MOBISTYLE

MOtivating end-users Behavioral change by combined ICT based modular Information on energy use, indoor environment, health and lifeSTYLE

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Publishable executive summary

This report - Deliverable 3.1 - presents the research activities within WP3 during the first year of the MOBISTYLE project. The structure of the report follows the definition of various methodological steps that were individuated in order to set up an effective monitoring plan and subsequently a successful engagement campaign that includes feedback on energy, Indoor Environmental Quality (IEQ) and health aspects.

The first section of the report provides an overview of the methodological framework highlighting the importance of an interdisciplinary approach that involves competences and knowledge from different fields. The general vision of the defined methodology is followed by in-depth insights into the various research steps.

In line with this, the report first provides information on "what" has to be measured and "how". This requires a thorough understanding of occupant behaviour mechanisms on one hand, and a good knowledge of the several case studies involved in the MOBISTYLE project on the other. Detailed information on the building characteristics of the MOBISTYLE testbeds (e.g. HVAC systems, installed monitoring systems and communication protocols, functional zones, typical occupancy profiles and others) were therefore collected and systematically structured for further applications and analyses.

The accurate assessment of information on the building characteristics and environments goes along with a more aware definition of the parameters that have to be monitored in the single case studies and the means by which they can be collected. Indeed, this report provides an overview of parameters that should be collected in the various MOBISTYLE case studies and a preliminary definition of sensor typologies that could be used to collect the data.

Then, based on the defined parameters, a special focus is put on the definition and description of the Key Performance Indicators (KPIs) for energy, IEQ and health. Along the lines of the KPI definition, data analysis approaches are established in order to transform the monitored (or raw) data into functional KPIs, hence providing applicable information for the IT and platform developers (WP4 and WP5).

Next to the transformation of the monitored data into KPIs, a key task of WP3 regards the transformation of the KPIs into useful and understandable information for the end-users. Therefore, the established KPIs are evaluated for their expected level of comprehensibility by the building occupants. Indeed, the last section of the report gives a first overview on potential energy awareness campaign strategies that might engage different types of end-users/personas to adopt, in the long-term, a more healthy and energy-conscious behaviour.

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1 Introduction

This report introduces a methodology aimed at providing information on how building occupants interact with building controls and systems and save energy increasing their health and comfort conditions, through education, networking, and community.

Today, occupants' health and wellbeing have become key requirements in buildings and represent a new form of sustainability. People spend about 90% of their time inside buildings, thus the physical built environment can have even more considerable impacts on people's health than their lifestyle itself. The concept of investing in people and improving their physical (and psychological) health and wellbeing is common sense for companies, since usually 90% of corporate expenses are represented by employees' salary and benefits.

Indoor environment and health are concepts strictly connected to each other and can be firmly related to energy use, as well. In line with this, the core idea of MOBISTYLE methodology is to integrate these three concepts and link them to the way people behave in a multidisciplinary and innovative manner (Figure 1).

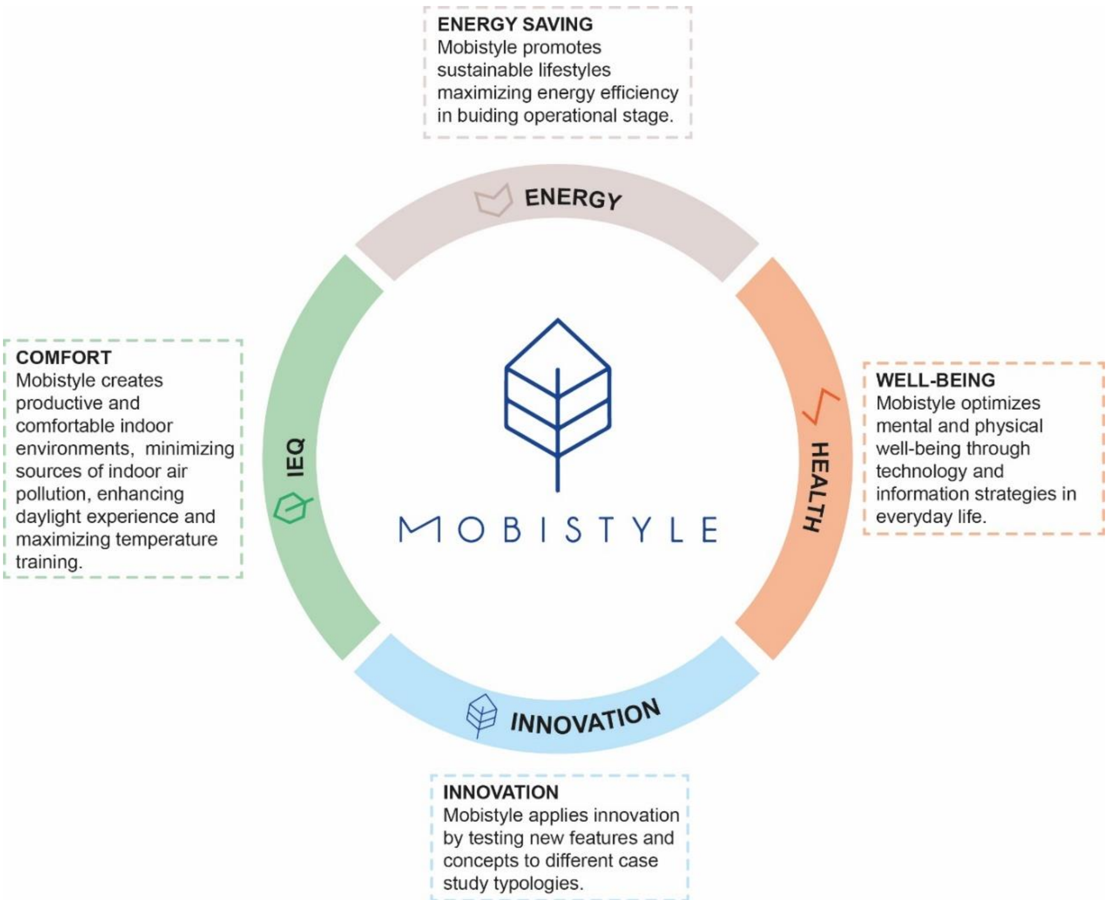

Figure 1: Overview of MOBISTYLE methodology

Buildings are dynamic, and the interactions of operators, occupants, and designers all influence the way in which buildings will perform [1, 2, 3]. At the core of the MOBISTYLE methodology it is then the belief that technical solutions alone are not sufficient to face great challenges of saving energy while still maintaining or even improving current comfort levels and occupants' health [4]. Buildings are engineered using tested components and generally reliable systems and appliances, whereas people can be unreliable, variable, and perhaps even irrational. The studies in literature also reveal the gap between how designers expect occupants to use a building, and how they will actually operate it. Indeed, ordinarily, there is often a significant discrepancy between the designed and the real total energy use in buildings. The reasons of this gap are generally poorly understood and largely have more to do with the role of human behaviour than the building design. Consequently, knowledge of user's interactions within building is crucial to better understanding and obtaining a more valid predictions of building performance (energy use, indoor climate) and effective operation of building systems. If the subject of past research activities and project is the building-plant system, nowadays it is the occupant-building-plant one.

This methodology aims to foster awareness of the importance of human health and wellbeing in buildings and communities. Designing, constructing and managing the sustainability of buildings, districts and cities is a key part of ensuring a brighter future for us all while increasing architectural value. This methodology highlights human health and comfort to the forefront of building practices and devise buildings that are not only better for the planet, but also for people. MOBISTYLE approach aims to introduce the concept of bringing together three areas of sustainability by going in depth through the ideology, structure, certification process and existing case studies. The basis for the concept categories is introduced along with communication strategies to create sustainable buildings and healthy people.

MOBISTYLE approach fosters with this methodology a holistic formula for people to reach better health and wellness outcomes, leading to energy savings thanks to their behavioural change. The methodology consists of features across key concepts that comprehensively address not only the design and operations of buildings, but also how they impact and influence human behaviours related to health and well-being.

The methodology analyses in detail each interaction between the main nodes of the complex eco-system constituted by users, buildings, energy and health and indoor environment (Figure 2). The main goal is then to implement the interaction between the different actors/elements in the ecosystem in a sustainable perspective.

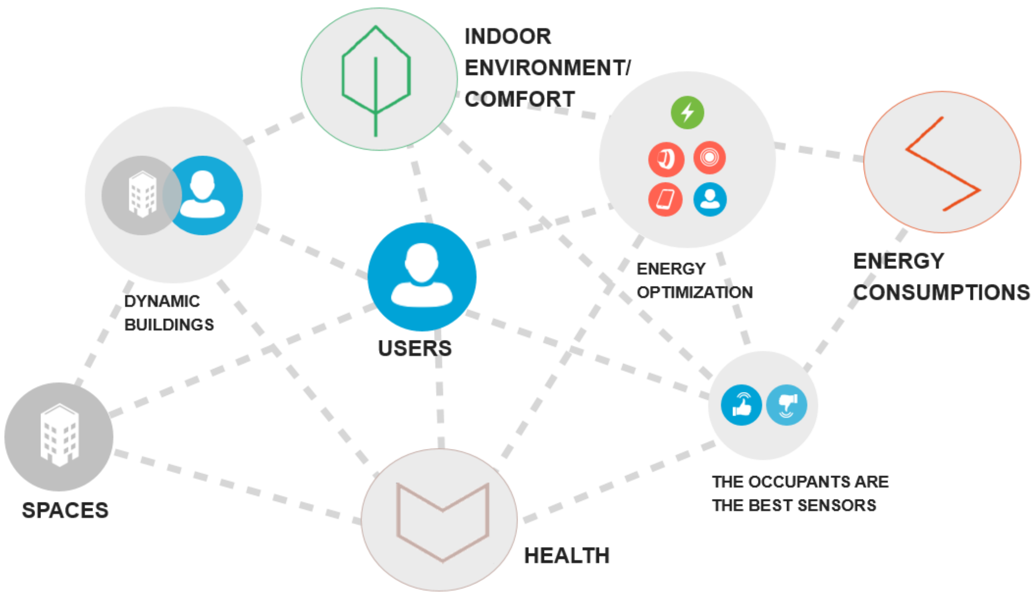

Figure 2: Ecosystem overview

As shown in Figure 2, in this eco-system, the “USER” is an active node interacting with the building and systems causing changes in indoor environmental quality and energy consumption [5, 6, 7]. “USER” node is activated by technology to be part of the sensing system (i.e. sensors and devices), receiving feedbacks on indoor environmental quality and health levels and the outcomes on energy savings. As a result, people will interact with the building and systems in a more “informed” and aware manner.
Technology is then used to design buildings that help people work, live, perform and feel their best.
Technology is a fundamental tool to let buildings be flexible and dynamic.
The “DYNAMIC BUILDING” node refers then to buildings becoming active, flexible and adapting themselves according to the preferences of the users. A set of indoor, outdoor, fixed and wearable sensors gain and provide data through an app. Tailored information from and to users let the system learn and adapt itself to the user needs.
The main outcome in the methodology related to “DYNAMIC BUILDINGS” is to develop a coordinated set of guidelines for indoor and outdoor environmental monitoring systems and sensors. Accurately measuring indoor and outdoor environmental factors provides data that can meaningfully impact comfort conditions and human health. MOBISTYLE methodology provides guidance to this sensor-based systems with which different variables should be monitored, how to interpret their data to solve real building-performance problems, and what equipment provides the best solutions.
Energy (plug load, electricity, heating, etc.) and indoor/outdoor environmental parameters (temperature, relative humidity, etc.) will produce data that should be interpreted, and communicated. Actually, this sensors equipment of the building implies more than outdoor temperature driven heating, e.g. if the user would like to lose weight, he/her could introduce a temperature training for his/her room. In-field monitoring, focus group surveys and interviews have been matched to achieve a better knowledge of the hidden “individual” layers. Questionnaire surveys of the focus group emerged as optimal tools for discovery of a new layer of social, contextual, and group interaction constructs related to driving forces and individual motivations. A survey research framework is thus developed in the framework of Task 2.2 in WP2 to provide quantitative descriptions on the collective and social motivations within the complexity of various social groups in the different case studies’ environment, under a different geographical context, culture, and norms. The results of preliminary ethnographic inquiry are summarized in D2.2 [9]. *Inventory of user needs and expectations* and the recommendations for developers arising from WP2 in D2.3 [10] *Recommendations for improvement and further development of solutions.*
In the MOBISTYLE methodology, the multidisciplinary interaction between the main nodes of the eco-system is identified towards sustainable lifestyles, considering especially environmental psychology.
Besides the environmental and energy monitoring, a specific communication strategy should be developed to interact with users providing them with information on comfort and health-related actions and energy use. As presented in literature [8], people should learn how and when they are using energy, whether such actions lead to relatively high or low consumption, and whether it is decreased or increased in comparison with their previous actions. In Figure 3 the horizon of the behavioural change is presented summarizing the progress that people should internalize before achieving a long lasting behavioural change. Simple, immediate and easy-to-interpret information is needed to produce awareness and an appropriate mechanism to reduce energy consumption. Devices and data processing allow to provide users feedback on energy, comfort and health. Thus people could make the right choice covering a dynamic and incisive role in the entire ecosystem.

