
Thermal energy from the external environment - Free cooling	0	1	1
Thermal energy from the external environment - Heat pump	0	1	1

France

Table 39 Possible values of primary energy factors in France, updated from [71]

Energy carrier	$f_{P,NREN}$*	$f_{P,REN}$*	$f_{P,TOT}$*
Natural gas	1	0	1
GPL	1	0	1

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Fuel oil	1	0	1
Coal	1	0	1
Solid biomass	1	0	1
Liquid and gaseous biomass	1	0	1
Electric energy from the grid	2.3	0	2.3
District heating	1	0	1
Municipal solid waste	1	0	1
District cooling	1	0	1
Thermal energy from solar collectors	0	1	1
Electric energy produced by photovoltaic, small scale wind/hydro electricity (self-consumed)	0	2.58	2.58
Electric energy produced by photovoltaic, small scale wind/hydro electricity (exported to the grid)	0	1	1
Thermal energy from the external environment - Free cooling	0	1	1
Thermal energy from the external environment - Heat pump	0	1	1
Solid biomass (pellets)	1	0	1

Table 40 Possible Primary energy factors in Cyprus chosen by [72] and [73]. $f_{P,TOT}$ = total primary energy factor, $f_{P,REN}$ = renewable primary energy factor, $f_{P,NREN}$ = non-renewable primary energy factor.

Energy carrier	$f_{P,NREN}$	$f_{P,REN}$	$f_{P,TOT}$
Natural gas	0	0	0
GPL	1.1	0	1.1
Fuel oil	1.1	0	1.1
Coal	0	0	0
Solid biomass	0.01- 1.10	0	0.01- 1.10
Liquid and gaseous biomass	0.01- 1.10	0	0.01- 1.10
Electric energy **from** the grid	2.7	0	2.7
District heating	0	0	0
Municipal solid waste	0.34	0	0.34
District cooling	0	0	0
Thermal energy from solar collectors	0	1	1
Electric energy produced by photovoltaic, small scale wind/hydro electricity (self-consumption)	0	1	1
Electric energy produced by photovoltaic, small scale wind/hydro electricity (export **to** the grid).	0	1	1

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Thermal energy from the external environment - Free cooling	0	1	1
Thermal energy from the external environment - Heat pump	0	1	1

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

13 Annex 3 – Electricity Tariff and Grid Rent Pricing in Norway

Table 41 Electricity Tariff (excluding taxes) for business and other consumption from 01.04.2022 [74]

Electricity Tariff for Industry and Other Consumption				
Tariff	Energy Measured systems with power limitation through main fuse / overload protection		Fixed (€./year)	Energy Level (€ cent /kWh)
	230 volt	400 volt		
T40	2 x 25 ampere / 3 x 16 ampere	3 x 16 ampere	90	2.01
T41	3 x 63 ampere	3 x 40 ampere	2 90	2.01
T42	3 x 80 ampere	3 x 63 ampere	4 40	2.01
T43	3 x 160 ampere	3 x 125 ampere	7 15	2.01

Table 42 Grid rent for business consumers [32]

Group	Fixed joint (€/year)	Energy joint sommar (€ cent /kWh)	Energy-linked winter (€ cent /kWh)	Power joint sommar (€/kW/mo)	Power joint winter (€/kW/mo)
Main fuse ≤ 80 Amps	280	1.5	1.5	-	-
Main fuse > 80 Amps	480	1.5	1.5	-	-
Annual consumption > 100 000 kWh	880	0.3	0.47	17	40
High voltage system	2080	0.24	0.41	17	40
Flexible consumption barn tension	880	0.3	0.470	6	14
Flexible consumption high voltage	2080	2.40	4.10	9	22

