MOBISTYLE

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

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Summary

This report presents the research activities within WP3 during the second year of the MOBISTYLE project. The structure of the report follows the definition of various monitoring periods and evaluation steps that were individuated in order to test the effectiveness of the combined feedback campaigns and the economic performance of MOBISTYLE solutions.

The first section of the report highlights that planning for an evaluation and the development of ad-hoc evaluation methodologies in advance can help to overcome unexpected evaluation challenges at the different MOBISTYLE case studies, lead to more useful results, and improve the optimization process of the project. Furthermore, the importance of taking into account non-market and external benefits of MOBISTYLE solutions application on key impact areas (e.g. indoor environmental quality, health, etc.) is underlined by the introduction of the Cost-Benefit Analysis methodology in the MOBISTYLE evaluation strategy.

The second section of the report provides a detailed description of the MOBISTYLE monitoring periods and evaluation steps that should be tailored for each MOBISTYLE testbed. This part describes the aim and durations of the monitoring periods and an overview of "what" should be evaluated, or rather which parameters should be analysed, in order to get a deeper insight on the **outcomes** of the MOBISTYLE project during (intermediate evaluation) and at the final stage (final evaluation) targeting energy use, health, indoor environmental conditions and behavioural change. On the other hand, this first section also provides information on which parameters should be investigated in order to evaluate the **process** of the proposed MOBISTYLE methodology itself. Two alternative strategies are investigated addressing the testing of behavioural persistence (**impact** evaluation) and the testing of feedback in selected target groups.

The third section is aimed at showing "how" the parameters defined in section 2 can be quantitatively and qualitatively evaluated by providing recommendations for case study holders to evaluate the MOBISTYLE outcomes in the individual testbeds. In particular, this section provides general **guidelines** for three essential monitoring phases (M0, M1, M2) and follow-up evaluation steps (E1, E2, E3) that have to be tailored to the needs and peculiarities of the individual MOBISTYLE testbeds.

The fourth section is focused on cost benefit analysis as a tool to measure the economic performance of MOBISTYLE project, by assessing its positive (benefits) and negative outcomes (costs). The section is structured in sub-sections according to the main steps of the Cost-Benefit Analysis method. Each sub-section starts with the main theoretical issues and then provide some suggestions about its application to MOBISTYLE demo cases. The main topic related to this part of the evaluation strategy lays in the opportunity to include all the possible direct and indirect effects that the digitalization of a building with concurrent provision for personalized ICT-based knowledge services can bring, assuming the perspective of the occupants and, more in general, of the society. In this sense the Cost-Benefit Analysis is a proper economic tool, allowing to include in the appraisal both market and non-market benefits of MOBISTYLE applications.

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1 Introduction

Extended literature in the field of project management has highlighted that the evaluation process should not be an afterthought [1][2]. Planning for an evaluation and developing ad-hoc evaluation methodologies beforehand can help to overcome unexpected evaluation challenges by mitigating risks in advance (e.g. definition of parameters that have to be evaluated to answer certain research questions or to verify if the project goals were achieved, timing of the project), lead to more useful results, and improve the optimization process of the project. Indeed, planning the evaluation helps articulating research goals and identifying areas for improvement. Evaluation can also be a beneficial tool for communicating project results and demonstrating the effectiveness of deployed strategies. An evaluation should be driven by a specific set of questions, which are the foundation of all evaluation efforts, and that can focus on any stage of a project and generally fall into one of the following categories: Outcome evaluation, impact evaluation, and process evaluation.

The **outcome evaluation** determines how well the desired outcomes and associated objectives for a project are met. In the MOBISTYLE project, this refers to achieving pre-set goals in terms of energy savings, improved indoor environmental quality and well-being of the occupants (Figure 1). These goals are meant to be achieved by a pro-active change of the occupants' behaviour, which therefore has to be tackled as a key parameter during the evaluation process. The **impact evaluation** assesses longer-term changes in social, economic, and environmental conditions, as well as long-term maintenance of desired behaviours [3]. This type of evaluation addresses if the occupants adopt the new behaviour in their daily routines in a long-term perspective and if pre-set goals can be maintained during time. The **process evaluation** analyses the development and implementation of a project in different stages by assessing whether strategies were implemented as planned, and whether expected outputs were produced [4][5]. This type of evaluation allows for identifying possible optimization and improvements of the implemented MOBISTYLE strategies.

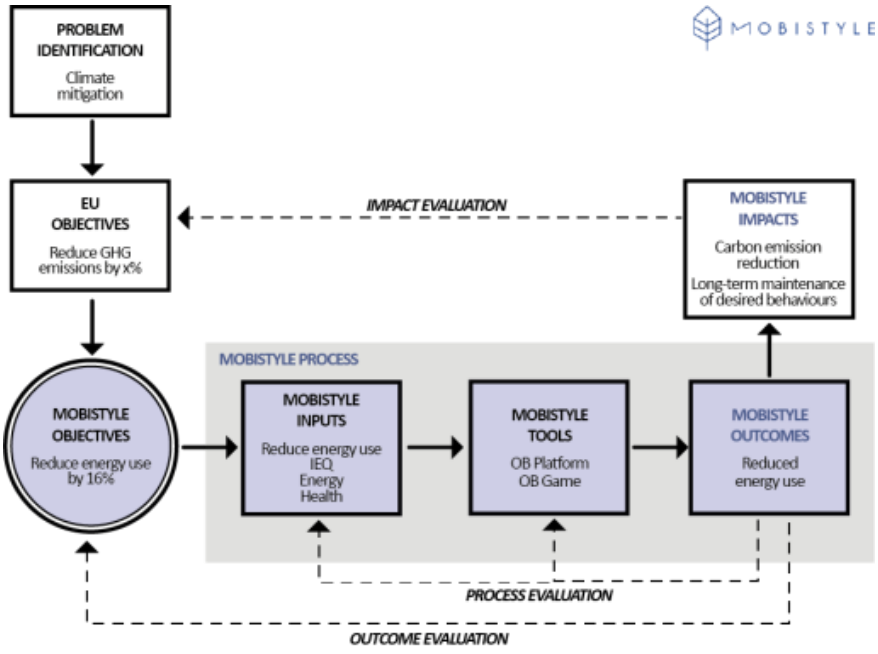


Figure 1: Overview of the overall evaluation process.

The MOBISTYLE evaluation strategy is hence designed to evaluate the project's effectiveness (estimating the extent to which the project's outcomes meet its objectives) and the project's relevance (identifying if the project's goal are responding to the identified users' needs).

A key objective of the proposed evaluation strategy is to define methods that allow for assessing the amount of energy saved during and at the final stage of the MOBISTYLE project. Particularly, energy savings refer to the reduction in energy use in the case studies resulting from the implemented MOBISTYLE solutions. This means that variations due to other boundary conditions that impact the variation of energy uses should be excluded from the evaluation, such as strong seasonal variations, changes in occupancy, or other contextual factors (e.g. investments in energy efficiency or conservation strategies that are not related to MOBISTYLE) (Figure 2). The outcomes of MOBISTYLE energy savings should hence be described as the observed change in energy use by participants and exclude any change that is not caused by the project [2].

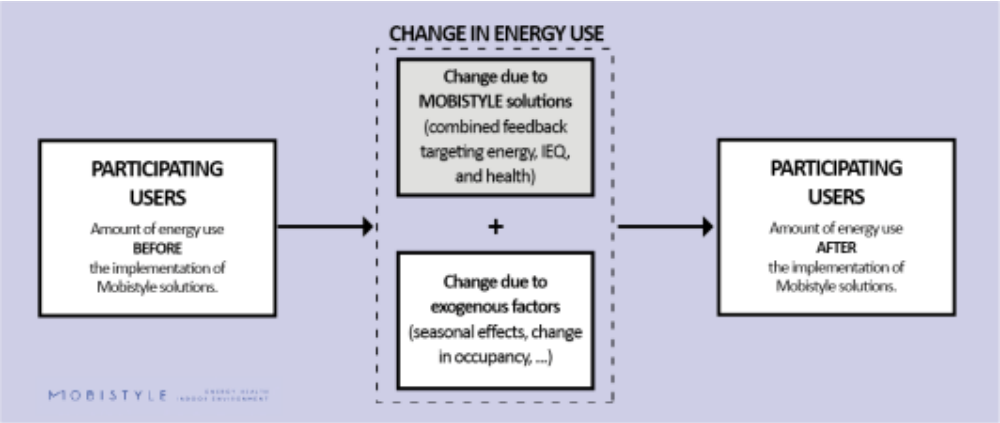


Figure 2: Change in users' energy use.

The MOBISTYLE evaluation strategy also provides a framework to develop a Cost-Benefit Analysis, in order to assess the economic performance of the application of MOBISTYLE solutions in buildings where a central role is attributed to the users as active components of the system In particular, outcomes of MOBISTYLE applications have to be evaluated against a counterfactual scenario to define if they include some additional costs and benefits to be quantified, monetized and discounted in order to calculate some economic indicators that enable the evaluator to judge the project from the point of view of its social performance. To do this, the methodology reported asks for the computation of initial and running costs and running financial benefits (namely the energy billed saving) of MOBISTYLE applications on the demo cases, to which non-market and external benefits should be added. In particular, thanks to this economic evaluation tool, benefits related to very important issues for MOBISTYLE project like indoor environmental quality and health can be included in the appraisal.