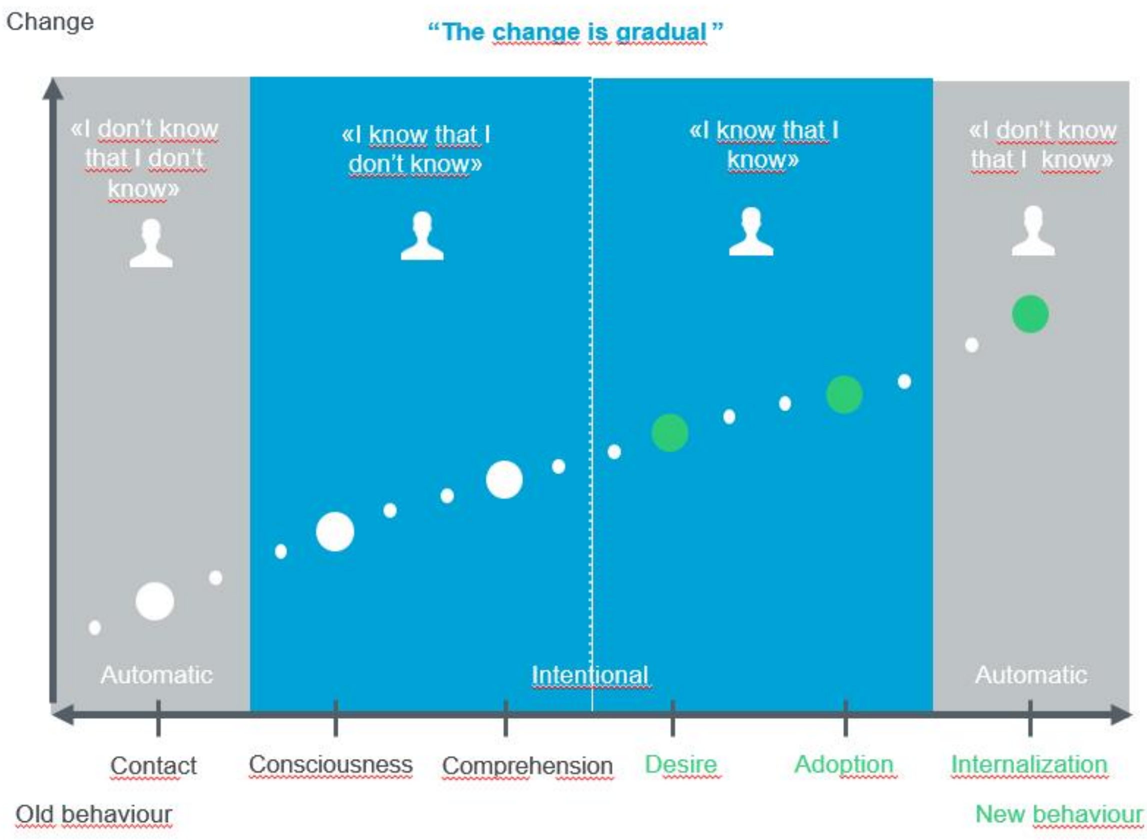

Figure 3: The internationalization of changing behaviour

Human-centred MOBISTYLE methodology fosters a new concept of sustainable comfort, that could be scaled up and produce a flexible control of city energy consumption.

1.1 Aim of the report

The final aim of this report – in a broader perspective – is to provide a standardized multidisciplinary methodological approach to enhance the state of the art of information, knowledge, and insights on satisfied, healthy, and energy-efficient occupant behaviour in the building sector.
For the MOBISTYLE project, the research activities described in this report aim at forming a solid base for the further development of an effective monitoring plan and a successful engagement campaign including feedback related to energy, IEQ, and health aspects. In line with this, the report aims at providing in-depth insights into the various steps of the methodological framework. The latter include:

- an accurate analysis of the building characteristics and environments of the MOBISTYLE testbeds,
- the definition of parameters to be monitored and related data collection features,
- the definition of KPIs (energy, IEQ and health),
- the definition of data analysis approaches for transforming monitored data into KPIs, and
- the definition of awareness strategies for transforming the KPIs into useful (and understandable) information for the end-users.

2 A methodology to combine energy, comfort, and health

A deep understanding of occupant behaviour requires a multidisciplinary approach and involvement of various scientific expertise [4]. By bringing together the necessary scientific expertise, a step towards understanding occupant behaviour and the way occupants can be motivated can be made, a way to raise awareness that brings action and to providing end-users confidence of choosing the right thing and making the right decisions concerning energy and health can be found.

The proposed methodology brings together expertise on (Figure 4):

- **energy**, mechanical engineering, and physics to understand the relation between energy use and occupant behaviour as well as the relation with **indoor environmental quality**;
- **health** science to establish the relation between individually based thermo-physiology and health;
- **anthropology** to understand factors influencing consumer choices and the impact of consumer behaviour on energy use, indoor environment, and health;
- knowledge from **ICT** experts to develop ICT solutions, an environment of Internet of Things (IoT) and modifications of monitoring and data acquisition technologies.

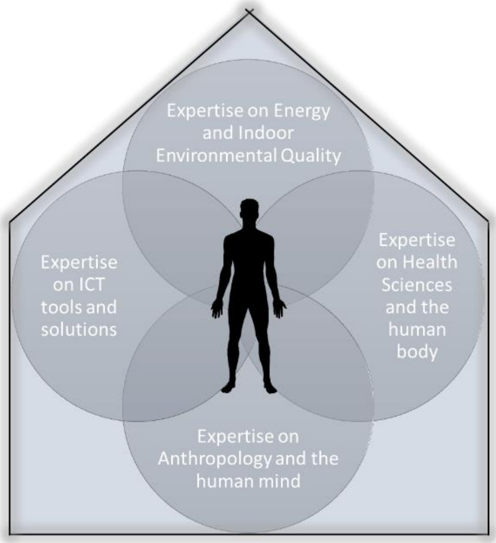

Figure 4. Matching expertise for behavioural change and energy savings

The joint effort is supported by research on an international level from a broad scientific research community. Many scientists and public health practitioners recognize that environmental conditions have an effect on health [11, 12, 13], but the general public has only recently come to understand that this causal relationship affects their day-to-day lifes. Besides thermal conditions, it is well known that indoor air quality is also strongly linked to human health [14] (Figure 5). It is important to minimize the exposure to pollutants like breathable particles (from traffic and activities in the building), chemical emissions (from cleaning agents, furniture, textiles, etc.), mould spores (from organic materials at too high humidity levels), animal allergens, radon and combustion gases as high exposures typically lead to headache, eye, nose, and throat irritation, allergic reactions, dizziness, fatigue, etc. The impact on human health is determined by factors like pollutant type, concentration, exposure duration, method of exposure and, very importantly, individual sensitivity of the person exposed. It is important to adapt the indoor conditions to the needs of the individual, especially for sensitive persons. Studies show that body temperature regulation is strongly linked to the cardiovascular function for internal body heat transport, metabolic function for body heat production (i.e. energy expenditure affecting body weight balance) [15].

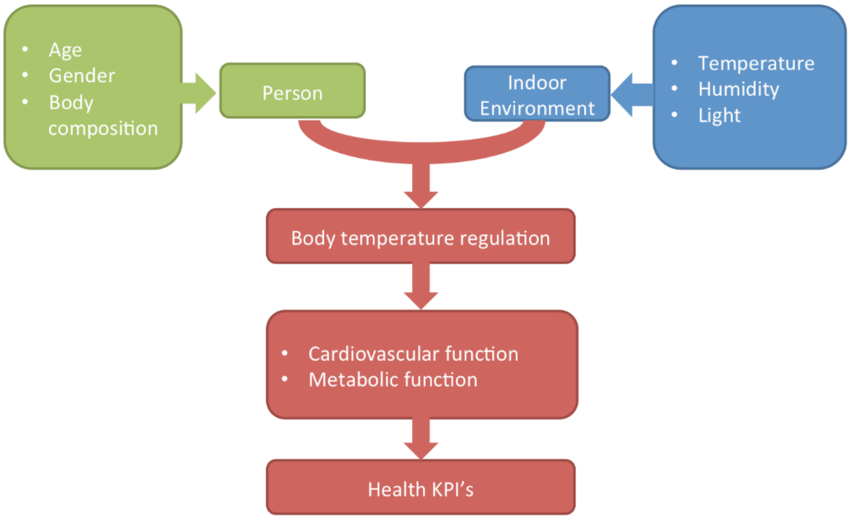

Figure 5: Combination of Individual and environmental parameters for health KPIs

The following figure (Figure 6) shows the four main issues developed in the methodology:

1. Investigate the operation of energy systems through behaviour-related data collection (monitoring campaign on building and users' data) and monitoring of human presence and practices.
2. Understand the human behaviour (comfort, health) through user data analytics (from wearable sensors), stochastic modelling, and energy simulations.
3. Improve the building performance (energy, thermal comfort, IAQ) by integrating behavioural solutions (awareness campaign).
4. Develop strategies to transform different specific indicators into useful knowledge for the final users.

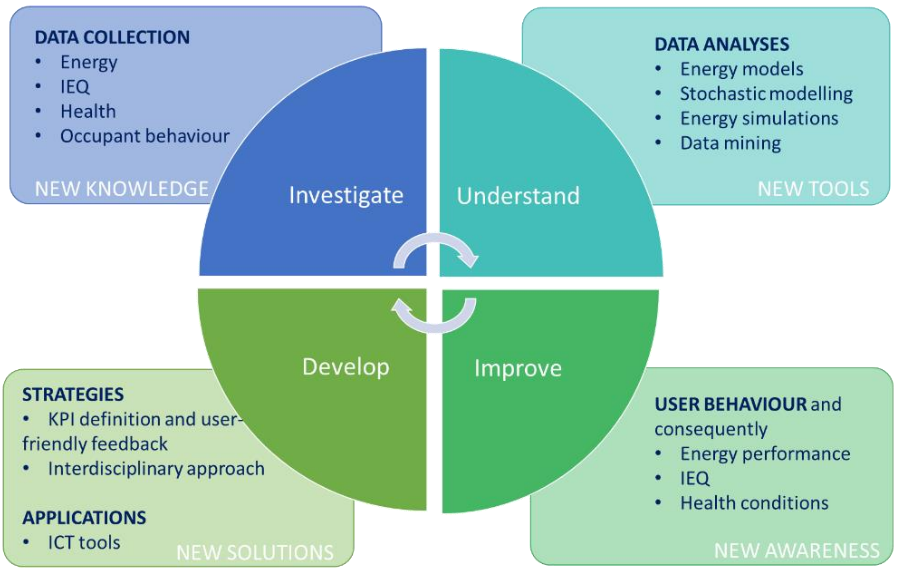

Figure 6: The four areas of the proposed methodology

The procedure for assessing indoor environment, health, and energy in relation to the occupant behaviour may be split into the following phases:

- **monitoring,**
- **data elaboration,**
- **data analysis.**

Monitoring must always be continuous in time, with suitable sampling rates and time spans. This is essential in order to be sure to detect short-time and ‘‘pulsed’’ events, and to gather data with a satisfactory statistical relevance. Moreover, the procedure must be freely configurable, in order to be coupled to any monitoring or BEMS system, and to adapt the analysis to different requirements (number/type of monitored parameter, tolerance ranges, etc.). The monitoring procedure must also be safe and reliable. Occasional failures in the measurement systems or in the analysis must not affect past and future elaborations. Particular care must be given to the data check and ‘‘filtering’’, in order to achieve the maximum representativeness of the surveys, and to minimise the loss of data. Data verification procedure must also be able to manage actual sets of data, which are frequently discontinuous, not contiguous, possibly with unreliable and meaningless values during certain periods. Once the trend-log sets have been collected and verified, the following steps concern data elaboration and analysis.

The use of synthetic indexes is considered essential, at least at the first stage of the analysis, since simple, raw trend-log sets are too huge to analyse and difficult to translate in terms of system performances. For this reason, the methodology is developed in five main steps.

1) **PARAMETERS DEFINITION.** This step addresses the first key question of the methodological framework, or rather “Which data should be collected in each case study?” towards an effective monitoring and engagement campaign. This requires a thorough understanding of occupant behaviour mechanisms on one hand, and a good knowledge of the several case studies involved in the MOBISTYLE project on the other. Therefore, an accurate study on the characteristics of the various MOBISTYLE testbeds has to be performed.
2) **DATA COLLECTION.** This step addresses the second key question, or rather “How should the data be collected?”. This refers mainly to the preliminary identification of sensor typologies (Fixed, wearable, mobile application) that permit to collect the parameters defined in Step 1. This step is strictly connected to the activities performed in WP6 concerning the definition of monitoring action plans for the single case studies.
3) **DATA ANALYSIS.** This step aims at answering the third key question, or rather “What does the data tell us?”. Statistical modelling and data transformation are used to transform the raw/monitored data into applicable data and desired units. Hence, this step is crucial for IT and platform developers (WP4 and WP5) and is the basis for the elaboration of Key Performance Indicators (KPIs) defined in the next step.
4) **KPI DEFINITION.** This step is crucial to understand how the data can help us to evaluate energy savings, health-related aspects, occupants’ well-being in the indoor environment, and behavioural change through synthetic indicators that describe the evolving situation from a reference benchmark state.
5) **AWARENESS CAMPAIGN.** This is the crucial point for the overall success of the outlined methodology, responding to the core question: “How can KPIs be easily understood by the occupants and help to change their behaviour in a long lasting manner?”. Mobile applications,

serious games, advertisements, and newsletters could be applied to increase user engagement and awareness.

2.1 Effect of occupant's behaviour on energy, comfort and health

To understand the mechanisms of occupants' behaviours, there is the need to monitor the behaviour itself and its drivers but also to determine the cause and effect relationships that these behaviours have with energy consumption, indoor and outdoor environment, and the occupants' health status and sense of comfort. This point is one of the main challenges of this project. In other words, whether it is possible, by cross-referencing the data, to understand every condition or variation correlated to some specific behaviour. This "knowledge" is very important for the project goals because it permits to generate tailor-suited feedback for the users.

The types of behaviour significant for the analysis can be listed here below:

- User interaction with the heating/cooling system (i.e. thermostat adjustments),
- Window opening and closing actions,
- Door opening and closing actions,
- Switching on/off of whitegoods and general electrical devices,
- Regulation of solar shadings,
- Artificial light switching and regulation (if dimming is possible),
- Mechanical ventilation adjustment (if HVAC systems are not fully automated).