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

14 Annex 4 – Pilot Installation: monitoring specifications

Norway

Country	Name	Occupancy info	Zone area (m2)	Floor number	Nominal number of people	Building number	Type of Sphensors to be installed	Monitoring parameters
NORWAY	Eidet Omsorgsenter	Patient room, elderlies	21.7	2	1	B01	423	CO2, VOC, PM1,2.5,4,10
						B01	401	T_air, RH
		Patient room, elderlies	21.7	2	1	B01	423	CO2, VOC, PM1,2.5,4,10
						B01	401	T_air, RH
		Patient room, elderlies	21.7	2	1	B01	423	CO2, VOC, PM1,2.5,4,10
						B01	401	T_air, RH
		Patient room, elderlies	21.7	2	1	B01	423	CO2, VOC, PM1,2.5,4,10
						B01	401	T_air, RH
		Shared office, Nurses	10.9	2	5	B01	423	CO2, VOC, PM1,2.5,4,10
						B01	402	T_air, RH, Illuminance
	Ellingsøy Idrettshall	Main Hall (25m* 45m) -	1167.3	1	NA	B02	423	CO2, VOC, PM1,2.5,4,10
						B02	401	T_air, RH
						B02	423	CO2, VOC, PM1,2.5,4,10
						B02	401	T_air, RH
						B02	423	CO2, VOC, PM1,2.5,4,10
						B02	401	T_air, RH
		Dance room (98.9 m2) + social room (39.9 m2).	138.8	2	NA	B02	423	CO2, VOC, PM1,2.5,4,10
						B02	401	T_air, RH
						B02	423	CO2, VOC, PM1,2.5,4,10
						B02	401	T_air, RH
	Flisnes Barneskole	Classroom, 6-12 years old	?	1	?	B03	423	CO2, VOC, PM1,2.5,4,10
						B03	402	T_air, RH, Illuminance
		Classroom, 6-12 years old	?	1	?	B03	423	CO2, VOC, PM1,2.5,4,10
						B03	402	T_air, RH, Illuminance
	Hatlane Omsorgsenter	Patient room, elderlies	23.0	2	1	B04	423	CO2, VOC, PM1,2.5,4,10
						B04	401	T_air, RH
		Patient room, elderlies	23.0	2	1	B04	423	CO2, VOC, PM1,2.5,4,10
						B04	401	T_air, RH
		Patient room, elderlies	23.0	2	1	B04	423	CO2, VOC, PM1,2.5,4,10
						B04	401	T_air, RH
		Patient room, elderlies	22.8	2	1	B04	423	CO2, VOC, PM1,2.5,4,10
						B04	401	T_air, RH
		Shared office, Nurses	29.4	2	5	B04	423	CO2, VOC, PM1,2.5,4,10
						B04	402	T_air, RH, Illuminance
	Moa Helsehus	Shared office, Nurses	21.0	1	3	B05	423	CO2, VOC, PM1,2.5,4,10
						B05	402	T_air, RH, Illuminance
		Shared office, Reception	16.4	1	3	B05	423	CO2, VOC, PM1,2.5,4,10
						B05	402	T_air, RH, Illuminance
		Shared office, Nurses	?	2	?	B05	423	CO2, VOC, PM1,2.5,4,10
						B05	402	T_air, RH, Illuminance
		Break room (checking SBS	27.2	1	NA	B05	423	CO2, VOC, PM1,2.5,4,10
						B05	401	T_air, RH
		Individual offices (nurses, doctor, phsychologist,...)		1	1	B05	402	T_air, RH, Illuminance
		Individual offices (nurses, doctor, phsychologist,...)		1	1	B05	402	T_air, RH, Illuminance
	Spjelkavik Ungdomsskole	Classroom, 13-15 years old	74.2	2	28 students + 1 teacher	B06	423	CO2, VOC, PM1,2.5,4,10
						B06	402	T_air, RH, Illuminance
		Classroom, 13-15 years old	73.6	2	28 students + 1 teacher	B06	423	CO2, VOC, PM1,2.5,4,10
						B06	402	T_air, RH, Illuminance
		Classroom, 13-15 years old	71.5	2	28 students + 1 teacher	B06	423	CO2, VOC, PM1,2.5,4,10
						B06	402	T_air, RH, Illuminance
		Classroom, 13-15 years old	78.2	2	28 students + 1 teacher	B06	423	CO2, VOC, PM1,2.5,4,10
						B06	402	T_air, RH, Illuminance
		Shared office, Teachers	86.0	2	9	B06	423	CO2, VOC, PM1,2.5,4,10
						B06	402	T_air, RH, Illuminance
	Tennfjord Barneskole	Classroom, 6 years old	78.0	1	13-25 students + 1 teacher	B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance
		Classroom, 7 years old	55.6	1	13-25 students	B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance
		Classroom, 8 years old	56.3	1	13-25 students	B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance
		Classroom, 9 years old	56.3	1	13-25 students	B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance
		Classroom, 10 years old	56.3	1	13-25 students	B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance
		Classroom, 11 years old	57.0	1	13-25 students	B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance
		Shared office, Teachers	61.0	1	15	B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance
						B07	423	CO2, VOC, PM1,2.5,4,10
						B07	402	T_air, RH, Illuminance

France

France	G2ELab	Shared office	25.0	4	4	B08	402	T_air, RH, Illuminance
		Shared office	18.5	4	1	B08	402	T_air, RH, Illuminance
		Shared office	19.0	4	3	B08	402	T_air, RH, Illuminance
		Shared office	18.5	4	3	B08	402	T_air, RH, Illuminance
		Shared office	27.5	4	3	B08	402	T_air, RH, Illuminance
		Student Hall	42.0	4	3	B08	402	T_air, RH, Illuminance
		Classroom	78.5	4	25-34	B08	423	CO2, VOC, PM1,2.5,4,10
						B08	402	T_air, RH, Illuminance
		Laboratory	63.5	4	3	B08	423	CO2, VOC, PM1,2.5,4,10
						B08	402	T_air, RH, Illuminance

Cyprus

Cyprus	Guy Ourisson Building (GOB)	Shared office, Post-docs (30-40 y)	25.4	G	5	B09	423	CO2, VOC, PM1,2.5,4,10
						B09	402	T_air, RH, Illuminance
		Shared office, Post-docs (30-40 y)	27.6	1	5	B09	423	CO2, VOC, PM1,2.5,4,10
						B09	402	T_air, RH, Illuminance
		Shared office, Post-docs (30-40 y)	28.8	1	6	B09	423	CO2, VOC, PM1,2.5,4,10
						B09	402	T_air, RH, Illuminance
		Individual office, 40 y	20.4	1	1	B09	402	T_air, RH, Illuminance
		Individual office, 40 y	19.3	G	1	B09	402	T_air, RH, Illuminance
		Individual office, 50 y	17.5	G	1	B09	402	T_air, RH, Illuminance
		Individual office, 50 y	20.4	G	1	B09	402	T_air, RH, Illuminance
	Graduate School (GS)	Classroom, Graduate studenst and teachers	44.6	G	12	B10	423	CO2, VOC, PM1,2.5,4,10
						B10	402	T_air, RH, Illuminance
		Meeting room	28.9	G	7	B10	423	CO2, VOC, PM1,2.5,4,10
						B10	402	T_air, RH, Illuminance
		Individual office, Adult - F	13.9	G	1	B10	402	T_air, RH, Illuminance
		Shared office, PhD students (23-30 y)	79.8	1	16	B10	423	CO2, VOC, PM1,2.5,4,10
						B10	423	CO2, VOC, PM1,2.5,4,10
						B10	402	T_air, RH, Illuminance
		Shared office, PhD Students (23-30 y)	24.3	1	5	B10	423	CO2, VOC, PM1,2.5,4,10
						B10	402	T_air, RH, Illuminance
	Novel Technologies Laboratory (NTL)	laboratory activity	112.2	G	18	B11	423	CO2, VOC, PM1,2.5,4,10
						B11	402	T_air, RH, Illuminance
		laboratory activity	140.0	2	14	B11	423	CO2, VOC, PM1,2.5,4,10
						B11	402	T_air, RH, Illuminance
		Individual office	8.3	1	1	B11	402	T_air, RH, Illuminance
		Individual office	8.3	2	1	B11	402	T_air, RH, Illuminance
		Shared office	44.1	1	9	B11	423	CO2, VOC, PM1,2.5,4,10
						B11	402	T_air, RH, Illuminance
		Shared office	16.3	G	3	B11	423	CO2, VOC, PM1,2.5,4,10
						B11	402	T_air, RH, Illuminance