1.1 Aim of the report

The final aim of this report – in a broader perspective – is to provide a uniform and replicable evaluation strategy that allows for assessing the outcomes and impacts of a multidisciplinary engagement campaign aimed at enhancing the state of the art of information, knowledge, and insights on satisfied, healthy, and energy-efficient occupant behaviour in the building sector. This report also focuses on the

evaluation, the development and the implementation of such a project in different stages for exploiting optimization opportunities during the process.
For the MOBISTYLE project, the research activities described in this report aim at providing a guideline for assessing the evaluation in the different MOBISTYLE testbeds during different project stages and at verifying whether MOBISTYLE goals were achieved.

2 Evaluation method: Detailed monitoring periods and evaluation steps

To set up an effective evaluation process during the entire project, the proposed MOBISTYLE evaluation strategy consists of three monitoring periods (M0, M1, M2) alternated with follow-up evaluation steps (E1, E2, E3).

The MOBISTYLE monitoring campaign is divided in three essential **monitoring periods**:

- Initial monitoring (M0)
- Feedback provision (M1)
- Optimized feedback provision (M2)

Each monitoring period is followed by an **evaluation step**:

- Benchmark definition (E1)
- Intermediate evaluation (E2)
- Final evaluation (E3)

Over time, monitoring periods and evaluation steps are planned to be implemented in 6 steps scheduled as follows (Figure 3):

0 - Initial monitoring (M0)
1 - Benchmark definition (E1)
2 - Feedback provision (M1)
3 - Intermediate evaluation (E2)
4 - Optimized feedback provision (M2)
5 - Final evaluation (E3)

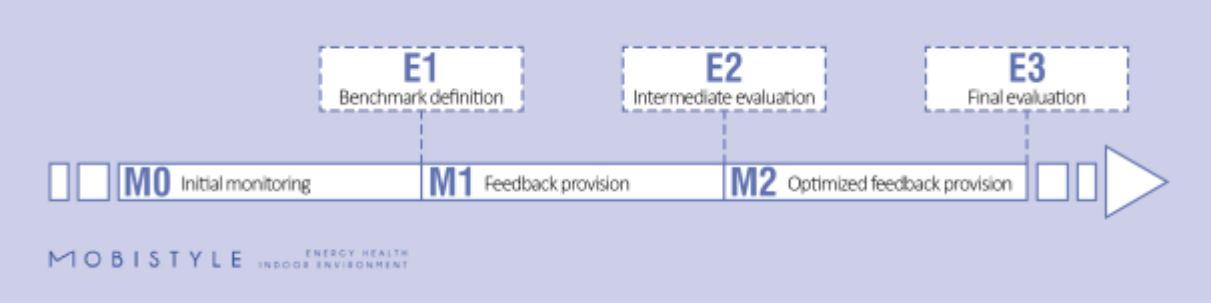


Figure 3: The MOBISTYLE evaluation strategy.

N.B: If during the monitoring period the occupants change (change in terms of occupants themselves or their number), then, a new cycle will begin (stage 1 to 5).

In this section, the objectives and content of three strategic monitoring periods (M0, M1, M2) and evaluation steps (E1, E2, E3) are described in detail. Tailored timelines including these steps shall be defined for each MOBISTYLE testbed for ensuring an effective and well-planned evaluation process.

2.1 0 – Initial monitoring (without feedback provision) (M0)

The aim of the initial monitoring period is to gather data for measuring and **assessing the baseline performance** in the project testbeds [6]. In each testbed, selected parameters (D6.1 - "Detailed final monitoring, awareness and information campaigns") [6] are measured and, if necessary, transformed into meaningful KPIs that describe the trends of energy consumption, indoor environmental quality, and health aspects, before the implementation of the MOBISTYLE services. The data collected in this initial phase hence serve as a comparative etalon in the evaluation process and will underlie the calculations required for the benchmark definition (E1). During the initial monitoring period, no service or feedback will be provided, for capturing the "usual" daily routines and habits of the occupants and the impact of the latter on the energy consumptions and indoor environmental conditions. During this phase, the only influence on the occupants might be an effect described by Hawthorne [7][8] in which 'subjects may behave differently, because they are aware that they are being studied.' However, this effect might slowly fade away if the users are observed for a sufficient amount of time (rebound effect).

For providing a reliable evaluation of the baseline performance, the duration of the initial monitoring phase should account for around **30% of the entire monitoring period**.

In this context, it is important to consider changes in occupancy in the single testbeds (e.g. hotel) since benchmark values might vary significantly among different occupants. Therefore, if occupants change during ongoing activities, this initial monitoring procedure should be repeated to establish an ad-hoc baseline.

Example: *in the Italian case study (hotel), at any time a new guest might arrive and stay for 8 months: in this case, the monitoring reference period should be repeated in the initial 2 months of the new occupation period.*

2.2 1 - Benchmark definition (E1)

The first evaluation step, or rather the benchmark definition, is aimed at analysing the collected data in M0 to provide a structured assessment of the baseline performance in the testbeds. The benchmark definition is used to measure performance using specific indicators resulting in a metric of performance that is then comparable to the same indicators in future evaluation steps (E2, E3). This evaluation step should include analysis and descriptive statistics on:

- **Benchmark values and trends of each defined Key Performance Indicator (KPI):** the data analysis allows for defining reference values of KPIs in the areas of energy, IEQ, and health (D3.1 "Detailed monitoring and information campaign parameters based on combined feedback")[9]. The reference values should be expressed in meaningful units of measurement and eventually be normalized based on specific parameters (e.g. number of occupants, Heating Degree Days, floor area).

- **Behavioural patterns of the occupants:** the interactions of the users with the technical building systems, building components (e.g. doors, windows) and home appliances should be reported and analysed for having a baseline behavioural profile. Particularly, the analysis of behavioural patterns should include:
  - Load profiles (energy use per individual building service as detailed as possible)
  - Average values/preferences in terms of IEQ parameters (e.g. T_{in}, CO_2)
  - Occupation patterns (e.g. time spent in the different indoor spaces)
  - Specific interactions with technical building systems, building components and home appliances (e.g. number of window/door openings, temperature control, blinds control, lighting control, usage of home appliances)

Furthermore, before providing feedback to the end users, the proposed ICT solutions (dashboard, mobile application) and feedback typologies should be tested with focus groups of the MOBISTYLE testbeds for optimizing their usability and functionalities. In this context, MOBISTYLE partner IRI-UL developed a **usability testing protocol** that investigates user expectations, intentions and experiences during a first approach of the users with the ICT solutions (see Annex A).

2.3 2 - Feedback provision (M1)

The second monitoring period includes the **provision of MOBISTYLE services and feedback through ICT tools** (dashboard, mobile application) to the end users and represents the core of the project. The data collected in this second monitoring period allows for assessing a comparative analysis to evaluate the changes in behaviour and related impacts on energy consumption, indoor environmental quality, and well-being of the occupants. Detailed information on the feedback typologies and implemented ICT solutions in individual testbeds can be found in D6.1 ("Detailed final monitoring, awareness and information campaigns")[6].

For achieving an effective change in behaviour, the monitoring period with feedback provision should account for at least **30% of the entire monitoring campaign**.

2.4 3 - Intermediate evaluation (E2)

The intermediate evaluation is aimed at gaining a first insight on the achievements of the MOBISTYLE strategy and implemented ICT solutions. This step allows for overseeing the current outcomes of the implemented strategies and the verification of a successful process. At this stage, it is possible to exploit first results for improving and optimizing feedback and other factors that might to some extent act as obstacle to the effectiveness of the proposed solutions (e.g. problems related to the usability of the ICT solutions, ineffectiveness of the provided feedback, difficulties in achieving energy saving goals).

An **outcome evaluation** assesses the effectiveness of the awareness campaign at an overall level of the project as well as in individual MOBISTYLE testbeds. This consists in a comparative analysis of specific KPIs defined during the benchmark definition (E1) and includes the evaluation of:

- **Energy savings:** The amount of energy used before (M0) and after the feedback provision (M1) is evaluated. It is necessary to consider external constraints (e.g. vacation period, long absence

period, seasonal variations). In this case, it is suggested to remove as much as possible data related to these irregular patterns; and consequently calculate the resulting energy savings. This result can be obtained by direct measurements or dynamic energy simulations.

- **Greenhouse Gas (GHG) emissions:** Once the amount of energy used is calculated, it is possible to link the results to the impact on the environment of each MOBISTYLE testbed. It is measured applying the conversion factors for primary energy (calculated for the used electricity or thermal energy typologies).

- **Indoor Environmental Quality (IEQ):** Variations of IEQ throughout the period M1 with respect to M0. The profile of IEQ parameters over time should be analysed. Main descriptive statistical parameters should be obtained: mean hourly values, standard deviation, minimum and maximum values during the investigation period, frequency distribution and cumulated frequency.

- **Health:** Questionnaires during the static and during the dynamic indoor environment (Dutch case study) will be delivered to the involved users. Moreover, body temperature, heart rate and physical activity will be recorded in a subset of participants. A comparison between the two different indoor conditions will be compared in two different seasons. The questionnaires are related to comfort, sensation, sleepiness, alertness and well-being.