What it is important to know about every type of behaviour can be summarized in the table below, applying the several questions highlighted in the Table 1.

	Aim	Method	Data source	Observation method
CHARACTERISTIC AND CAUSES	Definition of behavioural characteristics	• Identify the event when the behaviour occurs • Identify the event duration	• Sensor/Device state	Directly measured
		• Identify user preferences	• Sensor/Device state	Directly measured
		• Identify occupancy and movements	• Occupancy sensor state • User tracking	Indirectly measured
	Definition of behavioural influencing factors (drivers)	• Identify habits and occupancy patterns	• Sensor/Device state • Questionnaire	Indirectly measured (statistical analysis)
		• Identify environmental parameters (indoor/outdoor)	• Indoor / Outdoor Sensor	Directly measured
		• Identify the users (that can be affected) comfort perception before the behaviour • Identify contextual parameters (i.e. orientation, time of the days…)	• Blood pressure	Directly measured
			• Heart rate	Directly measured
			• General sense of wellbeing	User perception
			• Sense of control over one's surroundings	User perception
CONSEQUENCES	Effect of occupant's behaviour on energy, comfort and health	Identify the influence on energy consumption	• Indoor-outdoor temperature difference • Heating/cooling devices energy consumptions • Electric energy consumption • Solar radiation	Indirectly measured: Simple analysis (qualitative evaluation) Complex analysis (quantitative evaluation).
		Identify the influence on IEQ conditions	• IEQ sensors	Directly measured
		Identify the influence on users' health conditions	• Blood pressure	Directly measured
			• Heart rate	Directly measured
			• General sense of wellbeing	User perception
	Long term evaluations	Identify the long-term impact on energy consumption	• Frequency • Duration • Intensity	Indirectly measured
		Identify the long-term impact on users' health	• Frequency • Duration • Intensity	Indirectly measured

Table 1: Occupant behaviour measuring

2.2 Assessing occupant behaviour

Using Table 1 as a starting point, in this section it is possible to get into the details of how to collect all the data needed. Mainly the questions to answer for each behaviour are:

A) How to **measure the device state**/object state?

B) How to assess the energy consequences **quantitatively**?

C) How to assess the energy consequences **qualitatively** and how to give an energy score to a specific behaviour?

Measuring the device state (Question A) could be direct or indirect. The direct measure is obtained from the sensor dedicated to detect the variable strictly correlated to the investigated behaviour. Indirect measuring is correlating other parameters not directly affecting the behaviour but that could be related through physical laws. In the following table, different scenarios are identified to detect behaviours. Direct measuring delineates the best scenario since it does not require any transformation to arrive to the behaviour. In any case, it could not be applied into the monitoring plan since it could be expensive or not feasible. Thus, indirect measures became significant on obtaining the required data. Their correlation with the behaviour depends on the installed sensors.

Behaviour	**Direct measuring**	**Indirect measuring**
Thermostat adjustment	1) Thermostat reports the users' settings and sends data to the system monitoring.	2) Relation of the internal temperature with the variation of fuel/electricity consumption of the heating/cooling system.
Window/Door opening	1) Magnetic switch or by other type of electronics control.	2)Monitoring only the window/door state (open or closed) may not be enough. To assess the angle of opening or how much air change the window is causing, it could be possible to monitor the indoor temperature and the CO2 drop (pollutant concentration equation) in the house/room, evaluating the slope of the trend line of these two parameters starting from the moment of opening to the closing of the window. 3)To improve the previous measurement the wind speed/direction and the outside temperature should also be considered.
Mechanical ventilation (manual setting)	1) Thermostat allows user regulation of mechanical ventilation and sends data to the system monitoring.	2) The air change could be monitored directly from the AHU/ventilation system. (air flow meter or fan power consumption and fan characteristics).

Solar shading	1) Device sensors, which monitor the state.	2) Data can be obtained from the inside/outside lux level variation.
Whitegoods/appliances	1) Smart plug or smart device	
Light switching	1) Smart switch or lux meter	2) Data can be obtained from the inside lux level variation.

Table 2: Occupant behaviour measuring

Assessing the behaviour and its consequences on energy consumption **quantitatively** (Question B), all thermal-related behaviours (thermostat, window/door opening, solar shading, and ventilation) could be evaluated with an overall methodology to calculate the energy consequences of each behaviour one by one. The methodology illustrated in UNI EN 13790 and in the EN 52016-1 (monthly or weekly calculation method) correlate the following items:

- Measured thermal energy consumption,
- Occupancy and electricity consumption,
- Solar radiation,
- Internal and outdoor temperature,
- Air change rate.

From acquiring measured data and making assumptions for those data that are not directly measured, it is possible to estimate the impact of every item on the energy consumption. Some of the above listed items are related to measured parameters; for example, internal gain can be hypothesized by crossing measured electricity consumption with occupational data and air change rate is strongly related to window/door opening and to wind speed/direction.
After a certain period of preliminary measurements, the calculation error can be minimized by updating all the assumptions basing them instead on collected data. Assumptions can be updated and optimized with an iterative method to increase the goodness of fit between the items that are not directly measured and the parameters, which they are related to.
Regarding whitegoods (or other electrical appliances), the power consumption could be easily obtained from the smart plug or smart device, and the energy (on daily, weekly, monthly, etc… basis) can be easily calculated by integrating the measured power. Regarding artificial lighting, energy could be easily calculated knowing the power of the device and for how much time it was switched on.

To assess the behaviour qualitatively (Question C), it is important to start from the comfort recommendations contained inside the technical standards (EN 15251, EN 16798-1). The score for each behaviour can be developed as a scale (e.g. from 0 to 7), as shown in Table 3.

1	**VU**	2	**U**	3	**BA**	4	**A**	5	**AA**	6	**S/C/H**	7	**VS/C/H**

Table 3: Score scale

VU= Very Unsustainable/Uncomfortable/Unhealthy
U= Unsustainable/Uncomfortable/Unhealthy
BA= Below Average

A= Average
AA=Above Average
S/C/H= Sustainable/Comfortable/Healthy
VS/C/H= Very Sustainable/ Comfortable/Healthy

The energy consumption of the heating/cooling system depends on the heat exchanges across the building envelope so the occupant can decide how much will be the indoor/outdoor temperature difference with the thermostat adjustments. The score is developed to reduce energy consumption.

Heating				**Cooling**			
SET point [°C]	*Basal Score [f(setpoint temp.)]*	*Outdoor Temp. [°C]*	*Score correction [f(outdoor temp.)]*	*SET point [°C]*	*Basal Score [f(setpoint temp.)]*	*Outdoor Temp. [°C]*	*Score correction [f(outdoor temp.)]*
16	7	15	+10%	28	7	20	+10%
22	4	5	0%	25	4	30	0%
28	0	-5	-10%	18	0	40	-10%

Table 4: Score application example

To evaluate the user interaction with natural ventilation qualitatively (window/door openings), the CO_2 level before the opening and the variation of indoor temperature after the closure should be considered. If the heating/cooling system is able to compensate for the increase of thermal load, to understand if the window is open too much or if it is open for too long, a very low level of CO_2 could be an indicator.
Regarding the user preferences for mechanical ventilation, an idea of a possible score could be developed starting from the recommended value of air change contained inside the standards: 0,5 and 0,7 vol/h if occupied (ISO 15251:2008 [16]).
With respect to solar shading behaviour, it is important to keep in mind that not all of the solar light that enter in the houses is beneficial. Natural light could be an important cause for over-heating; and in case of no occupancy or if the natural light is above the optimal daylight factor, solar shading should be considered. For this reason, a probable score should consider the risk of increasing cooling needs and the impact on the visual comfort, considering what a sufficient daylight factor could be and when the room is occupied.
The behavioural score for whitegoods and appliances could be calculated based on frequency, washing temperature and loading (in case of washing machines and dishwashers). Standby should also be considered. To evaluate the light switching behaviour qualitatively, it is appropriate to highlight the relation with the occupancy.

Due to the nature of the MOBISTYLE project, different methods could be applied to each case study. Kildeparken, the Danish case study, will use a relative rating of various apartment units to benefit from the opportunity to collect a large amount of data. The data interpretation and, subsequently, the feedback provided to the users as part of the monitoring campaign in the Kildeparken case study will be based on a combination of standards, measurements, and relative comparisons between the established baseline and individual units in question. Using a 7-point scoring scale, developed as part of the WP3 deliverables, the conditions within an apartment unit can be assessed. Using the standard

EN 15251, the desired range for CO_2 and operative temperatures, in this example, for the heating season, can be interpolated between to establish conditions for which a score can be given.

Below, a brief summary of the principle will be presented (Table 5).

		CO_2, ppm above outdoor concentration	**Temperature (winter), °C**	**Temperature (summer), °C**	**Humidity (winter), %**	**Daylight level, lx**	**Energy % relative to other apartments**
1	**VU**	>1250	25	22	<20, >70	<50, >1000	+50
2	**U**	1100	24	23	20-70	50-1000	+25
3	**BA**	950	23	24	25-65	75-700	+10
4	**A**	800	22	25	20-60	100-500	Nominal energy use
5	**AA**	650	21	26	30-60	100-400	-10
6	**S/C/H**	500	20	27	30-55	150-350	-25
7	**VS/C/H**	<350	19	28	30-50	200-300	-50

Table 5: Application to Kildeparken case study

To link the environment with the user behaviour, the actions of the inhabitants are assessed using the same 7-point scale approach. The measurement equipment installed will collect data regarding system operations, user interaction with the systems, and link the existing conditions to one or a combination of several user behaviours. IEQ is the priority, followed by energy consumption. User behaviour is assessed based on their actions taken at various situations. If the CO_2 level is too high, yet the occupant opens a window, this is recognized by the system as a positive action, resulting in an encouraging feedback. Instead of scoring the steady state environment the user is in, providing feedback simply on the current measured parameters, the user will be provided with feedback related to their behaviour and interactions with the systems.

3 Parameters Definition and Data Collection

The first part of the methodology is aimed at reaching a better understanding of the different case studies, and catch all the characteristics defining each of them. Generally, the first two stages of the methodology outline:

- The general framework of the activities represented by the relationships between activities, outputs, and outcomes,
- well-defined measures and parameters,
- communication protocols to be integrated ,
- sensors for the monitoring and future evaluation strategies.

These stages are necessary to adequately identify existing available information and to determine what data are already available in order to decide what information should be collected for baseline purposes, and for monitoring and evaluation needs. Moreover, parameter definition and data collection are useful steps to summarize users' information needs, building use and support requirements, and last but not least, the budget for all monitoring and evaluation activities.

The key questions to address during Parameter Definition and Data Collection stages include:

- define data typologies to be collected
- identify methods and tools to be used to gather
- clarify sources to get the data from

There are two main types of data – qualitative and quantitative – and the type of data most appropriate for each case study depends on the indicators to be developed. Qualitative data consist of subjective answers to questions and interviews, like perceptions, experience, and opinions; instead, quantitative data involve numbers, percentages, and ratios. The most common methods used in qualitative data collection are observation, focus group discussions, and in-depth interviews. Outcome of qualitative surveys performed within MOBISTYLE project are reported in [9; 10].
Even if in the proposed methodology, both types of data are necessary to give to the users the right information to change their behaviour, focus of the present report are quantitative data. While qualitative data can be categorized and quantified for the purpose of data analysis, the most common methods of collecting quantitative data are in field monitoring campaign and secondary data review.
To perform this activity and gather quantitative data, a detailed template was developed (Figure 7). The template was aimed at gathering informational data of the case studies, focusing on building's uses and typologies, its functional zones, systems (space heating, space cooling, domestic hot water production, ventilation, and electricity), the Occupancy rate, and presence of existing energy, IEQ, behaviour (occupancy) monitoring system were investigated as well. Regarding the plant systems, generic information (i.e. system typology, generator type, nominal capacity of the generator), and specific distribution and operational data (i.e. system distribution typology, terminal devices type, presence of heat metering systems, operative months of the cooling/heating system) were collected.

A specific section of the template was dedicated to the historical data on energy consumption. Annual energy consumption for electricity, thermal energy consumed by heating system, hot water production, and the water consumption were required for the past three years.