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

Italy

Italy	C2 Tower	1A	Private apartment, living room	18.2	1	min:1; max:4/5	B12	401	T_air, RH
			Private apartment, bed room	18.8	1		B12	401	T_air, RH
		3B	Private apartment, living room	25.0	5	min:1; max:4/5	B12	401	T_air, RH
							B12	423	CO2, VOC, PM1,2.5,4,10
			Private apartment, bed room	17.5	5		B12	401	T_air, RH
		3C	Private apartment, living room	22.1	3	min:1; max:4/5	B12	401	T_air, RH
			Private apartment, bed room	15.3	3		B12	401	T_air, RH
		3D	Private apartment, living room	24.1	3	min:1; max:4/5	B12	401	T_air, RH
							B12	423	CO2, VOC, PM1,2.5,4,10
			Private apartment, bed room	18.7	3		B12	401	T_air, RH
		8A	Private apartment, living room	18.2	8	min:1; max:4/5	B12	401	T_air, RH
			Private apartment, bed room	18.8	8		B12	401	T_air, RH
	C3 Tower	1B	Private apartment, living room	25.0	1	min:1; max:4/5	B13	401	T_air, RH
			Private apartment, bed room	17.5	1		B13	401	T_air, RH
		3B	Private apartment, living room	25.0	3	min:1; max:4/5	B13	401	T_air, RH
							B13	423	CO2, VOC, PM1,2.5,4,10
			Private apartment, bed room	17.5	3		B13	401	T_air, RH
		5C	Private apartment, living room	22.1	5	min:1; max:4/5	B13	401	T_air, RH
			Private apartment, bed room	15.3	5		B13	401	T_air, RH
		7A	Private apartment, living room	18.2	7	min:1; max:4/5	B13	401	T_air, RH
							B13	423	CO2, VOC, PM1,2.5,4,10
			Private apartment, bed room	18.8	7		B13	401	T_air, RH
	C4 Tower	1C	Private apartment, living room	22.1	1	3	B14	401	T_air, RH
							B14	423	CO2, VOC, PM1,2.5,4,10
			Private apartment, bed room	18.8	1		B14	401	T_air, RH
		2B	Private apartment, living room	25.0	2	2	B14	401	T_air, RH
							B14	423	CO2, VOC, PM1,2.5,4,10
			Private apartment, bed room	17.5	2		B14	401	T_air, RH
		4C	Private apartment, living room	22.1	4	3	B14	401	T_air, RH
			Private apartment, bed room	18.8	4		B14	401	T_air, RH

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

15 Annex 5 – Post Occupancy Evaluations: the Brief questionnaire (DRAFT)

The questions

NOTE FOR PARTICIPANTS: The questionnaire is fully anonymized, and the experimental design is randomized, therefore NO data is related to the individual person. Therefore, every time you answer this questionnaire, we need to acquire few information to contextualize your feedback. Thank you for your understanding and precious support.

SECTION 1: Personal information

(purpose: understanding potential differences in thermal comfort perception, use of systems)

1.1. Gender

❑ Female

❑ Male

❑ Non binary

❑ Don't want to answer

1.2. Age

❑ < 18 years

❑ 18 – 24 years

❑ 25 – 34 years

❑ 35 – 44 years

❑ 44 – 64 years

❑ > 65 years

1.3. Body dimension

❑ < 18,5 (underweight)

❑ 18,5 – 24,9 (normal)

❑ 25 – 29,9 (overweight)

❑ 30 – 34,9 (obese)

❑ > 35 (extremely obese)

SECTION 2:
(purpose: understanding if individual factors may affect the thermal response of a person)

2.1. How do you feel now?

❑ I'm healthy and strong

❑ I'm tired

❑ I fell sick

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

2.2. Which ensemble best describe your clothing right now?

2.3. Which activity better describes what you are doing now?

2.4. Are you alone in this moment?

❑ Yes

❑ No

2.5. Are you a worker or user of the sport facility?

SECTION 3: thermal comfort assessment

(purpose: assessment of the thermal environment)