- **Behavioural change:** Questionnaires before (M0) and after the feedback provision (M1) will be delivered to the involved users. The investigations for assessing the behavioural change include: knowledge on MOBISTYLE project and its progress, change on comfort preferences and satisfaction and health-related aspects. Behavioural patterns should be compared before (M0) and after the feedback provision (M1) to assess the change of users' interactions with technical building systems, building components and home appliances. These interactions patterns involve: number of window/door openings, temperature control, blinds control, lighting control, usage of home appliances (e.g. analysis of instant power data related to individual devices). These trends should be correlated with IEQ conditions and (human) body parameters if available and the type, quantity and the quality of monitoring data allow the elaboration.

Furthermore, a **process evaluation** for a potential optimization and improvement of the implemented process shall be assessed. Separate evaluation for each category of provided feedback (for example, advices related to temperature control or stand by usage of home appliances) shall be performed. In this case, a comparative analysis of specific KPIs defined in the benchmark (E1) is needed for evaluating the results.

Questionnaire assessing the **usefulness of feedback** from the user's point of view shall be provided and addressed to the MOBISTYLE champions (designated person per building, always the same):

- **Typology**: Different feedback category will be analysed and compared in terms of achieved results. For example, it is possible to compare feedback related to heating, lighting, home appliances with the final energy used for heating, artificial lighting, home appliances to calculate where the major savings are obtained.

- **Time-frequency**: Efficacy of feedback frequency (hourly, daily, or continuous) leading to increased user awareness and the best results in terms of behavioural change shall be assessed.

- **Communication content:** The efficacy of the following characteristics should be verified for the provided feedback
  - Type (numerical, graphical),
  - Communication strategy (prompts, pop-up message, educative advices, serious game, newsletters),
  - Length (concise/long),
  - Wording and design (efficacy of the chosen terms in the message),
  - Content (antecedent, i.e. announcing the availability of positive or negative consequences; consequent, i.e. providing advices about the action carried out at that specific moment),
  - Credibility (coherency of provided feedback),
  - The level of detail of the provided information.

- **Tools:** The efficacy of paper-based (poster, brochure) or ICT-based (mobile phone, website, email, room displays) communication media should be evaluated in terms of
  - Usability;
  - User-friendliness, ease of use, barriers;
  - Reliability;
  - User satisfaction/experience;
  - Adaptability for meeting research goals and expected energy savings.

The efficacy of the tools can be further evaluated by acquiring directly information from the ICT tools that allow for assessing:

- How frequently the users interact with the tools (analytics for sub-tools e.g. number of asked questions through the 'help' sub-tool) and the relation with the time of sending a notification;
- Length of use (number of hours, analytics for sub-tools);
- How many people downloaded the MOBISTYLE application.

2.5 4 - Optimized feedback provision (M2)

Based on the results and recommendations of the intermediate evaluation (E2), in this monitoring period data based on optimized feedback provision is collected. The gathered data will underlie the final evaluation of the MOBISTYLE project for evaluating if the project's goals were achieved.

The optimized feedback after E2 should be delivered for an appropriate period (around 25%) of the entire monitoring period.

Example: some typology of feedback might be more effective than another. If for instance a large amount of energy saving can be related to a specific electric device then this feedback should be prioritized. On the other hand, if a specific feedback is ineffective (does not lead to any improvement of energy uses, IEQ or health), it should be revised or eventually replaced.

2.6 5 - Final evaluation (E3)

In the final evaluation the same assessments of E2 should be performed. Particularly, the final evaluation is a comparative analysis between monitoring phase M2 (provision of optimized feedback) and monitoring phase M1 (feedback provision) and M0 (initial monitoring).

Moreover, this final evaluation step is aimed at verifying **if MOBISTYLE goals were achieved** in terms of:

- Energy savings;
- Number of end users
  - Changing their behaviour;
  - Understanding information about IEQ, energy and health;
  - Actively using the tools and services;
  - Finding information services usable and attractive;
  - Finding wearable technology meaningful and useful;
  - Embedding services in daily routines.

2.7 Alternative strategies: Testing behavioural persistence

Concerning the **impact evaluation** of the implemented MOBISTYLE strategy, it is necessary to understand to which extent the occupants adopt the new and more conscious behaviour in their daily routine once the MOBISTYLE project is over. According to the behavioural automatization process presented in D3.1, the **long-term behavioural change** can be described as follows (Figure 4):

- **Unawareness:** The occupants might not be aware if and/or how their behaviour might impact energy consumption, their indoor environment quality and their own well-being (“I don’t know that I don’t know”);

- **Learning:** With the help of the MOBISTYLE awareness campaign, the occupants learn about how their behaviour affects building energy use, the indoor environmental quality and their well-being (“I know that I don’t know”);

- **Habit formation:** The occupants start putting into practice the information they learnt and may develop a change in routine habits (“I know that I know”);

- **Internalization of behaviour:** The occupants adopt and internalize the new and more conscious behaviour and now act automatically (“I don’t know that I know”).

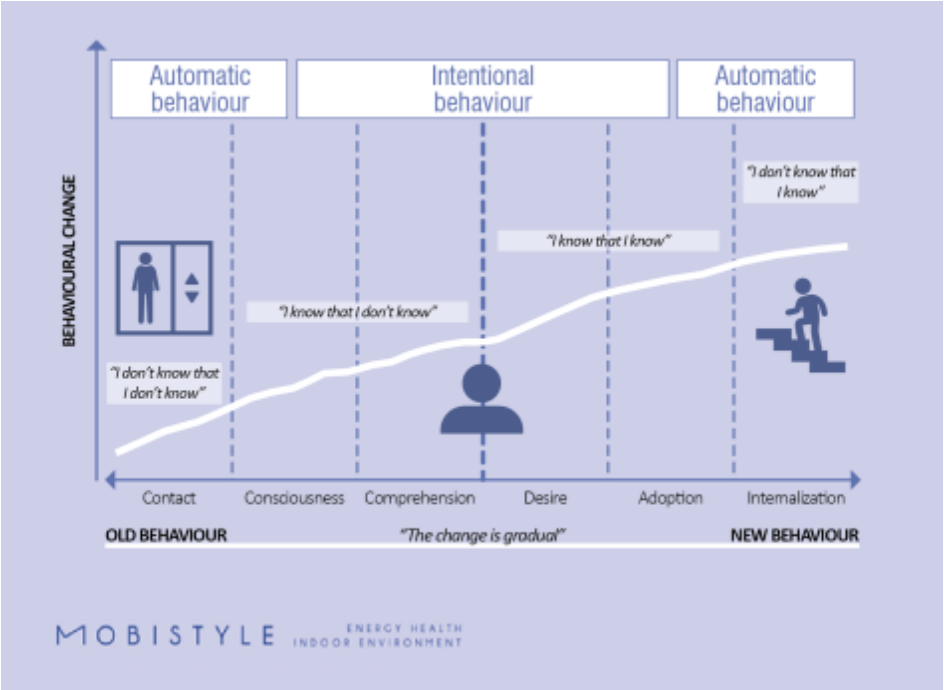


Figure 4: Behavioural change objective.

The main purpose of this alternative evaluation strategy is hence to test the behavioural persistence of the engaged occupants, or rather to verify if there is a long-term change in users' habits and the internalization of new behaviour as part of daily living and routines, also without active input from the MOBISTYLE team. In this case, the proposed evaluation process described in the previous sections should be extended by introducing a new monitoring period (M3) and another intermediate evaluation step (E3). In this circumstance, the final evaluation (E4) will occur after the M3. The schedule will then be changed as follows (Figure 5):

0 - Initial monitoring (M0)
1 - Benchmark definition (E1)
2 - Feedback provision (M1)
3 - First Intermediate evaluation (E2)
4 - Optimized feedback provision (M2)
5 - Second Intermediate evaluation (E3)
6 - Behavioural persistence (M3)
7 - Final evaluation (E4)

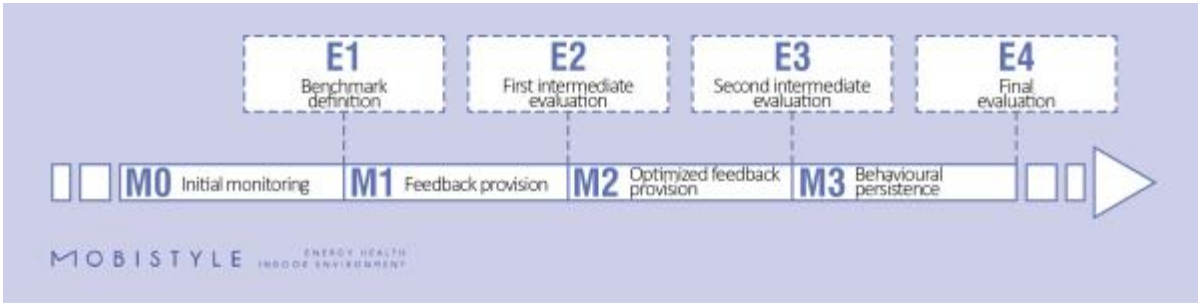


Figure 5: Alternative evaluation strategy: Behavioural persistence.

After the monitoring phase in which optimized feedback is provided to the users (M2), a second intermediate evaluation of achieved results shall be planned (E3). In this evaluation, the same impacts as in evaluation E2 are assessed. Particularly, changes in behavioural patterns shall be carefully analysed and compared to the outcomes in M1 and M2. In monitoring phase M3, should last enough time (10%-15%), monitoring will continue tracking IEQ, energy, health and behavioural patterns but feedback provision for the users will be interrupted in order to observe if the occupants will maintain the new behaviour also without MOBISTYLE tools and services.