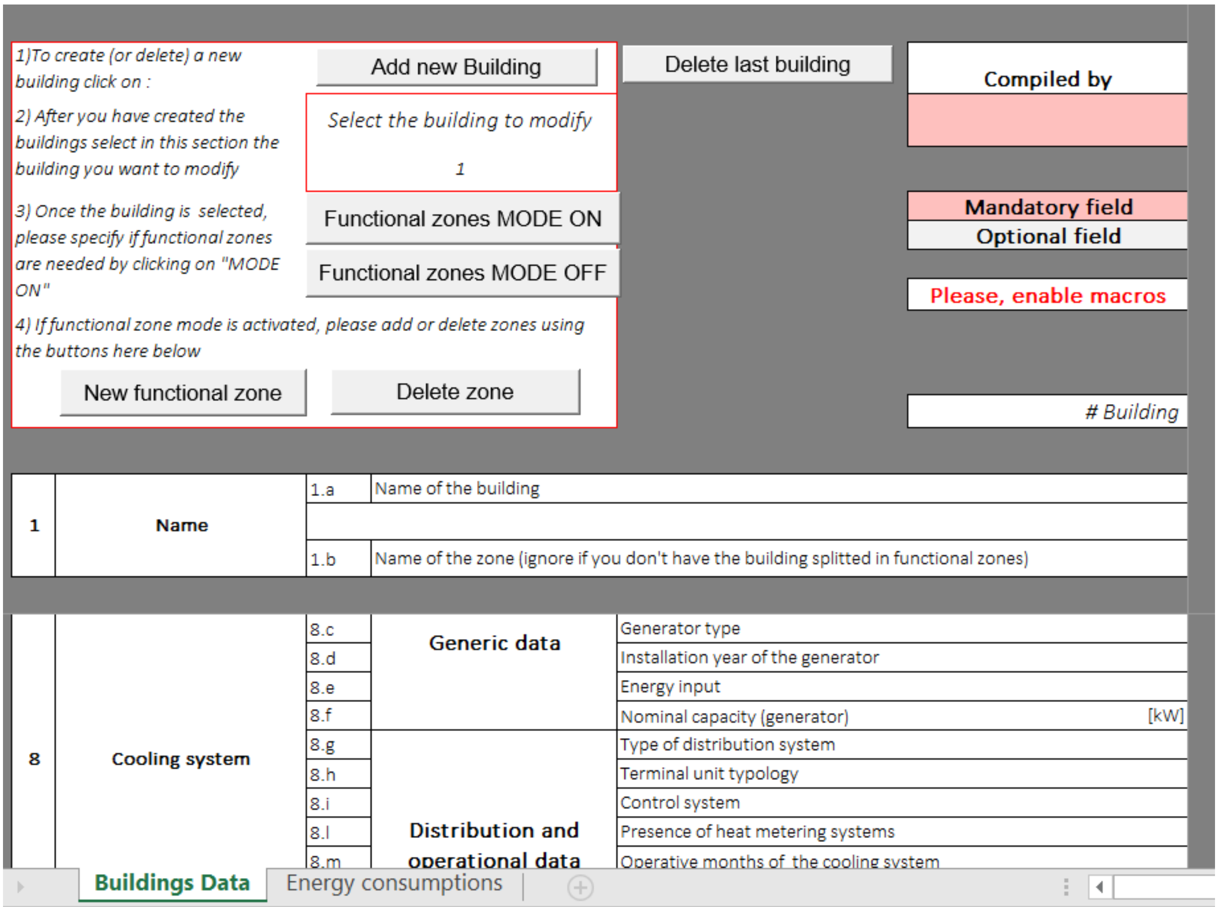

Figure 7: The template to gather data on case studies.

Data gathered with this template were coupled with the information obtained in WP6 for the monitoring plan to characterize all the case studies in detail. In the following tables, the main features of the different case studies are summarized.

Case study	Intended use	Zones typologies
aZM Herstelzorg	Rehabilitation Centre MUMC	Patient rooms Rehabilitation room Doctor's office
Hotel L'Orologio	Residence Hotel	Residence apartments Reception
Kildeparken	Residential houses	Residence households
Wroclaw city	Apartments	Apartments
Ljubljana University	University (Offices + Lecture rooms + Library + Laboratory)	Offices Lecture rooms type 1 (small, medium) Lecture rooms type 2 (big) Library Laboratory

Table 6: Intended use and zone typologies of the different case studies

Tables from 6 to 9 highlight the complexity and specificity of the case studies within MOBISTYLE project, in particular in relation to existing systems, the installed monitoring systems, and, consequently, monitoring protocols.

Case study	Plant system typology
aZM Herstelzorg	Generation: Heat Pump Heat transfer fluid: Water Terminal units: Concrete core activation DHW: separate electric boilers
Hotel L'Orologio	Generation: Condensing boilers, chiller Heat transfer fluid: Water Terminal units: Radiators, Fan coils DHW: Condensing boilers (integrated with heating)
Kildeparken	Generation: District heating Heat transfer fluid: Water Terminal units: Radiators (Floor heating in hallway and bathroom) DHW: Heat exchanger in each block
Wroclaw city	-
Ljubljana University	Generation: Boilers and chillers, AHU Heat transfer fluid: Water, air Terminal units: Radiators (TRVs), Fan coils, air diffusers DHW: Boilers (integrated with heating)

Table 7: Plant system typologies for each case study

Case study	Energy	IEQ	Health	Behaviour	Outdoor
aZM Herstelzorg	Heat Cold Electricity Water	Temperature RH CO_2	-	-	Weather station *Temperature* *RH* *Solar radiation* *Wind speed and direction*
Hotel L'Orologio	Natural gas	Temperature	-	Occupancy Window and door openings Thermostat adjustments	-
Kildeparken	Heating DHW Cold water	Temperature RH	-	Thermostat adjustments	A weather station at the department, 3 km from the case buildings
Wroclaw city	Electricity	Temperature RH	-	-	-
Ljubljana University	Heat Cold Electricity Water	Temperature RH (AHU level) VOC (AHU level)	-	Occupancy Window and door openings Light switching Solar shading adjustments	Temperature RH Solar radiation Wind speed and direction

Table 8: Existing monitoring system for each case study

Case study	Platform	Communication protocol
aZM Herstelzorg	-	-
Hotel L'Orologio	-	KNX - open
Kildeparken	The website in the case description https://www.ista.com/varmekontrol/loesninger/teknologi/	-
Wroclaw city	-	-
Ljubljana University	SCADA	Open (but no 3rd party access directly to SCADA, possible to get tags via separated database)

Table 9: Communication protocols applied in the case studies

From the available data of each case study, a list of parameters for monitoring could be defined for each area of investigation (Energy, IEQ, health, behaviour). Table 10 summarize how the existing parameters could be integrated to have a sufficient amount of information to characterize energy consumption, indoor environmental quality, and health status, and give the users information to change their behaviour consequently. Thus, the following table is valid for each case study, giving the framework within each of them could choose the monitoring system.

Case study	Energy	IEQ	Health	Behaviour	Outdoor
all	Natural gas Heat Cold Electricity Water: DHW and cold water	Temperature RH CO_2	Skin temperature Heart rate Blood pressure	Occupancy Window and door openings Thermostat adjustments Light switching	Temperature RH Solar radiation Wind speed and direction

Table 10: List of parameters to gather in each case study

The step "Data collection" of the methodology is useful to match the list of sensors outlined in Deliverable D2.1 [17] with the defined parameters. For each area of interest (energy, IEQ, health, outdoor, and occupant behaviour) an identified parameter is coupled with the sensor typology suitable for monitoring it. In the following, all the matches are reported.

ENERGY	
Parameter	**Sensors**
Natural gas Heat Cold Electricity Water	Gas meter Heat and cooling energy meter (Ultrasonic heat meter UH50) Power meter/Multimeter/Pulse counter Single-jet dry dial meter/Pulse (hot) water meter
INDOOR ENVIRONMENTAL QUALITY	
Parameter	**Sensors**
Temperature RH CO_2	Thermocouple Hygrometer NDIR (Non Dipersive Infrared)
HEALTH	
Parameter	**Sensors**
Skin temperature Heart rate Skin Blood flow Sweat rate Metabolic rate Activity monitoring Gait p.6MWT Body composition Brain activity Daily activity	iButton 3D Accelerometer & heart rate sensors (Chest belt) Perimed Qsweat Omnical Accelerometer (MOXX) Accelerometer (MOXX) Cosmed Electrods measuring electrical waveforms (EPOC) 3D Accelerometer
OUTDOOR ENVIRONMENT	
Parameter	**Sensors**
Temperature RH Solar radiation Wind speed and direction	Weather station
OCCUPANT BEHAVIOUR	
Parameter	**Sensors**
Occupancy Window opening Door opening Thermostat adjustments Light switching Plug Load	PIR /Inductance sensor/Ultrasonic Contact sensor Contact sensor Electronic TRV/Smart Thermostat Rocker switch/Photo sensor/Lux meter Plug meter

Table 11: Identified parameters and sensors

4 Data Analysis and KPIs

The quality and utility of monitoring, evaluation, and research in the project fundamentally relies on the ability to collect and analyse quantitative and qualitative data. An effective methodology needs to plan not only for the collection of data, but also for data analysis and elaboration. Once data have been gathered, the next step of the methodology involves an analysis to match with the monitoring requirements, knowledge extrapolation and future evaluation strategies. Progress in technology and the increased availability of computer-based techniques to analyse data have made analysis much faster, particularly for huge amount of data. Anyway, not always there is the need to perform analysis with high complicated computer packages, depending on the type of data available. Key concept is that data are analysed in a way to provide answers to key monitoring and assessment process questions that are used to increase energy, IEQ, health or other user-based performance. It is fundamental that data collection and analysis should result in a useful knowledge process, and that the results transformed into useful knowledge for the users.

The different collected measurements could be numerical or categorical. It is important to distinguish between these two types of variables, as the analysis that can be performed for each type is slightly different. Categorical variables are made up of a group of categories. Occupants' gender (male/female) is a categorical variable, as is quality of education (good; bad; average). Numerical variables are numbers. They can be counts (e.g. number of participants at a focus group) or measures (e.g. window open or closed) or durations (e.g., opening duration).

Since in the MOBISTYLE project, the two types of variables are collected, data analysis is then useful to elaborate different types of raw data into significant indicators.

Since the word "indicator" comes from the Latin words "in" (towards) and "dicare" (make known), it means that, once developed, it provides a sort of guidance about what information should be collected and used to identify the progresses.

For this reason, each developed performance indicator needs a detailed definition. Then, it is fundamental to be precise about all technical elements of the indicator statement and to include the unit of measurement in the definition. The detail of the definition should be high enough to garantee that different people at different times (i.e. for each demo cases), given the task of collecting data for a given indicator, would collect identical types of data.

Before selecting indicators, the purpose of the monitoring should be considered (e.g., to assess the state of the environment, to assess energy performances). In the MOBISTYLE project, the goal is to combine data related to energy use, indoor environmental quality, and health issues to give to the users the right knowledge to change their behaviour.

A key role is the planning of data elaboration. It is fundamental to plan in advance how performance data for individual indicators or groups of related indicators will be analysed; to identify data analysis elaboration and data presentation formats to be used; to consider if and how the following aspects of data analysis should be taken into account:

- **Disaggregated data comparison.** For indicators with disaggregated data (for example energy data), it is fundamental to plan how it will be compared, displayed, and analysed.
- **Comparison of current (building, energy, IEQ, health) performance against multiple benchmarks.** For each indicator, plan how actual performance data will be compared with past performance, monitored or reported (vertical benchmarking), or planned or targeted

performance or other relevant benchmarks (for example horizontal benchmarking with similar users).

- **Identify hidden relationships among performance indicators.** It means to determine possible internal analysis of the performance indicators to determine interrelationships between variables.

The methodology defined in the MOBISTYLE project was aimed at defining an inventory of all possible KPIs in the three areas (energy, IEQ, health), giving a brief explanation and their units. Data analysis for elaborating raw monitored data into KPIs are also provided. Since indicators are an "indication" - they provide a snapshot of a meaning that people can easily absorb, a first evaluation of the expected overall level of understanding by the users of the identified KPIs is also provided.
In the following tables, selected indicators for each area are reported.
Regarding the Primary Energy consumption indicator (EP), for an easier understanding, one energy carrier (e.g. oil) will be selected in MOBISTYLE project.
Although the users might be familiar with the concept of Emission of $CO_{2,equivalent}$, it might be hard to understand how much the own carbon footprint influences the environment. Thus, there is some translation needed, such as how many trees it takes to absorb the total building emissions, e.g. a single tree can absorb CO_2 at a rate of 22 kg per year. Emission of $CO_{2,equivalent}$ is an indicator of climate change, thus the emissions examples could be connected to consequences of climate change. Costs are a more familiar indicator for the users and euro is a significant motivation factor. Cost is an important parameter to be presented to some user groups in relation to current/previous consumption. For this reason, externalities (costs wise) of Emission of CO_2 could be explained to the users (https://www.eea.europa.eu/data-and-maps/indicators/en35-external-costs-of-electricity-production-1/en35) or the Normalized natural gas/district heating/district cooling use to occupant number indicator could be expressed also as €/occ . Attention should be paid to give users a short-term indicator (weekly, bi-weekly, monthly), since yearly is not very useful for motivation. Short term indicator is required also for Electricity use ratio (EEUR), where per day/real time feedback should be preferred.

KPI		
Total building energy performance indicators	**Primary Energy consumption (PE).** Represents the overall annual building energy consumption. It is necessary to use the primary energy conversion factors to transform the energy related to the different carriers into primary energy. Can be related to the conditioned net building area or the conditioned net building volume.	kWh/year kWh/m^2year kWh/m^3year
	Emission of $CO_{2,equivalent}$. Measures the amount of $CO_{2equivalent}$ caused by the energy consumption. A measure of how much carbon dioxide and how much the users might contribute to climate change is created. It is necessary to use national CO_2 conversion factors in order to translate	$kgCO_{2,equivalent}$/year $kgCO_{2,equivalent}$/m^2year $kgCO_{2,equivalent}$/m^3year

	the different types of energy related to carriers into emissions. Can be related to the conditioned net building area or the conditioned net building volume.	
Electricity building performance indicators	**Electricity consumption.** Measures the amount of electricity in a certain period (daily, monthly, yearly). Depending on the installed HVAC systems, it can also be divided for different end uses, such as space heating and cooling. Can also be referred to specific electric domestic appliances, to the lighting system and to domestic hot water production. Can be related to the conditioned net building area or the conditioned net building volume. We expect the user to know about the existence of this indicator, still for some users it might be hard to quantify kWh. 1 kWh could for example be (1) one cycle of your washing machine (2) Having television turned on for around 3 hours (3) 48 hours of laptop use (4) Using your kettle ten times (5) Using a desktop computer for 4 hours.	kWh_{el}/year kWh_{el}/m^2 year kWh_{el}/m^3 year
	Costs for electricity consumption. Represents the amount of money the users have to pay for their bills related to electric energy consumptions (can be divided for different end uses or different domestic appliances). The users can easily understand and relate to costs.	€/year
	Electricity use ratio (EEUR). Indicates the ratio between the actual effectively used power and the installed power.	$kW_{el,used}/kW_{el,installed}$ (%)
	Normalized electricity use to occupant number. Relates the building electricity consumption during the occupancy hours to the number of occupants. This indicator might be used for "energy-racing" to compare different functional areas of the same building.	kWh_{el}/occ
Natural gas building performance indicators	**Natural gas consumption.** Measures the amount of natural gas, measured in a point, related to a certain period (monthly, yearly). Depending on the installed HVAC systems, it can be related to space heating and domestic hot water production. In the case of space heating, it can be also normalized to heating degree days (HDD) in order to take into account the variation of climate conditions. Can be related to the conditioned net building area or the conditioned net building volume.	kWh_{ng}/year kWh_{ng}/m^2 year kWh_{ng}/m^3 year kWh_{ng}/m^2(HDD) year