3.1. At this precise moment, would you prefer the room temperature to be … ?

3.2. How do you judge the room temperature on a personal level?

3.3. At this precise moment, how do you find the room temperature?

3.4. At this precise moment, how do you perceive the room temperature?

3.5. At this precise moment, would you prefer the humidity to be … ?

3.6. How do you judge the humidity on a personal level?

3.7. At this precise moment, how do you find the humidity?

3.8. How would you best describe the source or sources of discomfort if any?

❑ Air movement is too low

❑ Air movement is too high

❑ Stuffy air

❑ Too much daylight

❑ Lack of daylight

❑ Glare

❑ Temperature is too high

❑ Temperature is too low

❑ Humidity is too high (damp)

❑ Humidity is too low (dry)

❑ Background noise too high

❑ Noise from ventilation system

SECTION 4: Set rules to extract annotations from the Sphensors timestamps

❑ Season (spring, summer, autumn, winter)

❑ Sunlight availability (dark semester, light semester)

❑ Period of the day (morning, afternoon, night)

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

16 Annex 6 – POE Brief questionnaire with designed graphics (DRAFT)

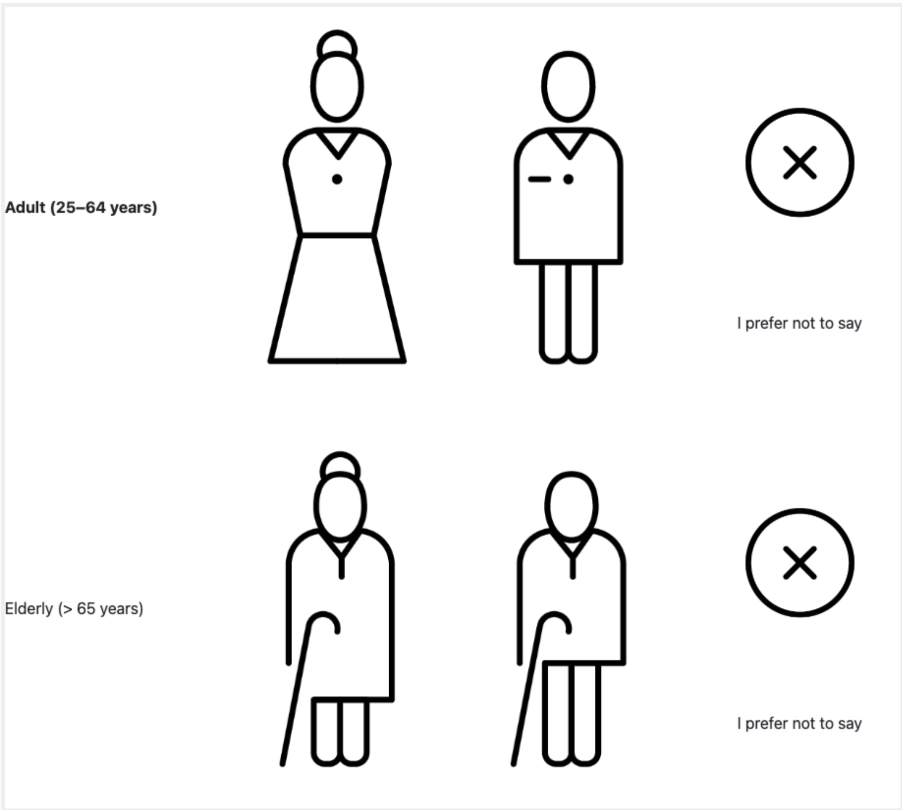
In collaboration with the Partener Geonardo, specific graphics are under preparation for POE questionnaires. In the following, a draft of the Brief questionnaire for Health care buildings is reported.

POE Questionnaire 1

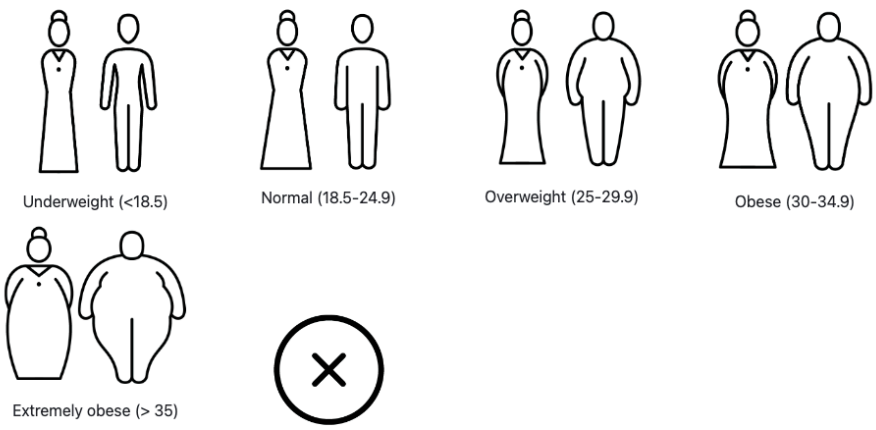
Test questionnaire for Health care buildings