The last stage of the procedure is the final evaluation (E4). With respect to the basic evaluation procedure, the final evaluation should specifically depict the tendency of the occupants to continue performing the new behaviour, saving energy and maintaining good IEQ and health conditions, while changing their lifestyle in a long-lasting manner. At this stage, the outcomes of the behavioural persistence analysis could contribute to investigating specific research questions on project outcomes on the long term, such as gaining a deeper knowledge on:

- The types of feedback that lead to the most effective behavioural change;
- Time thresholds necessary to induct behavioural persistence in the users after which tailored feedback is no longer needed;
- How communication design, tools, and feedback developed within the MOBISTYLE project shape perspectives for a long-lasting internalization of the new behaviour.

2.8 Alternative strategies: Testing feedback in selected target groups

In alternative to the basic evaluation procedure, it is also possible to divide the target audience of the awareness program into a few selected feedback groups, which need to be selected accurately for obtaining **homogeneous and comparable samples**. The key idea behind this approach is to understand impacts on occupant behaviour **when diversified feedback (or no feedback) is provided to comparable groups of end-users**. This strategy should only be applied if the sample size of potential target groups is big enough (e.g. Polish case study).

On one hand, this strategy allows testing the effectiveness of feedback provision or the effect of implementing optimized feedback strategies in M2. As an example, feedback could still be provided to one group, while feedback provision is stopped for another group during M2. On the other hand, another option could be providing optimized feedback to Group 1, while Group 2 still receives basic feedback as in M1. Depending on the purpose of testing feedback groups, different scenarios could be devised as illustrated below.

In this case, the evaluation procedure changes as follows:

0 - Initial monitoring (M0)
1 - Benchmark definition and feedback group definition (E1)
2 - Feedback provision (M1)
3 - First Intermediate evaluation (E2)
4 - Diversified feedback (or no feedback) options for different feedback groups (M2)
5 - Second Intermediate evaluation (E3)
6 - Behavioural persistence (M3)
7 - Final evaluation (E4)

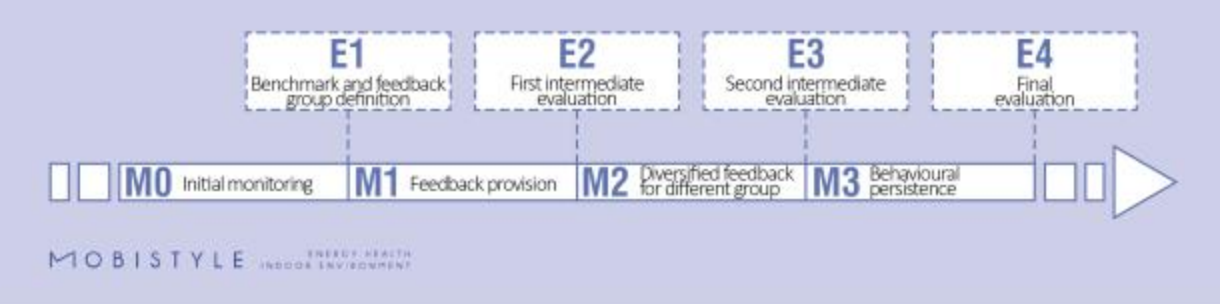


Figure 6: Alternative evaluation strategy: Testing feedback in selected target groups.

The following lines and figures present four potential scenarios in which feedback is tested in selected target groups. In the first scenario, after the monitoring period M0, people will be divided in two homogenous groups in stage M1 (Figure 7). One of these groups (group 1 in the figure) will be provided with feedback, while group 2 will continue not receiving feedback. In this scenario, the evaluation time E2 will select the most efficient feedback that will be provided in stage M2 to group 2. In M2 group 1 will not receive feedback, testing a short-term behavioural persistence. After the evaluation time E3, aimed at verifying the efficacy of optimized feedback on group 2 short-term behavioural persistence in group 1, both group 1 and group 2 will not receive any kind of feedback. The purpose in this case is to test long-term behavioural change on group 1 and the short-term efficacy of optimized feedback on behavioural change (evaluation E4).

In the second scenario, both group 1 and group 2 will receive feedback during the stage M1, while after the evaluation E1, in stage M2 optimized feedback will be provided only to group 1. Group 2 will be tested for short-term behavioural persistence. In stage M3 both the groups will be tested for behavioural persistence: long-term behavioural change on group 1 and the short-term efficacy of optimized feedback on behavioural change (evaluation E4).

The third scenario differs from the second scenario since during stage M2, both groups will be provided with feedback (optimized feedback to group 1 and “initial” feedback to group 2). In monitoring stage M3, behavioural persistence will be tested: in this case the purpose is to check if a longer period of initial feedback provision will produce the same behavioural persistence (and energy savings) of optimized feedback (E4).

The last scenario differs from scenario 3 during the monitoring stage M3, where only group 1 will be tested for behavioural persistence while group 2 will be still provided with optimized feedback. The evaluation in this case will the final energy savings due to a longer period of optimized feedback provision.

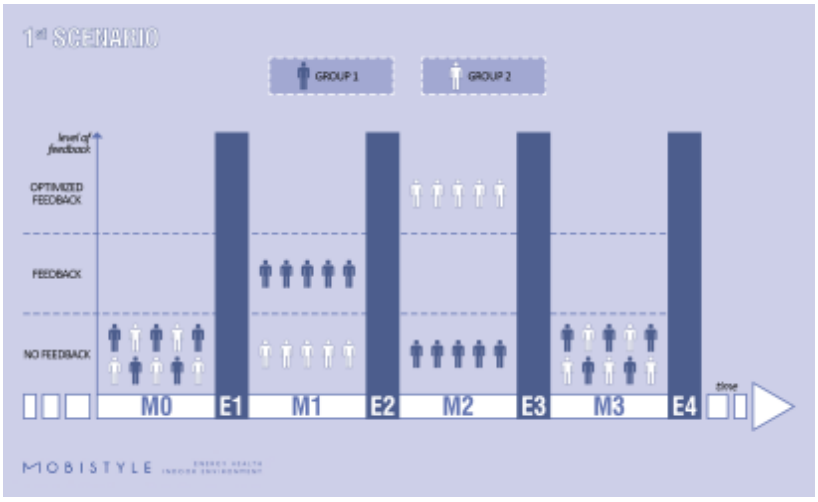


Figure 7: Testing feedback in selected target groups: Scenario 1.

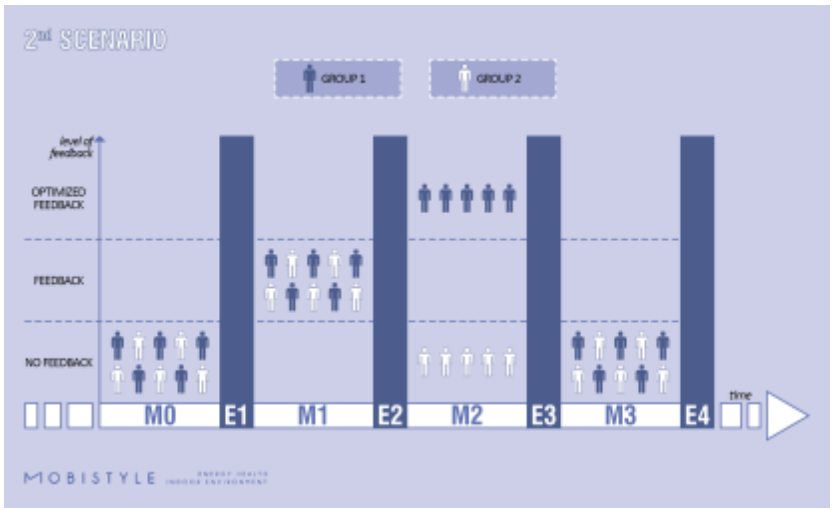


Figure 8: Testing feedback in selected target groups: Scenario 2.

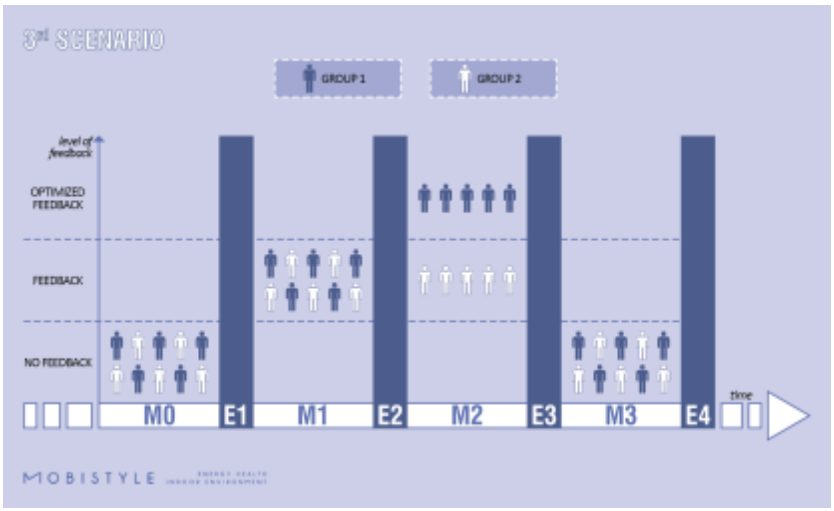


Figure 9: Testing feedback in selected target groups: Scenario 3.