	Costs for natural gas consumption. Represents the amount of money the users have to pay for their bills related to natural gas consumptions (can be divided for different end uses). The users can easily understand and relate to costs.	€/year
	Normalized natural gas use to occupant number. Relates the natural gas consumption of the building during the occupancy hours to the number of occupants.	kWh_{ng}/occ
District heating building performance indicators	**District heating consumption.** Measures the amount of district heating related to a certain period (monthly, yearly). Depending on the installed HVAC systems, it can be related to space heating and domestic hot water production. In the case of space heating, it can be also normalized to heating degree days (HDD) in order to take into account the variation of climate conditions. Can be related to the conditioned net building area or the conditioned net building volume.	$kWh_{dh}/year$ kWh_{dh}/m^2 year kWh_{dh}/m^3 year $kWh_{dh}/m^2(HDD)$ year
	Costs for district heating consumption. Represents the amount of money the users have to pay for their bills related to district heating consumptions (can be divided for different end uses, for example space heating, domestic hot water production, ...). The users can easily understand and relate to costs.	€/year
	Normalized district heating use to occupant number. Relates the district heating consumption of the building during the occupancy hours to the number of occupants.	kWh_{dh}/occ
District cooling building performance indicators	**District cooling consumption.** Measures the amount of district cooling, measured in a point, related to a certain period (monthly, yearly). Depending on the installed HVAC systems, it can be related to space cooling; it can be also normalized to cooling degree days (CDD) in order to take into account the variation of climate conditions. Can be related to the conditioned net building area or the conditioned net building volume.	$kWh_{dc}/year$ kWh_{dc}/m^2 year kWh_{dc}/m^3 year $kWh_{dc}/m^2(CDD)$ year
	Costs for district cooling consumption. Represents the amount of money the users have to pay for their bills related to district cooling	€/year

	consumptions. The users can easily understand and relate to costs.	
	Normalized district cooling use to occupant number. Relates the district cooling consumption of the building during the occupancy hours to the number of occupants.	kWh_{dc}/occ
Domestic water performance indicators	**Domestic water use.** Measures the usage of domestic water in a certain period of time (monthly, yearly). The users are expected to have considerable knowledge about litres, of course the latter could also be transformed in other terms (e.g. bottles).	m^3/year or l/year
	Specific domestic water use. Measures the usage of domestic water in a certain period (day, week, month or year) and normalized on the conditioned net area/conditioned net volume/number of occupants.	m^3/m^2 year m^3/m^3 year m^3/occ
	Costs for domestic water use. Represents the amount of money the users have to pay for their bills related to domestic water use. The users can easily understand and relate to costs.	€/year

Table 12: Identified KPIs in energy field.

KPI		
Thermal Comfort	**Operative Temperature.** Represents the temperature measured in the room. It can be given as the present value or as an average value for a given time period (daily, weekly).	°C
	PMV. The PMV is an index that predicts the mean value of the votes on the thermal environment of a large group of persons on a 7 point thermal sensations scale (hot, warm, slightly warm, neutral, slightly cool, cool, cold)	-3; +3
	PPD. The PPD index predict the percentage of thermally dissatisfied persons. It predicts the percentage of persons voting +3, +2, -2 or -3 on the PMV index.	%
	Thermal comfort category. Based on the percentage of thermally dissatisfied persons (PPD index) thermal comfort sensations are divided into different categories (Cat. I PPD<6%; Cat. II PPD<10%; Cat III PPD<15%; Cat. IV PPD > 15%). It can be given as the present	I-IV (Mechanically cooled)

	value or as an average value for a given time period (daily, weekly)	
	Thermal comfort category (adaptive approach). Thermal comfort categories taking into account that thermal sensation of people changes with the outdoor environment in free running buildings where users have possibilities to adapt to the indoor environment. It can be given as the present value or as an average value for a given time period (daily, weekly)	I - III (Adaptive)
	Draught rate. The draught rate expresses the percentage of persons predicted to be bothered by draught.	%
	POR. The Percentage Outside the Range index, POR, calculates the percentage of occupied hours, when the operative temperature is outside a specified range.	%
Indoor Air Quality	**PD.** The PD is an index that predicts the number of people expected to be dissatisfied with the indoor air quality (mainly persons as pollution source) when entering a room. It can be given as the present value or as an average value for a given time period (daily, weekly).	%
	Indoor air quality category (human perception). Based on the percentage of expected dissatisfied persons with the indoor air quality (Cat. I PPD<15%; Cat. II PPD<20%; Cat III PPD<30%; Cat. IV PPD > 30%). It can be given as the present value or as an average value for a given time period (daily, weekly). Categories are also defined based on the relation between the indoor CO_2 concentration above the outdoor concentration (assumed as 400 ppm) and the percentage of persons dissatisfied with the indoor air quality (Cat. I CO2<550ppm; Cat. II CO2<800ppm; Cat III CO2<1350ppm; Cat. IV CO2 > 1350ppm). It can be given as the present value or as an average value for a given time period (daily, weekly)	I-IV
	Level of CO_2. Represents the measured level of CO_2 in the indoor environment. It can be given as the present value or as an average value for a given time period (daily, weekly).	ppm
	Level of relative humidity.	%

	Represents the measured level of relative humidity in the indoor environment. It can be given as the present value or as an average value for a given time period (daily, weekly).	
	Indoor air quality category (humidity). Defined based on the level of relative humidity (Cat. I RH<50%; Cat. II RH<60%; Cat III RH<70%; Cat. IV RH> 70%). It can be given as the present value or as an average value for a given time period (daily, weekly).	I-IV
	POR. The Percentage Outside the Range index, POR, calculates the percentage of occupied hours, when the indoor air quality (perceived, CO2 or RH) is outside a specified range.	%
Visual comfort	**Maintained luminance (general and task lighting).** Represents the level of illuminance in the space and at the main areas of occupancy (work desks, reading chairs etc.) The acceptable range is 100-1000 lux; 100 for general lighting, 300-500 for task lighting and maximum 1000 lux to avoid the risk of glare (if glare is not measured separately by, for example, a fish eye lens). Measurements should be performed at 0.8 meters to represent working areas. Can be given as the present value or as an average value for a given time period (daily, weekly).	lx
	UGR (Unified Glare Rating). Is used as a measure of glare from all visible lamps divided by the the background lumination of the room. The European Standard EN 12464 regulates the lighting of indoor workplaces, with values of UGR ranging from 5 to 40 with the lower number being better. However, if the UGR < 13 – the glare is discreet and will go unnoticed; UGR > 28 – will certainly cause a distraction.	-
	Ra (Colour rendering index). Ra value is the ability of the light to reproduce colours from the material or the things it falls on. The lower the Ra value, the poorer the light is able to reproduce colours from the material or the things it falls on. An acceptable range is 40-100, however, higher values (especially those above 80) are preferred)	-
	Daylight distribution – optional. Represents the 80% exceeded value of the defined 'nominal minimum' luminance value below which only 20% of the floor area is permitted to drop. As the luminance is not constant across the room, in rooms lit from the sides only, the value will fall quite sharply as the reference point is moved from the perimeter. The daylight distribution will	-

	ensure an even uniformity of the luminance. (Can be measured by a fish eye lens.)	

Table 13: Identified KPIs in indoor environmental quality field.

KPI		
Health and wellbeing	**Blood pressure.** A prolonged increase in blood pressure (raised blood pressure) is a major risk factor for various cardiovascular diseases (e.g. stroke and coronary heart disease). Normal systolic blood pressure between 90 and 120 mmHg, normal diastolic blood pressure between 60 and 90 mmHg (WHO). Frequent measurement is suitable for living lab conditions but might be impractical for free living conditions. To ensure comparability between measurements it is important to be in resting conditions when measuring blood pressure.	mmHg
	Heart rate. Heart rate is the amount of contractions of the heart muscle in a certain period of time and can be easily influenced by changes in environment or activity. This also makes it difficult to define a certain threshold for heart rate. According to the American Heart Association, a normal heart rate during rest is between 60 and 100 beats per minute for an average person. Monitoring of heart rate is easy with current monitor devices.	beats/min
	Core temperature. Also referred to as body temperature. Maintaining a (fairly) constant core temperature is important for various processes throughout the human body. A normal core temperature ranges from 36.5 to 37.3 degrees Celsius. Individual core temperature might be influenced by multiple factors (e.g. age, sex, circadian rhythm or disease). Direct measurement of core temperature is easy in a research setting, in daily living conditions indirect measurements can be used (e.g. ear or rectal temperature).	°C
	Skin temperature. Skin temperature can be measured on several locations on the human body. Different locations lead to different interpretations of the measured temperature. The skin temperature might play a role in a person's percept of temperature and comfort. Skin temperature can be measured in both research and daily living conditions, however, interpretation of the results is not straightforward due to measurement sites on the skin.	°C
	Daily activity	Activity counts

	Daily exercise decreases the risk of developing various chronic diseases such as diabetes and cardiovascular diseases. Daily activity can be easily tracked using activity monitors or step counters. However, the outcome of any activity counter might be influenced by the mounting location and should therefore be taken into account.	Steps / day
	Sleepiness The Karolinsky Sleepiness Scale (KSS) is a subjective scale to assess the subject's sleepiness score. Subjects are asked to indicate how sleepy they are/ feel on a scale ranging from extremely alert to extremely sleepy	subjective score for sleepiness
	Thermal sensation score The thermal comfort and sensation scale aims to address the thermal sensation and comfort score of an individual. The scale contains questions about whole body thermal comfort as well as questions addressing local thermal comfort and sensation. Additionally, there are some questions about controlling the thermal settings.	-

Table 14: Identified KPIs in health field.

The second activity related to KPIs identification aims at evaluating an overall expected level of understanding by the end-users. The level of understanding is described on a 5-step scale from hard to easy. In the following table, identified KPIs in the areas of energy, indoor environmental quality, and health, are matched with a comprehensibility level. Actually, for each identified user of the case studies ("personas" as defined in [24]), this level of understanding could be different. For this reason, a further transformation of KPIs into useful knowledge for the users is needed (awareness campaign).

KPI	Overall expected level of understanding				
	Hard	Fairly Hard	Neutral	Fairly Easy	Easy
Primary energy consumption (EP)		X			
Emission of $CO_{2,equivalent}$			X		
Electricity consumption			X		
Costs for electricity consumption					X
Electricity use ratio (EEUR)	X				
Normalized electricity use to occupant number				X	
Natural gas consumption			X		
Costs for natural gas consumption					X
Normalized natural gas use to occupant number				X	
District heating consumption			X		
Costs for district heating consumption					X
Normalized district heating use to occupant number				X	
District cooling consumption			X		
Costs for district cooling consumption					X

Normalized district cooling use to occupant number				X	
Domestic water use					X
Specific domestic water use				X	
Costs for domestic water use					X
Operative Temperature					X
PMV				X	
PPD for thermal comfort			X		
Thermal comfort category		X			
Thermal comfort category (adaptive approach)		X			
Draught rate			X		
POR for thermal comfort			X		
Indoor air quality category (human perception)		X			
PPD for indoor air quality		X			
Level of CO2			X		
Level of relative humidity		X			
Indoor air quality category (humidity)		X			
POR for indoor air quality					
Maintained luminance				X	
UGR (Unified Glare Rating)	X				
Ra (Color rendering index)				X	
Daylight distribution		X			
Blood pressure		X			
Heart rate			X		
Core Temperature				X	
Skin Temperature		X			
Daily Activity				X	
Sleepiness score				X	
Thermal sensation score			X		

Table 15: Overall level of understanding of KPIs.

As explained in the beginning of this section, monitored data should be elaborated to arrive to a synthetic indicator. This section provides the main formulas for transforming the raw data into KPIs. In the following table, each KPI is associated with the main elaboration from raw data available with the monitoring.