Personal information

1. Hello! Who are you?



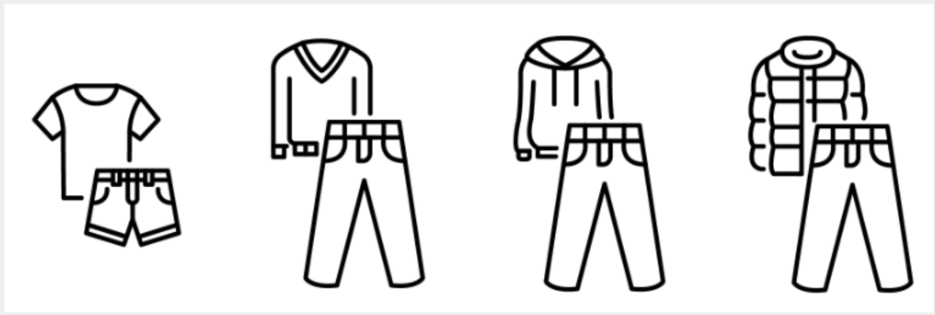
2. Body dimension



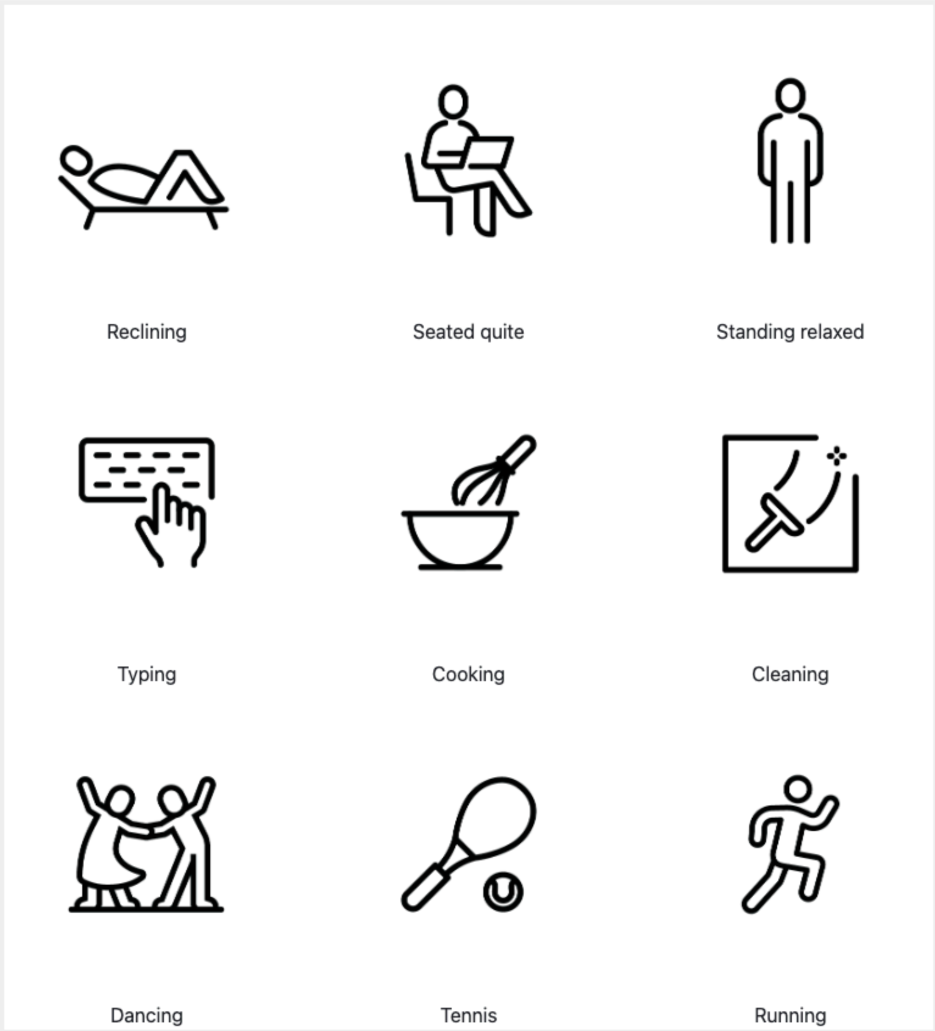
This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

I prefer not to say

3. Which ensemble best describe your clothing right now?



4. Which activity better describes what you are doing now?



This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

5. How do you feel now?

I'm healthy and strong | I'm tired | I feel sick

6. At this precise moment, would you prefer the room temperature to be ... ?

Lower | Without change | Higher

7. How do you judge the room temperature on a personal level?

Clearly unacceptable | Just unacceptable | Just acceptable | Clearly acceptable

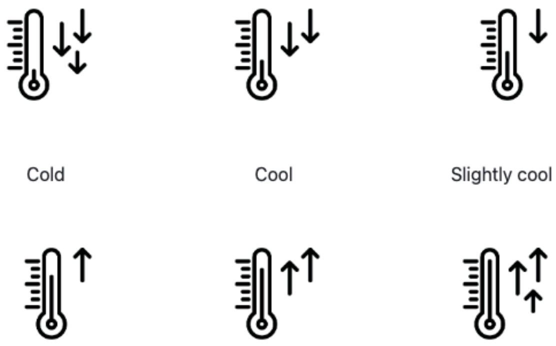
8. At this precise moment, how do you find the room temperature?

Very uncomfortable | Very uncomfortable | Uncomfortable | Slightly uncomfortable

Comfortable

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

9. At this precise moment, how do you perceive the room temperature?



Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot

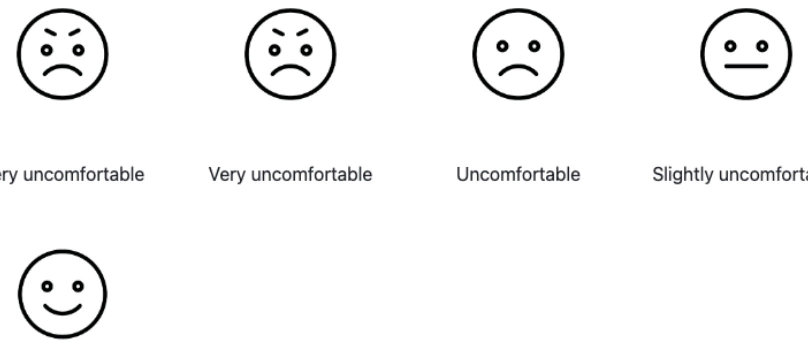
10. At this precise moment, would you prefer the humidity to be ... ?