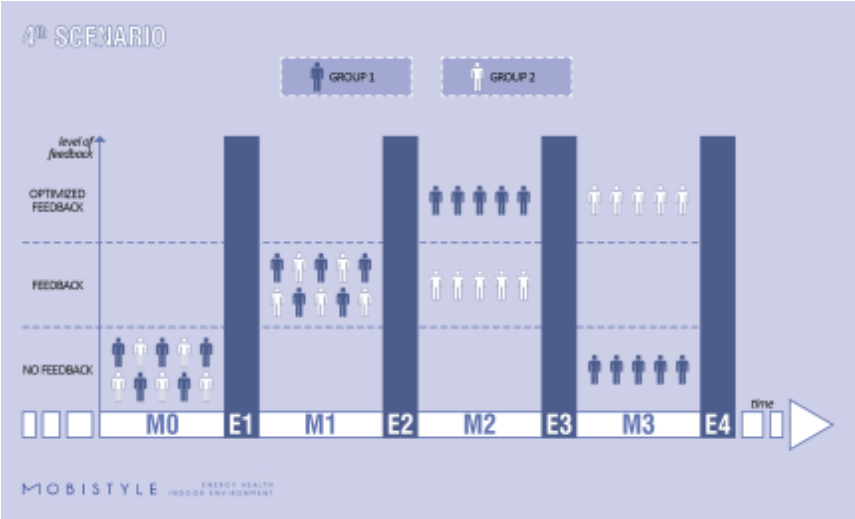


Figure 10: Testing feedback in selected target groups: Scenario 4.

3 Identification of the methods for each monitoring period and evaluation step

3.1 Guidelines for monitoring periods (M0 - M1 - M2)

Reliable monitoring campaigns are the key to an effective evaluation of the project outcomes [10]. The field monitoring must always be continuous in time, with suitable sampling rates and time span. This is essential for capturing even short-time and "pulsed" events and gathering data with a satisfactory statistical relevance. Moreover, the procedure must be freely configurable for enabling the interoperability with most monitoring systems (e.g. BMS, BEMS, BACS) and adapting the analysis to different requirements (e.g. number/type of monitored parameter, tolerance ranges). The monitoring system must be designed with caution, especially when considering the placement of indoor environment quality (IEQ) sensors [11]. It is important that the sensors yield a representative indication of the IEQ for each monitored space. For example, the impact of local heat sources on indoor air temperature measurements as well as the impact of air distribution on indoor air quality need to be thoroughly considered.

The monitoring procedure must be also consistent and reliable. Occasional failure in the measurement systems or in the analysis must not affect past and future elaborations. Careful attention must be given to the data check and "filtering" for achieving maximum representativeness of the surveys and minimising the loss of data. Data verification procedure must, also, be able to manage actual sets of data that are, frequently, discontinuous in time, not contiguous, with, possibly, unreliable and meaningless values during certain periods.

A reliable monitoring campaign ideally should reduce the amount of **missing data**. However, missing data can be a common occurrence and have an important impact on the conclusions that can be drawn from the data [12], and therefore from the outcomes of the MOBISTYLE project. Since the treatment of mixed data is very case-specific, we recommend that issues related to missing data shall be evaluated carefully from case to case. However, this section provides a few general guidelines.

The decision of ignoring or treating mixed data is strongly dependent on:

- **Percentage of missing data:** generally, a thumb rule is to drop missing data if minor than 5% of the total data, since it is inconsequential [13]. However, in long monitoring periods, such as the ones in this project, this percentage might be easily exceeded. In such case, the sources of error leading to missing data need investigation. From case to case, it should be carefully evaluated if the data can be treated for the analysis or specific research questions. In this case, the most common missing data treatment techniques are:
    - **Deletion:** Unless the nature of the missing data is completely random, a simple way to treat the missing data might be to delete it from the dataset, although this can lead to an important loss of information. This can happen (i) listwise (rows containing missing variables are deleted) or (ii) pairwise (only the missing observations are ignored and the analysis is one with the other remaining variables)[14].
    - **Imputation/interpolation:** The most popular imputation strategies are (i) Averaging techniques and (ii) Predictive techniques. In (i), missing values are inferred by means of averaging the mean, median, or mode. This allows for a quick estimate of the missing values, but eventually leads to a reduction of the variation in the dataset (since missing observations might have the same value) [15]. In (ii), the imputation of missing values assumes that the nature of the missing observation is not completely random and that the explaining variables to impute the missing observations are strongly correlated, otherwise this technique might yield imprecise estimates.

- **Typology of variables affected:** The technique for treatment of missing data should be carefully selected based on the characteristics of the variable in question. Generally, for some common variables in this project, the following aspects should be considered:
    - **Energy consumption:** Since this variable is incremental over time, the simplest way is to delete missing data from the dataset, unless there are long periods without observations, this will not significantly affect the outcomes.
    - **Instant power:** Since this variable is instant, a deletion technique is not the optimal solution. An alternative strategy can be using a predictive approach based on correlations between instant power and energy consumption.
    - **IEQ variables:** If data is missing in short time intervals, the missing data can be imputed with averaging techniques. However, since indoor environmental variables (air temperature, relative humidity, CO_2 concentration) can change very quickly over time (e.g. due to window opening), data should be dropped and averaging techniques should be avoided if missing data stretches over longer time intervals (> 15 mins).

3.2 Guidelines for benchmark definition (E1)

For **assessing the baseline performance in the MOBISTYLE testbeds**, the evaluators should refer to the definition of KPIs (energy, IEQ, health) and according formulas provided by D3.1 (“Detailed monitoring and information campaign parameters based on combined feedback”)[9]. The calculated KPIs will establish the **baseline for follow-up evaluation steps** after feedback (and optimized feedback) provision (E2, E3). For the evaluation phase, fixed parameters (e.g. number of occupants, floor area, volume, energy costs) related to specific KPIs need defining for each MOBISTYLE testbed or related target locations, such as individual apartments, houses, offices or lecture halls.

Descriptive statistics is a first approach for quantitatively describing the current performances of the case studies in terms of energy, indoor environmental quality, health, and behaviour [16]:

- **Energy:** From the elaboration of the measurements obtained through the monitoring activity, it is necessary to obtain, in addition to the **temporal profiles** of the average energy use over time related to **individual building services or home appliances**, also quantities aimed at a descriptive statistical characterization of the **total energy consumption** of each case study. Particularly, the following values should be calculated:
  - Maximum, minimum, average and standard deviation values of the energy use of each monitored building service or home appliance (if present) for significant periods;
  - Quartiles of the energy distributions for the various monitored building services and home appliances;
  - Frequency and cumulative frequency of energy use over time.

- **Indoor Environmental Quality:** The analysis should include **time profiles of thermo-hygrometric parameters and indoor air quality indicators**, as well as statistical values that are essential to describe and evaluate the indoor environmental quality (see more in section 3.3):
  - Mean hourly values (RH1h, T1h, $CO_2$1h);
  - Mean daily values (RH1d, T1d, $CO_2$1d);
  - Standard deviation (St. Dev.);
  - Minimum and Maximum values during the investigation period (Min, Max);
  - Frequency distribution and cumulated frequency.

  Comfort evaluations refer to the European Standard 15251 [17] and are described in section 3.3.

- **Health**: Collected data from the questionnaires and wearable devices allow for the calculation of the following statistical parameters:
  - Maximum, minimum, average and standard deviation values of body temperatures, heart rate and physical activity counts;
  - Maximum, minimum, average and standard deviation values of the obtained answers of the questionnaires in case of the visual analogue scales and 5 and 7 point scales.

- **Occupant behaviour patterns:** Interactions of the users with systems should be reported and analysed for having a baseline behavioural profile. The evaluation process needs to be conducted with caution, because it is analysing the implementation of an innovative and complex intervention in “living labs” located in a variety of sites during a long timeframe. These aspects could hinder complete demonstration of causation mainly due to motivators/triggers external to the MOBISTYLE intervention. Both quantitative and qualitative measurements maximize the accuracy for demonstration of causation. The following non-exhaustive still practical list of measurements serves as guidance:
  - **Quantitative measurements**
    - **Occupancy** (occupied/unoccupied [total person hours], number of occupants [persons]). Occupancy tracking can be done in a variety of ways e.g. movement and presence detection sensors, indoor localization of individual users using data from wireless sensor networks with portable nodes [18], people counting software using data from ceiling mounted cameras pointed straight down [19].
    - **Operation of technical building systems, building components and home appliances**

- Home appliances and ICT products (energy use);
- Heating system (room temperature heating setpoint; energy use – to be cross-checked with HDD, occupancy and normalised as needed);
- Cooling system (room temperature cooling setpoint; energy use – to be cross-checked with CDD, occupancy and normalised as needed);
- Ventilation system (number and duration of window openings; energy use of mechanical ventilation system – to be cross-checked with indoor emissions generating activities e.g. cooking, shower, occupancy and normalised as needed);
- Lighting system (energy use – to be cross-checked with length of day and occupancy and normalised as needed);
- Solar shading system (number and duration of openings/closings – to be cross-checked with length of daytime, sky nebulosity, solar irradiance, occupancy and normalised as needed);
- Domestic hot water system (energy use; water use – to be cross-checked with outdoor air temperature, occupancy and normalised as needed).