KPI Typology	DATA ANALYSIS

		Formula	Where…	Units
Total building energy performance indicators	**Primary energy consumption (EP)**	$EP = \sum_{i=1}^{n} E_{del,i} * f_{p,i}$	$E_{del,i}$ = delivered energy by energy carrier "i" (yearly) $f_{p,i}$= primary energy conversion factor for energy carrier "i" *	kWh/year
		$EP_S = \frac{EP}{S}$	S = conditioned net area of the building	kWh/m²year
		$EP_V = \frac{EP}{V}$	V = conditioned net volume of the building	kWh/m³year
	Emission of $CO_{2,equivalent}$	$CO_{2,eq} = \sum_{i=1}^{n} E_{del,i} * K_i$	$E_{del,i}$ = delivered energy by energy carrier "i" (yearly) K_i = $CO_{2,eq,i}$ for energy carrier "i" *	$kgCO_{2,equivalent}$/year
		$CO_{2,eq,S} = \frac{CO_{2,eq}}{S}$	S = conditioned net area of the building	$kgCO_{2,equivalent}$/m²year
		$CO_{2,eq,V} = \frac{CO_{2,eq}}{V}$	V = conditioned net volume of the building	$kgCO_{2,equivalent}$/m³year
Electricity building performance indicators	**Electricity consumption**	$E_{el} = \sum_{i=1}^{n} E_{el,i}$	$E_{el,i}$ = electricity consumption by different end use "i"	kWh_{el}/year
		$E_{el,S} = \frac{E_{el}}{S}$	S = conditioned net area of the building	kWh_{el}/m^2 year
		$E_{el,V} = \frac{E_{el}}{V}$	V = conditioned net volume of the building	kWh_{el}/m^3 year
	Costs for electricity consumption	$Cost_{E_{el}} = E_{el} * PR_{kWh,el}$	$PR_{kwh,el}$ = electricity tariff	€/year
	Electricity use ratio (EE_{UR})	$E_{el,UR} = \frac{PE_U}{PE_I}$	PE_U = effectively used power PE_I = installed power	$kW_{el,used}/kW_{el,installed}$ (%)
	Normalized electricity use to occupant number	$E_{el,occ} = \frac{E_{el}}{N_{occ}}$	N_{occ} = number of occupants	kWh_{el}/occ
Natural gas building performance indicators	**Natural gas consumption**	$E_{ng} = \sum_{i=1}^{n} E_{ng,i}$	$E_{ng,i}$= natural gas consumption by different end use "i"	kWh_{ng}/year
		$E_{ng,S} = \frac{E_{ng}}{S}$	S = conditioned net area of the building	kWh_{ng}/m^2 year
		$E_{ng,V} = \frac{E_{ng}}{V}$	V = conditioned net volume of the building	kWh_{ng}/m^3 year

		$E_{ng,HDD} = \frac{E_{ng}}{S * HDD}$	HDD = Heating Degree Days	$kWh_{ng}/m^2(HDD)$ year
	Costs for natural gas consumption	$Cost_{E_{ng}} = E_{ng} * PR_{kWh,ng}$	$PR_{kWh,ng}$ = natural gas tariff	€/year
	Normalized natural gas use to occupant number	$E_{ng,\ occ} = \frac{E_{ng}}{N_{occ}}$	N_{occ} = number of occupants	kWh_{ng}/occ
District heating building performance indicators	**District heating consumption**	$E_{dh} = \sum_{i=1}^{n} E_{dh,i}$	$E_{dh,i}$= district heating consumption by different end use "i"	$kWh_{dh}/year$
		$E_{dh,S} = \frac{E_{dh}}{S}$	S = conditioned net area of the building	kWh_{dh}/m^2 year
		$E_{dh,V} = \frac{E_{dh}}{V}$	V = conditioned net volume of the building	kWh_{dh}/m^3 year
		$E_{dh,HDD} = \frac{E_{dh}}{S * HDD}$	HDD = Heating Degree Days	$kWh_{dh}/m^2(HDD)$ year
	Costs for district heating consumption	$Cost_{E_{dh}} = E_{dh} * PR_{kWh,dh}$	$PR_{kWh,dh}$ = district heating tariff	€/year
	Normalized district heating use to occupant number	$E_{dh,\ occ} = \frac{E_{dh}}{N_{occ}}$	N_{occ} = number of occupants	kWh_{dh}/occ
District cooling building performance indicators	**District cooling consumption**	$E_{dc} = \sum_{i=1}^{n} E_{dc,i}$	$E_{dc,i}$= district cooling consumption by different end use "i"	$kWh_{dc}/year$
		$E_{dc,S} = \frac{E_{dc}}{S}$	S = conditioned net area of the building	kWh_{dc}/m^2 year
		$E_{dc,V} = \frac{E_{dc}}{V}$	V = conditioned net volume of the building	kWh_{dc}/m^3 year
		$E_{dc,CDD} = \frac{E_{dc}}{S * CDD}$	CDD = Cooling Degree Days	$kWh_{dc}/m^2(CDD)$ year
	Costs for district cooling consumption	$Cost_{E_{dc}} = E_{dc} * PR_{kWh,dc}$	$PR_{kWh,dc}$ = district cooling tariff	€/year
	Normalized district cooling use to occupant number	$E_{dc,\ occ} = \frac{E_{dc}}{N_{occ}}$	N_{occ} = number of occupants	kWh_{dc}/occ
Domestic water performance indicators	**Domestic water use**	DW	DW = domestic water use	m^3/year or l/year
	Specific domestic water use	$DW_S = \frac{DW}{S}$	S = conditioned net area of the building	m^3/m^2year

		$DW_V = \frac{DW}{V}$	V = conditioned net volume of the building	m^3/m^3year
		$DW_{occ} = \frac{DW}{N_{occ}}$	N_{occ} = number of occupants	m^3/occ
	Costs for domestic water use	$Cost_{DW} = DW * PR_{DW}$	PR_{DW} = domestic water tariff	€/year
Thermal comfort	**Operative temperature**	$OP = \frac{\sum_{i=1}^{1} OPi}{N}$	OP = Operative temperatue at a given time "i" N = number of measurements	ºC
	PMV	Explained in 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.	-	-3; +3
	PPD	$PPD = 100 - 95 * e^{-(0{,}03353*PMV^4+0{,}2179*PMV^2)}$	PMV = Predicted Mean Vote	%
	Thermal comfort category	I for PPD<6%; II for PPD<10%; III for PPD<15%; IV for PPD > 15%	TCC = Thermal comfort category by different PPD votes N = number of votes	-
	Thermal comfort category (adaptive approach)	$\Theta_{i\,max} = 0{,}33\Theta_{rm} + 18{,}8 \pm 2$ (Cat I) ±3 Cat II ±4 Cat III	$\Theta_{i\,max}$ = limit value of indoor operative temperature, °C	-
	Draught rate	$DR = (34 - t_a)(v - 0{,}05)^{0{,}62}(0{,}37 * v * Tu + 3{,}14)$	t_a = local air temperature in degrees Celsius v = local mean air velocity, in meters per second Tu = local turbulence intensity, in per cent, defined as the ratio of the standard deviation of the local air velocity to the local mean air velocity	%
	POR	$POR = \frac{\sum_{i=1}^{Oh}(wf_i * h_i)}{\sum_{i=1}^{Oh} h_i}$	wf = weighting factor which depends on the comfort range Oh = occupied hours	%
Indoor Air Quality	**PD based on ventilation rates**	$PD = 395 * \exp(-1{,}83 * q^{0{,}25})$ For q≥0,32 l/s * olf	PD = perceived air quality q=ventilation rate olf=pollution source strength	%

	PD based on CO_2	$PD = 395 * \exp(-15,5 * C_{CO_2}{}^{-0,25})$	PD = perceived air quality CO_2= Level of CO_2	%
	Indoor Air Quality category (human perception)	I for PD<15%; II for PD<20%; III for PD<30%; IV for PD>30%	PD=percentage of dissatisfied	-
	Level of CO_2	$C_i = \frac{\sum_{i=1}^{1} CO_2 i}{N}$	C_i = Level of CO_2 at a given time "i" N = number of measurements	ppm
	Level of Relative Humidity	$RH = \frac{\sum_{i=1}^{1} RHi}{N}$	RH = Level of relative humidity at a given time "i" N = number of measurements	%
	Indoor Air Quality category (humidity)	I for RH<50%; II for RH<60%; III for RH<70%; IV for RH>70%	RH= Level of relative humidity	-
	POR	$POR = \frac{\sum_{i=1}^{Oh}(wf_i * h_i)}{\sum_{i=1}^{Oh} h_i}$	wf = weighting factor which depends on the comfort range Oh = occupied hours	%
Visual comfort	**Maintained luminance**	$E_m = \frac{Lf}{A}$	E_m=maintained illuminance Lf=luminous flux (lm) A= area (m^2)	lx
	UGR	$UGR = 8 \log(\frac{0,25}{Lb} \sum \frac{L^2 \Omega}{p^2})$	Lb=brightness of walls and ceilings (background luminance) L=one luminaire's luminance Ω = the solid angle of the luminaire from the viewer's position p=the Guth index (value gets bigger the further the luminaire is from the line of sight of the viewer)	-
	Ra	Iterative process explained in http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightsources/appendixB.asp	-	-
	Daylight distribution	$\sum_{i=1}^{n} wf_i * A_i > 0,8 * A_{room}$ $wf_i = 1$ if $E_m \geq E_{m\ minimum}$ $wf_i = 0$ if $E_m < E_{m\ minimum}$	wf_i = weighting factor for a given measurement i A_i = given measurement area A_{room} = total room floor area E_m=maintained illuminance	-

			$E_{m\ minimum}$ = minimum maintained illuminance value	
Health	**Mean arterial pressure (MAP)**	MAP = (2*DiaBP + SysBP)/3	DiaBP = diastolic blood pressure SysBP = Systolic blood pressure	mmHg
	% of heart rate reserve (%HRR)	%HRR = $(HR – HR_{rest})$ / $(HR_{max} – HR_{rest})$ *100%	HR = Heart rate HR_{rest} = resting heart rate HR_{max} = maximal heart rate	%

Table 16. Raw data elaboration for KPI identification.

5 Awareness campaign

As underlined in [10], the approach used in MOBISTYLE is human- or people-centred. This approach focuses on actual needs of the users and attempts to include their habits, practices, ideas, desires in new products and services with the main goal to change their behaviour and save energy in buildings. Since both external and internal factors drive people to perform actions, there is the need to take into account physical, social, and cultural factors (such as community aspects as described in [10] like public dedication or peer pressure) to move towards a model to understand better how people behave and interact with building and system. Such indoor parameters influence and/or constrain the users' choices and behaviours, such as age, gender, social class, income, geographical position, and political differences, aside from information provision and economic incentives.

Energy information systems comprise software, data acquisition hardware, and communication systems that are intended to provide energy information to building users, energy and facilities managers, financial managers, and utilities. This technology has been commercially available for over a decade, however recent advances in Internet and other information technology, and analytical features have expanded the number of product options that are available. For example, features such as greenhouse gas tracking, configurable energy analyses and enhanced interoperability are becoming increasingly common.

Energy information systems are used in a variety of buildings operations and environments, and can be characterized in a number of ways. Basic elements of these systems include web-based energy monitoring, web-based energy management linked to controls, demand response, and enterprise energy management applications.

A number of industry experts have pushed for the adoption of building information systems that can provide facility managers and occupants with meaningful and actionable information.

It has been demonstrated [18] that connections to other people, living in the same community, matters the most in forming and changing daily habits and practices, including the ones connected to energy management, health, and wellbeing. Moreover, Shove [19] investigated how individuals' routines and habits up to "green beliefs" from social science influence energy and water pattern of usage,

To secure a sustainable energy development, attitudes and human behaviour need to be modified towards a more efficient and conscious energy usage. In this view, user awareness can be the growth driver of the future energy efficiency in the whole building system. Certainly, developing more compelling and smart appliances, equipped with user friendly interfaces will encourage people acceptance and comprehension of building controls.

Technology development is stepping up to fill the need for effective data visualization in buildings. These firms are developing a new generation of information displays—dashboards—with features and interfaces tailored to the needs of building owners, operators, and occupants. Distinct from conventional Energy Management and Control Systems (EMCSs), these information dashboards typically do not provide detailed system operation. Instead they are designed to visually display trends and anomalies, and to educate a broad range of building stakeholders about the ecological implications of building performance and occupant behaviour. Many of these products include real time information displays, and allow users to view data using a number of different metrics, such as energy nits, utility costs, or carbon emission equivalents. Several studies have examined how information feedback can help occupants to reduce energy, though the majority of these have focused on homes.

On average, these studies found that real-time energy feedback resulted in overall energy savings of 10-15% [20, 21, 22].

Since the 1970s, many researchers from various fields have studied how feedback on energy use impacts residential consumer understanding and behaviour [20, 21, 22]. Studies involving informative billing and periodic feedback have realized energy savings between 10 and 20%. It is assumed, based on theory and field research, that if residential consumers had more detailed and/or frequent information about their consumption, they would both better understand their energy use patterns and be able to change them effectively. Several field studies (Dennis et al., Winnet et al.) [23, 24] reported that significant energy savings can be made by providing antecedent information about methods of energy conservations. However, Wood and Newborough [25] underlined that an adverse effect can often occur in antecedent information studies, the so-called Fallback effect.

The Fallback effect has been defined by Wilhite and Ling [26] as "the phenomenon in which newness of a change causes people to react, but then the reaction diminishes and the newness wears off". Coherently to this statement, a study conducted by Hayes and Cone [27] found that information alone, such as a poster describing ways to reduce electricity consumptions of individual electric appliances, has a temporary effect in reducing electricity consumption. In fact, initially after the poster was distributed in one unit of a student housing complex, there was a 30% reduction in electricity usage; however, in the subsequent week, the energy savings had fallen to 9%. Another common problem, pointed out by Wood and Newborough [25], is that subjects may behave differently because they are aware they are being studied: this is known as the Hawthorne effect [28].

Two main conclusions can be drawn from a broad group of studies.

Van Houwelingen and Van Raaij [29] outlined three main functions of feedback:

- Feedback has a learning function: users learn about the connection between the amount of energy they use and the energy consuming behaviour,
- Habit formation: users put the information they have learnt into practice and may develop a change in a routine habit,
- Internalisation of behaviour: when people develop new habits after a while they change their attitudes to suit that new behaviour.

A study conducted by Sarah Darby in 2008 [30] presented an interesting literature survey of the persuasive methods that result in positive energy behavioural change.

Two types of information could be given to the users.

Antecedent strategies announce the availability of positive or negative consequences through information, prompts, demonstration, and commitments. Such supply information describes practical ways for reducing energy consumption and could be in the form of a brochure, notice, booklet posted through the door, TV programmes, or Internet sites

Consequence strategies provide rewards and feedback, following particular behaviour. Giving feedback information is the alternative way of informing users about their energy use and energy saving measures. It relates directly to a consumer's behaviour, providing advices about the action carried out at the moment. Moreover, within the context of residential buildings, feedback can be provided for an individual or for the household as a whole.

Time frequency is also an item to be developed within the context of persuasive technology.

First, real-time feedback has not been shown to stimulate more energy conservation than monthly or weekly feedback. What is new is the discussion of increased "awareness" as a major result of feedback. It seems that awareness, not behavioural change or financial savings, is the major impact of maximizing feedback frequency. Specifically, better results can be attained when feedbacks are immediate. Interestingly, Ammos and Van Raaij and Verhallen [29] found that the most effective feedback is that which more immediately follows an action.