Lower | Without change | Higher

11. How do you judge the humidity on a personal level?

Clearly unacceptable | Just unacceptable | Just acceptable | Clearly acceptable

12. At this precise moment, how do you find the humidity?



Very uncomfortable | Very uncomfortable | Uncomfortable | Slightly uncomfortable | Comfortable

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

13. How would you best describe the source or sources of discomfort if any?

- ☐ Air movement is too low
- ☐ Air movement is too high
- ☐ Stuffy air
- ☐ Too much daylight
- ☐ Lack of daylight
- ☐ Glare
- ☐ Temperature is too high
- ☐ Temperature is too low
- ☐ Humidity is too high (damp)
- ☐ Humidity is too low (dry)
- ☐ Background noise too high
- ☐ Not enough sound privacy
- ☐ Noise from ventilation system

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

17 Annex 7 – Post Occupancy Evaluations: the Satisfaction questionnaire (DRAFT)

The questions

NOTE FOR PARTICIPANTS: The questionnaire is fully anonymized, and the experimental design is randomized, therefore NO data is related to the individual person. Therefore, every time you answer this questionnaire, we need to acquire few information to contextualize your feedback. Thank you for your understanding and precious support.

SECTION 1: Personal information

(purpose: understanding potential differences in thermal comfort, use of systems)

1.4. Are you a worker or user of the sport facility?

0.2 Are you alone in the shared office?

1.1. Gender:

❑ Male

❑ Female

❑ Other

1.2. Age:

❑ < 18

❑ 18 – 24

❑ 25 – 34

❑ 35 – 44

❑ 45 – 64

❑ > 65

1.3. Education: number of years

❑ 0-6 (primary)

❑ 6-12 (secondary)

❑ 12-16 (professional or undergraduate academic, bachelor's)

❑ >16 (graduate academic, master's, higher)

1.4. Occupation – current or until retirement

❑ Researcher (pls specify field of expertise)

❑ Student (pls specify field of expertise)

❑ Laboratory technician (pls specify field of expertise)

❑ Office/clerical

❑ Maintenance

❑ Housekeeping/home maker

❑ Other – please specify…………………….

1.5. Health – Are you usually healthy or do you suffer of some chronic condition?

❑ Usually healthy

❑ Chronic condition – please specify…………………….

1.6. Which activity better describes what you typically do in this building?

SECTION 2: Perception of your indoor space and its impacts

(purpose: understand the perceived impact of the building quality and the indoor environment on people's health and wellbeing)

2.1. In the following list, mark any symptoms you experience after 4 hours at work / at home you're your room (you may mark more than one):

❑ Fatigue

❑ Sleepiness

❑ Eye irritation

❑ Headache

❑ Nose irritation

❑ Dry skin

❑ Sore throat

2.2. Are the symptoms you marked usually relieved when you leave the building / change room?

❑ Yes

❑ No

2.3. Please highlight your level of satisfaction with the aspects:

Ventilation:	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied
Temperature and humidity	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied
Noise: (1)	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied
Lighting:	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied
Odors: (2)	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

(1) It refers only to equipment noise (refrigerator, PC, fluorescent tubes etc.) or outside noises
(2) Odors from dust, mold, bathrooms or carpets

2.4. How would you best describe the source or the sources of discomfort, if any?

❑ Temperature is too high

❑ Temperature is too low

❑ Humidity is too high (damp)

❑ Humidity is too low (dry)

❑ Air movement is too low

❑ Air movement is too high

❑ Stuffy air

❑ Too much daylight

❑ Lack of daylight

❑ Glare

❑ Background noise too high

❑ Noise from ventilation system

2.5. Do you use one or more of the following options to adjust the environmental quality indoors?

❑ Open/close the window(s)

❑ Open/close the door(s)

❑ Switch on/off ceiling/desk fan

❑ Regulate the heating or air conditioning of the room

❑ Adjust windows blinds or shades

❑ Switch on/off the lighting

❑ Add/remove clothing layer

❑ Drink hot/cold beverage

❑ Plugged-in local/personal cooler/heater

❑ Others - Specify……………….

❑ You have no control

2.6. If you use one of the above options to adjust the indoor environment – does it make any difference?

❑ Only to thermal comfort

❑ Only to air quality

❑ Only to visual comfort

❑ To more than one comfort aspects

❑ To all

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

❑ It makes no difference

2.7. How satisfied are you with your working environment or building?

Overall satisfaction:	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied

State the reason/feature that affects your answer the most:

………………………………………………………………………………………………...

SECTION 3: Verification questions

…

SECTION 4: Annotations and long-term metrics

4.1. Calculate long-term metrics from monitored data

❑ Air temperature and Relative humidity

❑ Ambient temperature and Relative humidity

❑ Global irradiance on a horizontal plane

❑ …

4.2. Set rules to extract annotations from the Sphensors timestamps:

❑ Season (spring, summer, autumn, winter)

❑ Sunlight availability (dark semester, light semester)

❑ Period of the day (morning, afternoon, night)

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

18 Reference

[1] Burman E, Mumovic D, Kimpian J. Towards measurement and verification of energy performance under the framework of the European directive for energy performance of buildings. Energy 2014;77:153–63. https://doi.org/10.1016/j.energy.2014.05.102.