  - **Health trackers and wearables**: There is a large variety of wearables on the market (e.g. [20]). The selection of the wearable technology shall be made based on the actual scope of the device, although it should monitor at least heart rate, physical activity and body temperature for usefulness and meaningfulness purposes;
  - **Analytics of MOBISTYLE tools** (e.g. time of sending notifications, length of use, number of questions asked through the 'help' sub-tool).

- **Qualitative measurements** focus on adding meaning by creating an user perception layer on top of the quantitative measurements and shall cover occupant satisfaction, well-being, comfort, productivity/creativity as described in the behaviour change section of chapter 3.3 and health as described in the health section of chapter 3.3 and consider including other aspects such as illness (e.g. number of sick days, number of doctor visits, decreased effects of respiratory diseases, mental health).

3.3 Guidelines for intermediate evaluation (E2)

The **outcome evaluation** assesses the energy savings obtained in the MOBISTYLE testbeds and quantifies their environmental impact. A comparative analysis of specific KPIs defined in benchmark (E1) is necessary to establish changes in energy consumption, IEQ, health, and behavioural patterns of the occupants.

- **Energy:** Variations in terms of energy consumptions before (M0) and after the feedback provision (M1) are calculated according to the following equation (Figure 11):

$$\Delta\ Energy\ consumption\ (M0, M1) = Energy\ consumption\ (M1) - Energy\ consumption\ (M0)$$

considering that:

if Δ Energy consumption (M0,M1) > 0 - ***higher energy consumptions*** *during M1*

if Δ Energy consumption (M0,M1) = 0 - ***no savings*** *during M1*

if Δ Energy consumption (M0,M1) < 0 - ***energy savings*** *during M1*

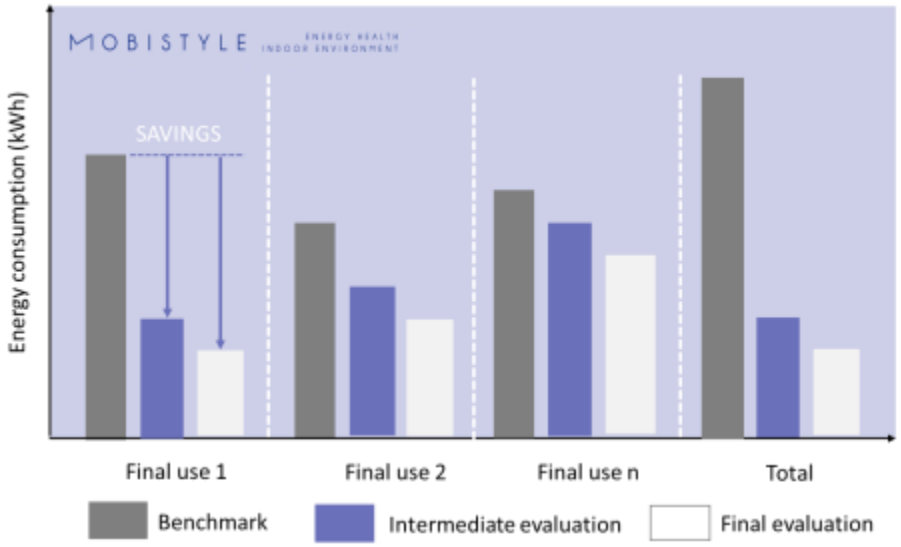


Figure 11: Example: Verifying energy savings for different final end uses at different stages of the projects. The outcomes should be related to different feedback typologies (see process evaluation).

For the calculation of percentage variations please refer to formulas provided in section 3.4. For evaluating solely the effects of the MOBISTYLE strategy on energy savings, it is necessary to consider the following constraints that might bias or artificially reduce/increase energy consumptions:

- **Unoccupancy (no occupants in the building)**
  A cause of irregular energy consumption profiles or a sudden reduction of the latter can be due to the short term absence of the building occupants (3-5 days) or long term unoccupancy during vacation periods or holidays (> 5 days). To avoid biasing the outcome evaluation, data collected in these periods should be excluded from the data analysis. Unoccupancy can be detected through missing interaction between occupants and the building services, long term reduced levels of CO_2 concentration, and occupancy sensors themselves. Furthermore, in some of the MOBISTYLE testbeds, unoccupancy might also be predicted in advance thanks to specific holiday periods (e.g. university) or bookings (e.g. hotel).

- **Seasonal effects or large variation of the outdoor air temperature:** In buildings that provide for **space heating and cooling**, energy consumption heavily depends on the climatic outdoor conditions. The colder the outside temperature in winter, the more energy it takes to provide space heating for a comfortable indoor environment. On the other hand, the warmer the outdoor air temperature in summer, the more energy is required to provide for adequate space cooling [21]. This means that, if during the monitoring period there is a change of season or a significant variation outdoor air temperature trends (to be verified through a comparative analysis), energy consumption related to space heating and cooling need to be normalized according to **Heating Degree Days (HDD)** or **Cooling Degree Days (CDD)**. In particular, HDDs are a measure to quantify the number of degrees that a daily average temperature is lower than a specific reference temperature, while CDDs are a measure to quantify the number of degrees that a daily average temperature is higher than a specific reference temperature. For the choice of the reference temperature and a s**imple ratio-based weather normalization of energy consumption** (with examples) please refer to [22].

- **Greenhouse Gas (GHG) emissions:** Once the amount of energy consumption is calculated, it is possible to analyse the resulting impact of the single case studies on the environment. In order to calculate the environmental impact (CO_2 emission) of the MOBISTYLE testbeds, it is necessary to select the conversion factors for each country and type of energy carriers (K_n, where n are the different countries), in which the testbeds are located. The $CO_{2,equivalent}$ will be calculated with the following equation:

$$CO_{2,eq} = \text{Energy consumption (M1)} * \text{Kn}$$

where Kn refers to the country-specific conversion factors:

Example: K1 (Italy) = 0.337 kgCO_2/kWh$_{el}$

To assess the effectiveness of the MOBISTYLE project in terms of environmental impact, it is required to define the change of emitted $CO_{2,eq}$ levels before (M0) and after feedback provision (M1):

$$\Delta\, CO_{2,eq}(M0, M1) = CO_{2,eq}\,(M1) - CO_{2,eq}\,(M0)$$

considering that:

*if Δ $CO_{2,eq}$ (M0,M1) > 0 - **higher impact on the environment** during M1*

*if Δ $CO_{2,eq}$ (M0,M1) = 0 - **no changes of the impact on the environment** during M1*

*if Δ $CO_{2,eq}$ (M0,M1) < 0 - **lower impact on the environment** during M1*

- **Indoor Environmental Quality**: This analysis is aimed at calculating variations of IEQ throughout M1 with respect to M0. Trends of the single IEQ parameters (air temperature, relative humidity, CO_2 concentration) should be analysed by providing **comparative time profiles**. Main **descriptive statistical parameters should be compared**: mean hourly values, standard deviation, minimum and maximum values during the investigation period, frequency distribution and cumulated frequency (see section 3.2) (Figure 12,13).

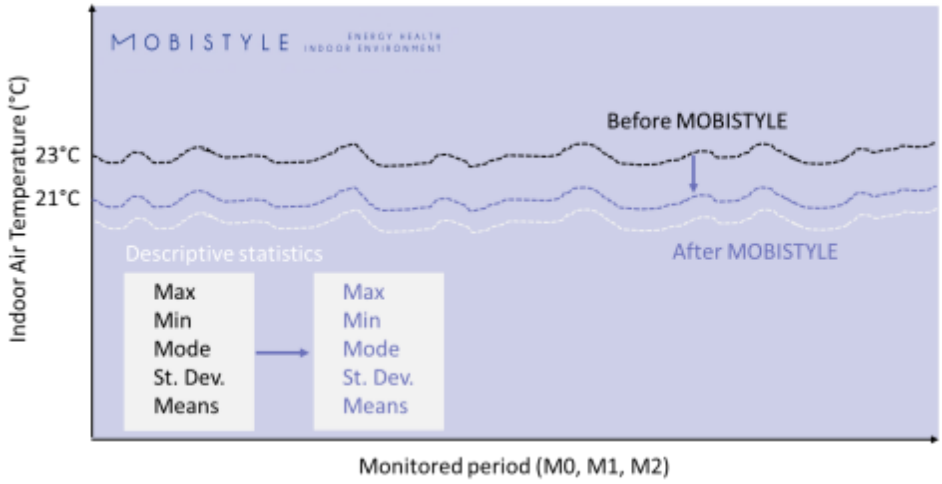


Figure 12: Example of a comparative time profile: Indoor air temperature.