Stern [22] argued that it is not the time step differences between days, weeks, and months that is important to communicate to users, but that the feedback appears immediately after an action that attempts the goal of energy saving. Stern also stated that the most effective energy information is that which captures the attention of the audience, gains involvement, and is credible and useful in the user's situation.

The second point is that an increase in sophistication of real-time feedback technology has not corresponded with an increase in measured energy savings. It seems that it is the presence of the information itself - not its presentation in a more salient, graphical format - that is causing the behaviour change.

As a consequence of the unclear economic advantage of real-time usage feedback over other forms of energy feedback information, the main applications of real-time feedback have been in either commercial settings for facilities managers, or in schools and universities as an educational tool and technological experiment.

In the MOBISTYLE project, the development of tools is done according to the people-centred design and development approach, i.e. by involving users and knowledgeable partners in the design and development processes. A balance between collaboration and competition has also proven to be an important factor for the MOBISTYLE project.

Findings of an extensive literature review, of experience on the feedback, and data, display that improved feedback can reduce consumption up to 20% with low capital (or no-capital) technology investment expenses [30]. In the MOBISTYLE project, the actual energy use influenced by the occupant behaviour will be measured and based on demonstrators. Moreover, the potential of the influence of changes in practices and behaviours on the building's energy savings will also be assessed. The measurable quantitative objective of MOBISTYLE is the reduction of energy use of at least 16 %, prompted by a combined smart metering and other consumption feedback systems on energy, IEQ, and health. With continuous and varied communication techniques, the goal is to encourage the energy savings even further and prevent that raised awareness does not lapse quickly. By educating the users, people have a sense of control and awareness of how the generated environment affects their health and well-being and how they spend their energy. As our daily practices and habits are complex and, therefore, hard to change, it is possible that after the project duration even further energy savings will be achieved; influenced by the new energy conscious user behaviour [31, 32].

The aim is to present a complex user behaviour in an understandable way where a user is invited to interpret communicated ideas in his or her way. The underlying purpose is the same for all the users; to make them aware that their energy wasteful behaviour can be improved by conscious changes in their daily actions.

Identification of user types (consumers) and observation of their everyday lifestyle is a prerequisite in such an approach in order to understand their needs. In the first phase, the MOBISTYLE project is focusing on an anthropological observation of the building users, looking at their engagement with buildings, building systems, and other information and communication technology (ICT) solutions in their everyday life. Through different qualitative inquiries (e.g. interviews, focus groups, participant observation) current habits of people are investigated to see how they use the existing technologies

and what is the key factor that would trigger them to change their behaviour. The anthropological approach enables gaining 'thick data', i.e. an in-depth understanding of human behaviour, which is able to penetrate beyond the quantified behaviour of 'big data', collected via technological solutions [33, 34]. This understanding defines requirements for ICT services and, therefore, the MOBISTYLE developers in order to develop user-friendly and attractive services.
Recommendation developed in [10] should be used for the awareness campaign; the IT solution will be integral part of the activities for influencing behaviour.
Summarizing general recommendations are the following:

- Emphasising smartphones: using a smartphone as the main platform for communication between the user and MOBISTYLE solution,
- Self-defined user profiles: enabling a possibility for the users to actively cooperate in creation and setting-up of their own profiles,
- Customised and location-based advices: providing advices, adapted to users and their local environment, which are based on sensor measurements,
- Calm technology principle: new IT-based solutions should not irritate the user with too frequent notifications; instead, they should support their habits from the "background" (with minimal cognitive load),
- Building systems and other home device controls: users should be able to adjust various parameters influencing his or her indoor comfort through the same IT-based solution,
- Expert advisors: people trust human experts (medical doctors, energy professional, air quality experts) providing them advices,
- Spreading the concept through leaders and trendsetters: when spreading the new motivation concept, it is worth focusing on early adopters and trendsetters who will engage others to use the IT solution in a community,
- "Feel the energy" approach: making energy more intuitive by connecting it to a physical activity or lighting as a primary association when referring to energy,
- Public dedication to a goal: when an individual's decision for changing a certain habit is presented to other people, a person is more motivated to stick to a certain commitment,
- Community size: buildings and settlements with larger number of inhabitants (above 150) witness problems of breakdown of social bonds; in such cases, the IT solution should support establishing new communities and creating new ties for exchanging information.

Findings from the MOBISTYLE focus groups showed that health is an important motivating factor to trigger user's attention [9, 10]. Many aspects of human health, physiology, and behaviour are dominated by the exposure to surrounding conditions. Therefore, the way different generated indoor environments (requiring a certain energy use) affect user's health and well-being is explored in the MOBISTYLE project.
Even if demo cases in MOBISTYLE project are quite different, the approach to the awareness campaign is uniform since the main objective is the same (i.e. energy savings due to behavioural change). This uniformity should not be applied to the communication to the user that should be tailored to the different types of the demo cases' users. As demonstrated in literature, long-term and continued interactions with them is a pre-requisite for an effective awareness campaign. Thus, even if in MOBISTYLE ICT solutions represent a valuable effort and necessary technology for delivering data and feedbacks to the users, continuous interaction with occupants through a mixture of communication channels is essential.

Summarizing the uniform approach used in MOBISTYLE awareness campaign is the following:

- Audience definition for delivering tailored messaging,
- Communication objective identification,
- Establish the previous knowledge of the audience on MOBISTYLE, health, comfort and energy savings,
- Barriers and obstacles to behavioural change identification,
- Demonstration of clear and easy results already achieved through behavioural change campaigns.

The awareness campaign strategies developed in MOBISTYLE, incorporate different types of communication mediums and the assessment of targeted audience identifies the best medium to use in order to better reach users. Moreover, targeted audience will influence the elaboration of the information (different types of users identified during the focus groups, recommendations from [9] and [10]). In any case, the framing messaging should be simple and memorable (sticky); advices and hints should be practical and the recommendation easily applicable, since it is easier for the users to modify their behaviour. For this reason, information should be provided in a clear way, to avoid lack of awareness and mistrust. Thus, the use of national language is essential to educate users (also on using MOBISTYLE tools). Furthermore, privacy issues and data security should be explained carefully to the users.

The following table shows examples of information translation to give the users the right knowledge to change their behaviour. The KPIs presented for each advice are extrapolated from Tables 12, 13,14, then the advice texts led to the people should be adapted to different users and situations (and different infrastructures as well)

Advice text	Field addressed	KPI	Brief explanation	Reference
The building (apartment) was responsible for X kg of CO_2/PM_{10}	ENERGY – IEQ- HEALTH	• Emission of $CO_{2equivalent}$ • PE	Can be calculated using emission factors	EU. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) [35]
People who use stairs have 15% more chances to live to the old age.	ENERGY - HEALTH	• Electricity consumption • Daily Activity	Taking the stairs saves X Wh of electricity, 1 minute of walking up or down the stairs uses 9,3 kcal (10,8 Wh or heat 1 l of H2O for 9,3 °C)	Stair use for cardiovascular disease prevention Philippe Meyer European Journal of Cardiovascular Prevention and Rehabilitation 2009,16 (Suppl 2):S17–S1 [36]
Exercise your thermoregulary system for increased energy expenditure capacity and resilience to extreme weather conditions!	IEQ - HEALTH	• Operative Temperature, PMV	Need to exercise our thermoregulatory system as part of a healthy lifestyle (use it or lose it). By regular exposure outside the thermoneutral zone: - Increase energy expenditure capacity - Increase resilience to more extreme weather conditions (important for healthy aging)	Healthy excursions outside the thermal comfort zone [37] Cold exposure – an approach to increasing energy expenditure in humans Article in Trends in Endocrinology and Metabolism · January 2014 DOI: 10.1016/j.tem.2014.01.001 · Source: PubMed [38]

Decrease the humidity and reduce asthma and allergy symptoms	IEQ - HEALTH	• Indoor air quality category (humidity) • Level of relative humidity • POR • Respiratory desease	*reductions in asthma and allergy symptoms if the moisture problems were prevented*	Health and productivity gains from better indoor environments and their relationship with building energy efficiency William J. Fisk Annu. Rev. Energy Environ. 2000. 25:537–66 p9 [39]
Due to drifting temperature, we saved X €.	ENERGY - IEQ	• Operative Temperature • Costs for electricity consumption • Cost for natural gas consumption • Costs for District Heating consumption • PMV • PPD • Thermal comfort category (adaptive approach) • POR	Temperature training (in peak hours)	Occupant responses and office work performance in environments with moderately drifting operative temperatures http://dx.doi.org/10.1080/10789669.2009.10390873 [40]
Turn off the lights and save your eyesight. After all, it is sunny outside!	ENERGY - IEQ	• Maintained luminance • UGR • Sleepiness	Lower melatonin secretion was independently associated with a subsequent obesity risk in a general elderly population.	Lower Melatonin Secretion and Obesity Risk: Longitudinal Analysis of Population-Based Prospective Cohort Study http://press.endocrine.org/doi/10.1210/endo-meetings.2016.OABA.8.FRI-638 [41]
Level of light in your work environment is not sufficient: increase the amount of daylight or use lights.	IEQ	• Maintained luminance	Eg. 500 lux lecture room and office, 100 hall	EN 12464-1 [42]
You should sleep more.	HEALTH	• Sleepiness	Give advice based on personal profile and sleep pattern monitoring by a wearable (less than 7 h for an adult not recommended)	Recommended Amount of Sleep for a Healthy Adult: A Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society Sleep. 2015 Jun 1; 38(6): 843–844. [43]
The cheaper energy tariff starts at X and finishes at Y h. Meanwhile, you can turn on the dishwasher.	ENERGY	• Electricity consumption • Costs for electricity consumption		McKENNA, E., GHOSH, K. and THOMSON, M., 2011. Demand response in low-carbon power systems: a review of residential electrical demand

				response projects. 2nd International Conference on Microgeneration and Related Technologies, Glasgow, UK, 4th-6th April. [44]

Table 17: Information for the users

The feedbacks identified in Table 17 could be delivered in different manners to the users, for example through screens at the entry areas, information booklet in common areas, they could have paper version rather than IT posts. The following is an example of messaging tailored to hotel guests.

> ***Example 1***
> *Technical message ideas hidden behind the users' information:*
> The building (apartment) was responsible for X kg of CO_2/PM10 yesterday
> *Sticky, catchy:* X trees are needed to absorb the CO2 emission from your room
> *Medium:*
> Screens at the room entrances, information booklet in hotel hall and reception. Paper version and IT posts. Frequent updates, with the daily visits of the receptionist, story boards. Telling them success stories.

The second phase of MOBISTYLE methodology related to awareness campaign will be based on a psychological theory called Theory Of Planned Behaviour – TPB [45] and anthropological theories, such as the Theory of Practice – TP, as assessed on the book "The Dynamics of Social Practice: Everyday life and how it changes"[31].

In the following bullet list, key points to be known are reported, accordingly to the TPB. They are required to predict whether a person intend to change his/her lifestyle towards a more energy-conscious behaviour:

- Whether the person is in favour of doing it (attitude);
- How much the person feels social pressure to do it (subjective norm)
- Whether the person feels in control of the action in question (perceived behavioural control);

By leveraging on these predictors, the chance that the person will intend to adopt a desired behaviour. and the chance of the person actually performing the behaviour in question could be increased.

In the first phase of awareness campaign, qualitative information related to users' needs and expectation, like age, gender, provenience, etc. were collected and then, an inventory of user needs and expectation and a protocols for the Focus group "Observation of users" energy consumption habits were prepared [9, 10]. The anthropological approach enabled to gain "thick data" with an in-depth understanding of human behaviour, (main motivation factors for them in their daily habitual patterns e.g. financial savings, health, environmental awareness), which is able to penetrate beyond the individual behaviour [46]. A specific questionnaire based on TPB [45, 47] will be applied to collect measures related to attitudes, subjective norms, perceived behavioural control and intention allow the definition of personalized goals for each users.

These qualitative data will be then supplemented in the second part of awareness campaign by quantitative "big data", collected via the MOBISTYLE technological ICT solutions. The second part of the awareness campaign then is focused on collecting quantitative information using a shared action plan between the different case studies. The main outcome of this action plan to highlight the optimized objective(s) of the behavioural change campaign, what are the main action that users could perform and could be influenced on performing and the monitored variables (actual energy use and

individuals' drivers and attitudes explored in TPB [45, 47]. Scenarios of behavioural change intervention in the different demo cases then will be derived and implemented into the app.
Using the questionnaire results, personalized short-term goals will be translated in actionable (behavioural changed) tasks to be performed by the users, also considering possible environmental constraints. One possible usage of the app is to track the performed behaviours to let individual assess himself/herself the behavioural performances: the app will be useful to help people to achieve the tailored task with personalized information and it will stop when the individual meets the desired goal or lower the degree of the proposed task.