[2] International performance measurement and verification protocol. Available from: Concepts and options for determining energy and water savings, vol. 1, International Performance Measurement and Verification Protocol Committee. http://www.evo-world.org. Efficiency Valuation Organisation website (IPMVP Public Library of Documents). (Accessed on 3 July 2021). 2002.

[3] American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Guideline 14-2014. Measurement of Energy, Demand, and Water Savings. 2014.

[4] International Performance Measurement & Verification Protocol. Concepts and Practices for Improved Indoor Environmental Quality. 2002.

[5] Association of Edison Illuminating Companies. Demand Response Measurement & Verification 2009.

[6] Directive (EU) 2018/844 of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. n.d.

[7] European Commission, Directorate-General for Energy, Verbeke, S., Aerts, D., Reynders, G., et al., Final report on the technical support to the development of a smart readiness indicator for buildings : final report, Publications Office, 2020, https://data.europa.eu/doi/10.2833/41100 n.d.

[8] BS EN 15232-1:2017. Energy Performance of Buildings. Part 1: Impact of Building Automation, Controls and Building Management Modules M10-4,5,6,7,8,9,10. n.d.

[9] ISO 52000-1: Energy performance of buildings – Overarching EPB assessment – Part 1: General framework and procedures. 2017.

[10] International Organization for Standardization. ISO 15927-6:2007. Hygrothermal performance of buildings - Calculation and presentation of climatic data Accumulated temperature differences (degree-days). 2007.

[11] ANSI/ASHRAE Standard 55-2020. Thermal Environmental Conditions for Human Occupancy. 2020.

[12] European Committee for Standardization. EN 16798-1 - Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6. 2019.

[13] International Standard Organization. ISO 7730:2005. Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. 2005.

[14] European Committee for Standardization, ISO. EN ISO 7726:2001 - Ergonomics of the thermal environment - Instruments for measuring physical quantities. 2001.

[15] Jensen SØ, Marszal-Pomianowska A, Lollini R, Pasut W, Knotzer A, Engelmann P, et al. IEA EBC Annex 67 Energy Flexible Buildings. Energy Build 2017;155:25–34. https://doi.org/10.1016/j.enbuild.2017.08.044.

[16] U.S. Energy Information Administration. https://www.eia.gov/tools/glossary/index.php?id=D n.d.

[17] Boisson P. Et al. Demand response in blocks of buildings deliverable: D5.1 monitoring and validation strategies. 2017.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

[18] Reynders G, Amaral Lopes R, Marszal-Pomianowska A, Aelenei D, Martins J, Saelens D. Energy flexible buildings: An evaluation of definitions and quantification methodologies applied to thermal storage. Energy Build 2018;166:372–90. https://doi.org/10.1016/j.enbuild.2018.02.040.
[19] Nik VM, Perera ATD, Chen D. Towards climate resilient urban energy systems: a review. Natl Sci Rev 2021;8:nwaa134. https://doi.org/10.1093/nsr/nwaa134.
[20] IEA Task 40/Annex 52. Measurement and Verification protocol for Net Zero Energy Buildings. A report of Subtask A IEA Task 40/Annex 52 Towards Net Zero Energy Solar Buildings n.d.
[21] Dawe M, Raftery P, Woolley J, Schiavon S, Bauman F. Comparison of mean radiant and air temperatures in mechanically-conditioned commercial buildings from over 200,000 field and laboratory measurements. Energy Build 2020;206:109582. https://doi.org/10.1016/j.enbuild.2019.109582.
[22] Vigna I, Pernetti R, Pernigotto G, Gasparella A. Analysis of the Building Smart Readiness Indicator Calculation: A Comparative Case-Study with Two Panels of Experts. Energies 2020;13:2796. https://doi.org/10.3390/en13112796.
[23] Directive (EU) 2018/ of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency n.d.:17.
[24] Yixiao M, Stijn V. Smart Readiness Indicator (SRI). Assessment package: practical guide SRI calculation framework v 4.4 2022.
[25] NVE-RME. Smart metering (AMS) 2022.
[26] Euroelectric. Dynamic pricing in electricity supply. 2017.
[27] ARERA. Smart metering 2020.
[28] Eurofound. Cyprus: Electricity Authority of Cyprus 2013.
[29] IEA. Energy Policy Review of France. 2021.
[30] Eurostat. Energy statistics available at https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_204/default/table?lang=EN n.d.
[31] Thomas Gundersen. What is the difference between grid rent and electricity? 2022.
[32] Mørenett. Grid Rent 2022.
[33] NordPool. Energy pricing system in Norway 2022.
[34] Statnett. Power Grid System in Norway 2022.
[35] Statistisk sentralbyrå. Price of electric energy for households 2021.
[36] NordPool. Day-ahead prices in Norway 2022.
[37] Cyprus Energy Regulatory Authority. Electricity Licences List 2022.
[38] Cyprus Parliament. Regulation of the Electricity Market Laws 2003 - 2017 (Consolidated) - Greek. 2017.
[39] Kyprianou I, Carlucci S, Serghides D. Energy affordability and trends of mortality in Cyprus. Int J Sustain Energy 2022:1–20.
[40] Eurostat. Electricity prices for non-household consumers - bi-annual data 2022.
[41] Decreto 26 giugno2015-Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici. n.d.
[42] Swing Gustafsson M, Gustafsson M, Myhren JA, Dotzauer E. Primary energy use in buildings in a Swedish perspective. Energy Build 2016;130:202–9. https://doi.org/10.1016/j.enbuild.2016.08.026.
[43] Salom J, Marszal AJ, Widén J, Candanedo J, Lindberg KB. Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data. Appl Energy 2014;136:119–31. https://doi.org/10.1016/j.apenergy.2014.09.018.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