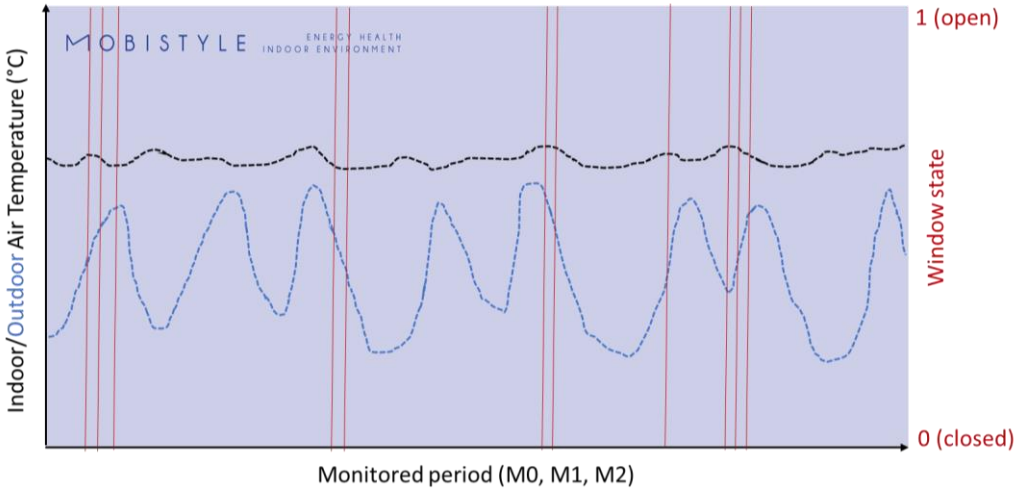


Figure 13: Other parameters can be added in the graph, such as outdoor temperature trends or behavioural patterns (e.g. window control behaviour, light switching, use of electric appliances).

For evaluating the conditions of comfort (or discomfort) during the three monitoring periods, it is required to calculate the amount of time, in which the occupants might perceive discomfort (Method A). Method B is optional. For both methods, the evaluators are asked to refer to classes indicated in EN15251 [17]. Since we are not directly monitoring operative temperature in the various MOBISTYLE case studies, we follow the procedure provided by EN15251 assuming indoor air temperature values instead of operative temperature values.

- **Method A:** Calculation of number/percentage of occupied hours (POR, as defined in D3.1) in which the indoor air temperature falls outside the range of predefined comfort classes (Class I, II, III) – this allows also for defining the number of hours outside these ranges (discomfort).

  For **building with mechanical cooling** (e.g. the Slovenian Demonstration Case) comfort ranges above and below Category I limits are introduced, namely Category II+ and Category II- respectively. Same subdivision is applied for the limits above/below Category II and Category III, namely with ranges Category III+/Category III- and Category IV+/Category IV, respectively.

  Example: Data representation of indoor air temperature in an office space using POR index and the subinterval method, Method A (for mechanical heated and cooled buildings).

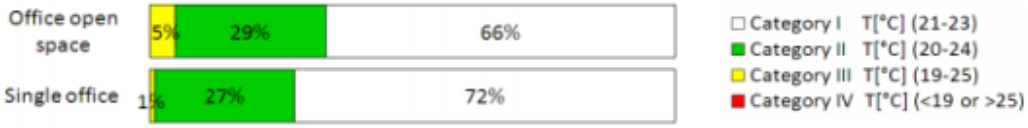


Figure 13: Method A: Indoor air temperature in office using POR index. [6]

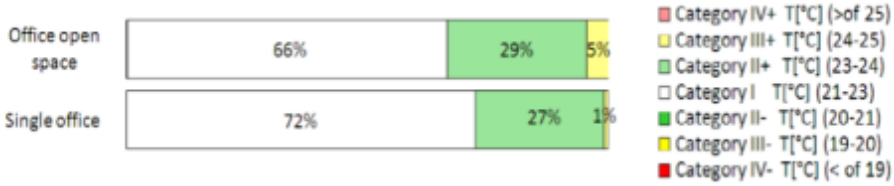


Figure 14: Method A (mechanical heated and cooled buildings): Indoor air temperature in office using above/below limits.[6]

Note that in Figure 13 and Figure 14 a constant temperature range is used for comfort categories (e.g. 21°C to 23°C for Category I).

In **naturally ventilated buildings** (e.g. Danish demonstration case) where the ventilation of the space is provided only by window openings and where users can freely adjust their clothing, the comfort categories for indoor air temperature are coupled together with outdoor air temperature.

The procedure of adjusting the comfort category limits is described in Annex A2 of EN15251[17].

1. Θ_{rm} = Outdoor running mean temperature (°C), exponentially weighted running mean of the daily mean external air temperature:

$\Theta_{rm} = (\Theta_{ed\,-1} + 0{,}8\,\Theta_{ed\,-2} + 0{,}6\,\Theta_{ed\,-3} + 0{,}5\,\Theta_{ed\,-4} + 0{,}4\,\Theta_{ed\,-5} + 0{,}3\,\Theta_{ed\,-6} + 0{,}2\,\Theta_{ed\,-7})/3{,}8$

where

$\Theta_{ed\,-1}$ is the daily mean external temperature for the previous day, °C

$\Theta_{ed\,-2}$ is the daily mean external temperature for the day before and so on until day 7, °C

2. Comfort category limits are recalculated as follows:

Category I: $\Theta_{i\,max} = 0{,}33\Theta_{rm} + 18{,}8 + 2$

$\Theta_{i\,min} = 0{,}33\,\Theta_{rm} + 18{,}8 - 2$

Category II: $\Theta_{i\,max} = 0{,}33\,\Theta_{rm} + 18{,}8 + 3$

$\Theta_{i\,min} = 0{,}33\,\Theta_{rm} + 18{,}8 - 3$

Category III: $\Theta_{i\,max} = 0{,}33\,\Theta_{rm} + 18{,}8 + 4$

$\Theta_{i\,min} = 0{,}33\,\Theta_{rm} + 18{,}8 - 4$

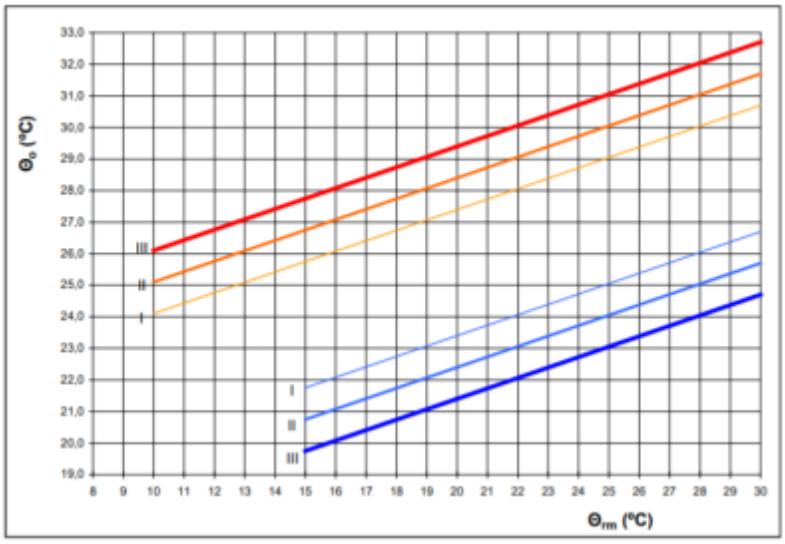
where

$\Theta_{i\,max}$ is upper limit value of indoor operative temperature, °C

$\Theta_{i\,min}$ is lower limit value of indoor operative temperature, °C

Θ_{rm} is outdoor running mean temperature, °C

These ranges are when $10 < \Theta_{rm} < 30$ °C for upper limit and $15 < \Theta_{rm} < 30$ °C for lower limit. In heating season when running mean outdoor temperature is below <10°C for the upper limits use the same (I, II, III) values as for mechanically cooled buildings (winter upper temperature) and for the lower limits when $\Theta_{rm} < 15$ °C use the same (I, II, III) values as for mechanically cooled buildings (winter under temperature).



Θ_{rm} (°C) = Outdoor running mean temperature Θ_0 (°C) = Operative temperature

Figure 15: Design values for the indoor operative temperature for buildings without mechanical cooling systems as a function of the exponentially-weighted running mean of the outdoor temperature. [17]

Note that in Figure 15 the temperature range for the different comfort categories is not constant but changes with outdoor running mean temperature.

- **Method B** (Degree hours criteria): In this method, the time during which the indoor air temperature exceeds the specified range during the occupied hours is weighted by a factor; the factor depends on the number of degrees with which the range has been exceeded (see Annex F of [17]).

1. The weighting factor, wf, equals 0 for $T_{limit,lower} < T < T_{limit,upper}$

   where T_{limit} is the lower or upper limit of the comfort range specified

   (e.g. 23.0°C < T < 26.0°C)

2. The weighting factor, wf, is calculated as

   $wf = T - T_{limit}$ when $T < T_{limit,lower}$ or $T_{limit,upper} < T$

3. To take into account the seasonal effect, the following has to be applied:

   *Cooling season: Σwf *time for $T > T_{limit,upper}$*

   *Heating season: Σwf *time for $T < T_{limit,lower}$*

- **Health:** For the health evaluation, the answers of the participants in the Dutch case study on tailored questionnaires during the static indoor environment and the environment with a dynamic profile will be compared. The aim of these questionnaires is to understand differences in terms of perception of the participants related to comfort, sensation, sleepiness and well-being. Moreover, physiological information will be obtained from a subset of participants that include skin temperatures, heart rate and physical activity. The results from physical parameters will be

compared with the results from the questionnaires. The results from the two indoor climate conditions will be compared using paired-test statistics.