5.1 Development of Stage II MOBISTYLE Behavioural Change Methodology [1]

The following chapter presents a guideline for elaboration of the MOBISTYLE questionnaire that will serve as a foundation when applying phase II of the MOBISTYLE behavioral change methodology, including the user awareness and engagement campaigns along the project lifetime (ensuring large-scale uptake).
The core concepts for the development of the questionnaire are drawn from a psychological theory called Theory Of Planned Behavior – TPB [45] and anthropological theories, such as the Theory of Practice – TP, as assessed on the book "The Dynamics of Social Practice: Everyday life and how it changes" [31]. Accordingly to the TPB (Figure 8), to predict whether a person intend to change his/her lifestyle towards a more energy-conscious behavior, we need to know:

- Whether the person is in favor of doing it (attitude)
- How much the person feels social pressure to do it (subjective norm)
- Whether the person feels in control of the action in question (perceived behavioral control)

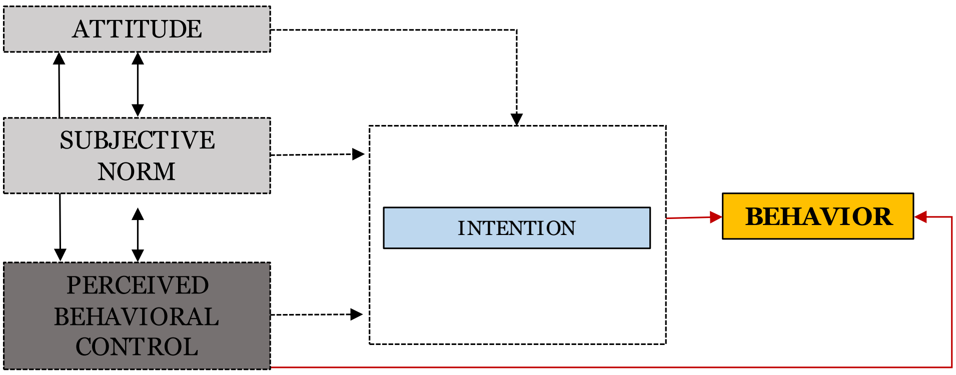

Figure 8. Structure of the Theory of Planned behavior [45]

By leveraging on these predictors, we can increase the chance that the person will intend to adopt a desired behavior and thus increase the chance of the person actually performing the behavior in question.

Methodology

Stage I

During Stage I, we collected "thick data" (qualitative information) related to users' needs and expectation. Outcomes of Phase I (WP2- IRI-UL) included:

[1] This chapter is developed as part of WP2 by S. D'Oca, A. Tisov and D. Podjed

Phase 1: Identification Phase. Different user groups were identified by a short online survey. Questions were focused on two categories (Part 1 and 2). In Part 1 of the questionnaire we collected data about age, gender, provenience, etc. In this part we took into account that personal data is also sensitive from ethical point of view. In Part 2 we carried out an overview of participants 'daily habits, energy consumption, use of home and work appliances, organization of space, etc.
Phase 2: Need's Analysis. Results of the survey have been used to prepare:
An inventory of user needs and expectation.
A protocols for the Focus group "Observation of users' energy consumption habits. "
We firstly performed a workshop for the creation of persona. The participants got a task to create 3-4 typical users as they imagine them – from their personality and biography to physical characteristics. A persona encapsulates a distinct set of behavior patterns which are identified through the analysis of interview data, and supported by supplemental quantitative data as appropriate.
We then performed focus groups of 5-7 users per country, different age group, gender, profession, technologies used at home and work, etc. = 30 users total, in which we asked participants to express their opinion on the identified personas.
Phase 3: people center development: The total 30 users will be employed for long-term in-depth study and engagement in product development and usability testing.
The qualitative approaches we used in Stage I have proven to be especially effective to track group dynamics and understand social patterns beyond individual behavior, especially in gathered communities. The anthropological approach enabled us to gain "thick data" with an in-depth understanding of human behavior, (main motivation factors for them in their daily habitual patterns e.g. financial savings, health, environmental awareness), which is able to penetrate beyond the individual behaviour [46]. These qualitative data will be then supplemented in Stage II by quantitative 'big data', collected via the MOBISTYLE technological ICT solutions (using the Holonix app in combination with indoor environmental sensors).

Stage II

In Stage II, we aim to collect quantitative information and we propose a shared action plan among different case studies. This action plan includes, for each of the Demo Cases, a full description of:

- Optimization objective(s) of the Behavioural Change Campaign;
- Definition of Action(s) that can be taken (and influences) from the users;
- Definition of the variables that can be monitored, related to:
    - actual energy usage (using indoor environment monitoring systems and smart meter data).
    - user's motivational drivers, attitudes, subjective norms and perceived behavioral control (using the questionnaire as a foundation of the app system architecture).

Based on to the information made available from the focus groups (Phase I), together with data coming from sensors, wearables and questionnaire responses, accordingly to the action Plans, during Phase II we will build scenarios of behavioral change intervention in the different demo cases to be implemented into the app (see Figure 9)

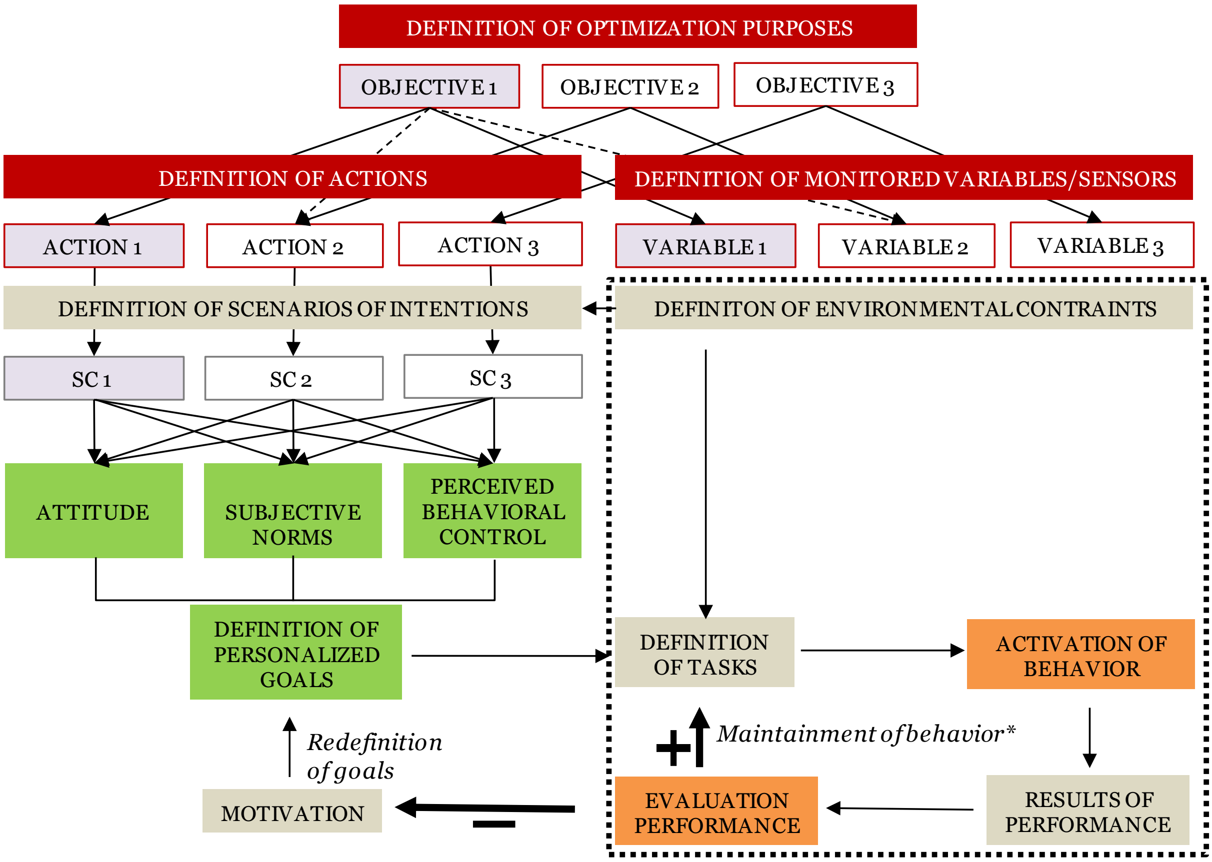

Figure 9. Structure of the Behavioral Change Intervention Action Plan, including the data gathering from sensors and questionnaire, and its implementation in to the app.

Demo Cases

Behavioral interventions are designed to change the behavior of specified users. We target to deploy separate behavioral change intervention for 3 different demo cases.

Target users per year	Demo Case
270	Offices (Ljubljana University)
1000	Homes (Polish Demo Case)
8030	Hotels (Torino Demo Case)

Elicitation Studies

The TPB questionnaire will be developed starting from the outcomes of elicitation studies conducted among small sample of people (i.e. 5 users) selected from the population we will be addressing with the app-questionnaire. We will use open-ended questions, which are normally presented in one-to-one interviews and focus groups. These 5 people can be the same selected for the focus groups developed as part of Phase I the activities of WP2.

Pilot of the questionnaire

We plan to ask 5 people from the relevant population of the three demo cases to answer a draft version of the questionnaire and whether they experienced any difficulty answering it. If necessary, grammar and wording of the questions will be modified after the focus groups.

We plan to test the proposed Behavioural Change Methodology, including a full version of the app-questionnaire, in the offices of the Ljubljana University. The design, administration and result analysis of the TPB questionnaire builds upon the experience gathered together with a pool of interdisciplinary experts in the context of Annex 66 proposing an integrated research framework for studying employees' behaviors in university buildings based on the TPB [47].

Administer the questionnaire

A finalized version of the questionnaire must be administered to the users of the 3 demo cases through the app. The MOBISTYLE app will help the user transform the intention to change behavior into actual exercised behavior, by following the schematic illustrated in Figure 10.

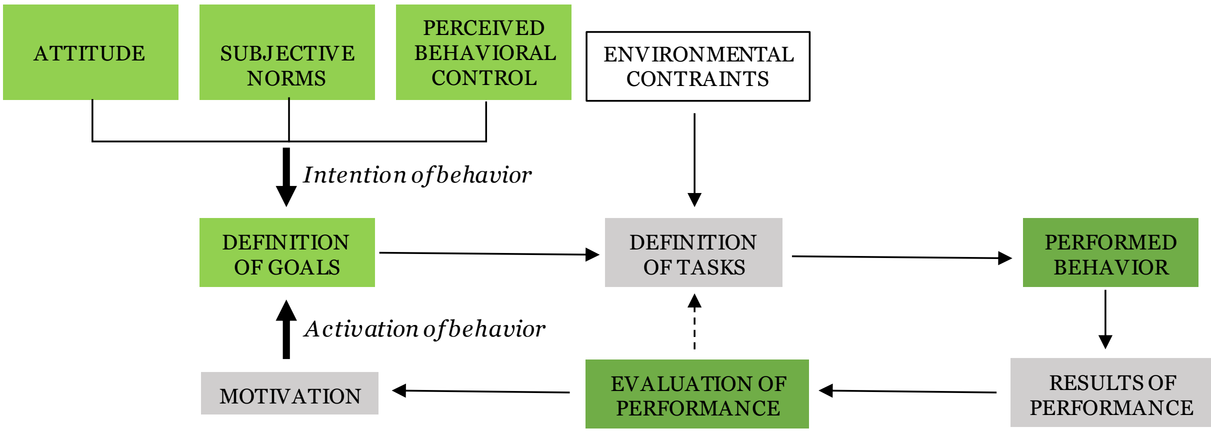

Figure 10. System architecture of the app functioning. Green boxes indicate inputs/action required from the user, while gray boxes indicates activities performed by the app.

1) First, the collection of measures related to attitudes, subjective norms, perceived behavioral control and intention allow the definition of personalized goals for each users.
2) Secondly, personalized short-term goals are translated in actionable (behavioral changed) tasks to be performed by the users, also considering possible environmental constraints.
3) Thirdly, the app will keep track of results of the performed behaviors.
4) The user will be free to personally evaluate the performance of his/her behavior.
5) The app will regularly prompt the user with motivational feedbacks (actionable tasks) to help the user achieving the activation of the tailored task-behaviors.

Whether the user will evaluate he/she has meet the personalized goals (contentment), then the app can stop working. Otherwise, the user can re-set the definition of task to a lower degree (i.e. increase the temperature from 19 °C to 20 °C), gradually engaging into more challenging behavioral change goals

6 Conclusion

This report presented the research activities within WP3 during the first twelve months of the MOBISTYLE project. The main contents of this report addressed the following key aspects:

- Develop and deploy a methodological approach for setting up an effective monitoring and engagement campaign that includes feedback on energy, Indoor Environmental Quality (IEQ), and health aspects.
- Develop benchmarks, such as historical energy consumption data of the case studies or findings of existing studies and norms, to which the data obtained during the engagement campaign can be compared.
- Propose solutions to overcome energy and environmental inefficiency due to poor operation or lack of information.
- Transform gathered energy, health, and IEQ data into meaningful information and useful knowledge to raise awareness for the building users.

In particular, this deliverable gave insights into the definition and contents of various methodological steps, which are considered to be the bedrock for setting up an effective monitoring plan and subsequently a successful engagement campaign.

First, the report provided an overview of the methodological framework highlighting the importance of an interdisciplinary approach that involves competences and knowledge from different fields. The general vision of the defined methodology is followed by in-depth insights into the various research steps that consisted in (1) Parameter definition, (2) Data collection, (3) Data analysis, (4) KPI definition, and (5) Awareness campaign.

Detailed information on the building characteristics of the MOBISTYLE testbeds (e.g. historical energy consumptions, installed HVAC systems, installed monitoring systems, and communication protocols, functional zones, typical occupancy profiles and others) were collected and systematically structured. This document provided an overview of parameters that should be collected in the various MOBISTYLE case studies and a preliminary definition of sensor typologies that could be used to collect the data. Then, based on the defined parameters, a special focus was put on the definition and description of the Key Performance Indicators (KPIs) for energy, IEQ, and health. Along the lines of the KPI definition, data analysis approaches were established in order to transform the monitored (or raw) data into functional KPIs, hence, providing applicable information for the IT and platform developers (WP4 and WP5). The last section of the report focused on the key task of WP3 concerning the transformation of the KPIs into useful and understandable information for the end-users. The established KPIs were evaluated for their expected level of comprehensibility by the building occupants. Furthermore, this document outlined a first overview on potential energy awareness campaign strategies for engaging different types of end-users/persons to adopt a more healthy and energy-conscious behaviour in the long-term.

Next steps of research will include (i) the definition of a validation procedure to test the effectiveness of the proposed methodological framework, (ii) the definition of detailed benchmark values based on the first monitoring phase of each testbed, without any form of feedback, (iii) development of KPIs related to occupant behaviour that permit to further enhance the quality of feedback.

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