[44] Arens E, Humphreys MA, de Dear R, Zhang H. Are “class A” temperature requirements realistic or desirable? Build Environ 2010. https://doi.org/10.1016/j.buildenv.2009.03.014.
[45] d’Ambrosio Alfano FR, Palella BI, Riccio G. The role of measurement accuracy on the thermal environment assessment by means of PMV index. Build Environ 2011. https://doi.org/10.1016/j.buildenv.2011.01.001.
[46] van Marken Lichtenbelt W, Hanssen M, Pallubinsky H, Kingma B, Schellen L. Healthy excursions outside the thermal comfort zone. Build Res Inf 2017. https://doi.org/10.1080/09613218.2017.1307647.
[47] Lan L, Tang J, Wargocki P, Wyon DP, Lian Z. Cognitive performance was reduced by higher air temperature even when thermal comfort was maintained over the 24–28°C range. Indoor Air 2022. https://doi.org/10.1111/ina.12916.
[48] Zhang F, Haddad S, Nakisa B, Rastgoo MN, Candido C, Tjondronegoro D, et al. The effects of higher temperature setpoints during summer on office workers’ cognitive load and thermal comfort. Build Environ 2017;123:176–88. https://doi.org/10.1016/j.buildenv.2017.06.048.
[49] Porras-Salazar JA, Schiavon S, Wargocki P, Cheung T, Tham KW. Meta-analysis of 35 studies examining the effect of indoor temperature on office work performance. Build Environ 2021. https://doi.org/10.1016/j.buildenv.2021.108037.
[50] Lehmann EL, Romano JP. Testing Statistical Hypotheses. Springer; 2005.
[51] Seltman H. Experimental Design and Analysis. 2013.
[52] DeVellis R. Scale development: Theory and applications. 2012.
[53] Thompson B. Exploratory and confirmatory factor analysis: Understanding concepts and applications. American Psychological Association. 2004.
[54] Rupp RF, Vásquez NG, Lamberts R. A review of human thermal comfort in the built environment. Energy Build 2015. https://doi.org/10.1016/j.enbuild.2015.07.047.
[55] International Organization for Standardization. ISO 8996:2021 Ergonomics of the thermal environment - Determination of metabolic rate. n.d.
[56] Carlucci S, Erba S, Pagliano L, de Dear R. ASHRAE Likelihood of Dissatisfaction: A new right-here and right-now thermal comfort index for assessing the Likelihood of dissatisfaction according to the ASHRAE adaptive comfort model. Energy Build 2021;250:111286. https://doi.org/10.1016/j.enbuild.2021.111286.
[57] Nicol JF, Hacker J, Spires B, Davies H. Suggestion for new approach to overheating diagnostics. Build Res Inf 2009;37:348–57. https://doi.org/10.1080/09613210902904981.
[58] Carlucci S, Causone F, De Rosa F, Pagliano L. A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. Renew Sustain Energy Rev 2015;47:1016–33. https://doi.org/10.1016/j.rser.2015.03.062.
[59] Schweiker M, Carlucci S, Andersen RK, Dong B, O’Brien W. Occupancy and Occupants’ Actions. 2017.
[60] Nouicer A, Meeus L. The EU clean energy package. Florence Sch Regul 2019.
[61] IEA. Demand Response 2021.
[62] Bloomberg. New Energy Outlook 2021.
[63] Smarten. Explicit Demand Response in Europe. 2017.
[64] European Commission. Italian Implementation Plan. 2020.
[65] Ministry of Energy in Cypus. Cyprus’ Integrated National Energy and Climate Plan. 2018.
[66] Kathirgamanathan A, Péan T, Zhang K, De Rosa M, Salom J, Kummert M, et al. Towards standardising market-independent indicators for quantifying energy flexibility in buildings. Energy Build 2020;220:110027. https://doi.org/10.1016/j.enbuild.2020.110027.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

[67] Perera ATD, Nik VM, Chen D, Scartezzini J-L, Hong T. Quantifying the impacts of climate change and extreme climate events on energy systems. Nat Energy 2020;5:150–9. https://doi.org/10.1038/s41560-020-0558-0.
[68] Perera ATD, Javanroodi K, Nik VM. Climate resilient interconnected infrastructure: Co-optimization of energy systems and urban morphology. Appl Energy 2021;285:116430. https://doi.org/10.1016/j.apenergy.2020.116430.
[69] Perera ATD, Nik VM, Wickramasinghe PU, Scartezzini J-L. Redefining energy system flexibility for distributed energy system design. Appl Energy 2019;253:113572. https://doi.org/10.1016/j.apenergy.2019.113572.
[70] Nik VM, Moazami A. Using collective intelligence to enhance demand flexibility and climate resilience in urban areas. Appl Energy 2021;281:116106. https://doi.org/10.1016/j.apenergy.2020.116106.
[71] Pagliano L, Erba S, Peuportier B. Definition of indicators and assessment methods - an AZEB projects Report. 2019.
[72] Mesimeris, T., et al. Cyprus' Draft Integrated national energy and climate plan for the period 2021-2030. Nicosia: Republic of Cyprus. 2019.
[73] Hitchin R, Engelund TK, Bjarne KK. Primary Energy Factors and Members States Energy Regulations: Primary factors and the EPBD. In Concerted Action: Energy Performance of Buildings (p. 4). 2018.
[74] Nordvestnett. Electricity Tariff for Business and Household sector in Norway 2022.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683