- **Behavioural change**: In a broader perspective, this part evaluates the responses of MOBISTYLE participants on tailored questionnaires or interviews before (M0) and after the feedback provision (M1). The aim of these questionnaires/interviews (please see examples in Annex B) is to gain a deeper knowledge on changes in terms of perception of the participants related to comfort, energy, health, and the MOBISTYLE project. The questionnaire should consist of 5 sections (A-E) with a set of specific questions (e.g. Question 1_A, question 2_A, …, question n_A) and 1 optional section (F):

  A. New perception of comfort (Question 1_A, question 2_A, …, question n_A) – consider using available tools developed in other EU funded projects [23]
  B. New perception of energy and related costs (Question 1_B, question 2_B, …, question n_B)
  C. New perception of health (Question 1_C, question 2_C, …, question n_C)
  D. Perception of feedback provision and MOBISTYLE project (Question 1_D, question 2_D, …, question n_D)
  E. Intention to change one's behaviour in a long-lasting manner (Question 1_E, question 2_E, …, question n_E)
  F. New perception related to purchasing activities e.g. interest in technical building system upgrade, interest in new technical building system, interest in overall renovation (Question 1_F, questions 2_F, …, question n_F)

- **Behavioural patterns:** This part evaluates the changes in behavioural patterns before (M0) and after the feedback provision (M1) based on quantitative and qualitative measurements. The main aim of this evaluation is gaining insights about the actual changes in behavioural patterns and demonstrate causation. Because quantitative measurements generate datasets that quickly amount to big-data levels it is advised using visualizing tools i.e. carpet plots [24] for behaviour pattern analysis. For example, such a visualising tool is BELOK Operation Analysis [25] (download link) developed based on the Pia visualization tool [26]. A few examples of carpet plots, developed in BELOK Operation Analysis based on measured data (1 January 2011 – 31 December 2011) from office building Gångaren 11, Stockholm, Sweden ([27]), can be visualised in Figure 16 and Figure 17. Figure 16 shows that the night setback was implemented in the middle of January and is turned off at 4 a.m. The peak demand for reheating the building after the night setback is lower compared to when air handling units are running. In addition, Figure 16 illustrates clear patterns, both weekly and seasonal, which is to be expected. Weekly due to the air handling units scheduled operating hours and seasonal due to the varying transmission losses due to varying outdoor temperature. It can be seen in Figure 17 that in the morning and evening, some air handling units are running outside "scheduled operating hours" because occupants activated the "extended operation" by pressing any of the buttons located on each office floor. Moreover, Figure 17 illustrates lower air flow rate during February corresponding to a deliberate control feature i.e. lowering the air flow rate during low outdoor temperature. Lastly, Figure 17 displays that the AHUs are running during October nights which is not expected. This was supposedly due to some "forgotten" night cooling feature that remained active from summertime. Visualizing occupant behaviour parameters for certain periods enables identification of specific patterns of use and baseline occupant behaviour. This establishes a situation of knowing what to expect, thus facilitating evaluation processes aiming to identify changes in behaviour based on quantitative measurements. The analysis assumes that

the data consist of a systematic pattern (usually a set of identifiable components) and random noise (error) which usually makes the pattern difficult to identify. Most analysis techniques involve some form of filtering out noise for making the pattern more salient. Most patterns can be described in terms of two basic classes of components: trend and seasonality. The former represents a general systematic linear or (most often) nonlinear component that changes over time and does not repeat or at least does not repeat within the time range captured by our data (e.g., a plateau followed by a period of exponential growth). The latter may have a formally similar nature (e.g., a plateau followed by a period of exponential growth), however, it repeats itself in systematic intervals over time. Those two general classes of components may coexist in real-life data. The qualitative measurements generate easier to manage datasets than the quantitative measurements. The evaluation process has a straight forward approach in terms of identifying changes in behaviour meaning that the collected occupant feedback via questionnaires is directly analysed for the relevant periods. Lastly, it is useful to cross-check quantitative and qualitative measurements for adding meaning by creating an user perception layer on top of the quantitative measurements.

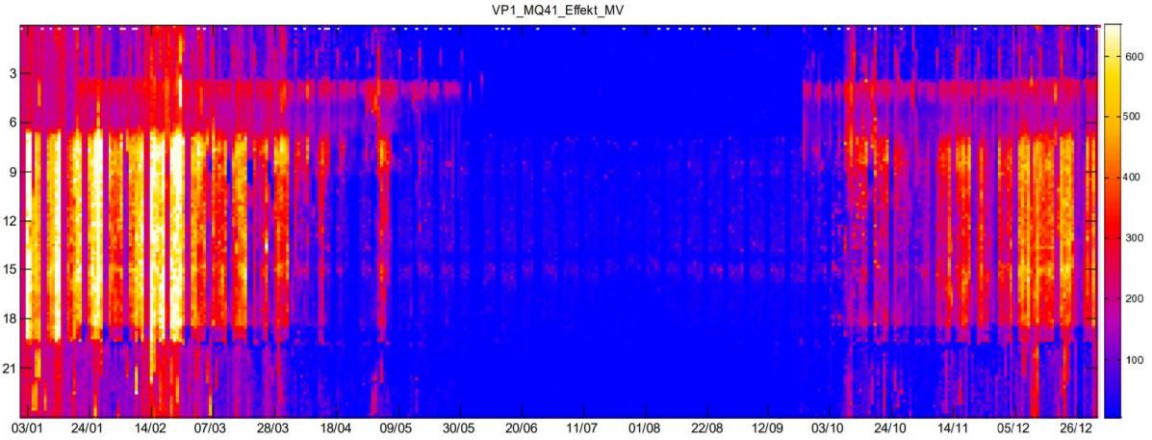


Figure 16: Carpet plot of purchased district heating power (kW) colour-coded according to the right-hand side scale (blue means a power close to 0 kW and white means a power over 600 kW). The hours of the day according to the left-hand side scale are represented as a function of the days of the year. Domestic hot water energy use is included in district heating energy use.

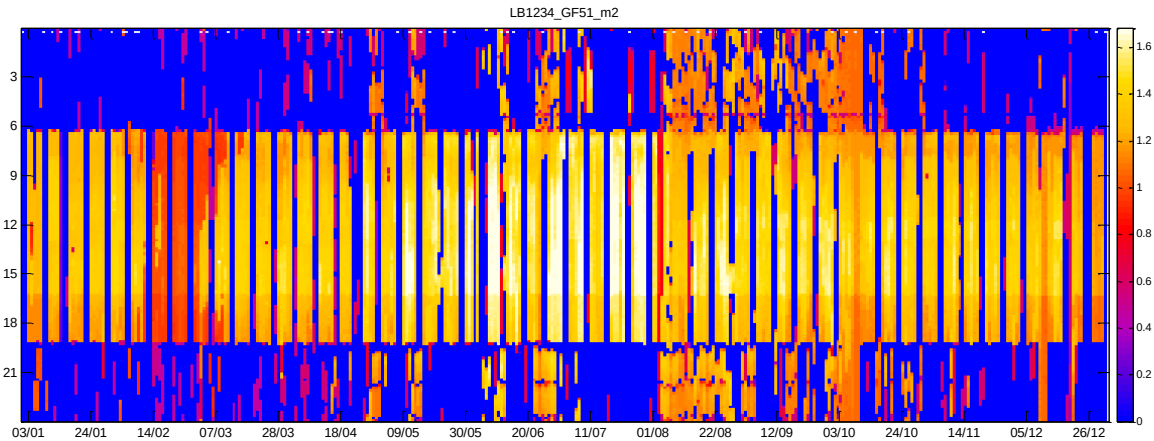


Figure 17: Carpet plot of supply air flow l/(s·m2) for all air handling units. The hours of the day according to the left-hand side scale are shown as a function of the days of the year.

In the **process evaluation,** possible optimization and improvements of the implemented process should be assessed. Separate evaluation for each category of provided feedback (for example, advices

related to temperature control or stand by usage of home appliances) should be performed. In this case, a comparative analysis of specific KPIs is necessary to evaluate the results.

- **TYPOLOGY:** For each case study, it is necessary to evaluate the effectiveness of feedback categories related to different final energy uses and indoor environmental quality:

  1. Heating
  2. Cooling
  3. Lighting
  4. Domestic hot water
  5. Natural ventilation
  6. Home appliances
  7. IEQ

  To test the effectiveness of the different feedback categories in terms of **energy savings** (from 1 to 5), it is required to compare the relative variation of energy uses of each feedback category before (M0) and after (M1) the feedback provision (see also Figure 11). Hence, for each feedback category *n* the percentage of variation should be calculated according to the following equation:

$$Percentage\ of\ variation\ n = 100 * [Energy\ use\ (M1) - Energy\ use\ (M0)]/Energy\ use\ (M0)\ [\%]$$

  To test the effectiveness of the different feedback categories in terms of **indoor environmental quality** (6), it is required to compare the relative variation of the percentage of hours outside the comfort rage (POR) for each feedback category before (M0) and after (M1) the feedback provision:

$$Percentage\ of\ variation\ n = 100 * [\ POR\ (M1) - POR\ (M0)]/POR\ (M0)\ [\%]$$

- **TIME-FREQUENCY:** This evaluation assesses how much feedback is provided per day for each category defined in the previous paragraph (categories 1 to 6). The analysis for the frequency can vary for different periods/durations t (e.g. week, month, M0, M1).

$$Frequency\ (t) = number\ of\ feedback\ category\ n/number\ of\ days\ (t)$$

  It is then possible to evaluate the effectiveness of different time frequencies at which feedback is provided for the same feedback category (e.g. is it better to provide feedback for a specific home appliance daily or weekly?). This allows to find the frequency (e.g. once per week, once per day, continuously) with which major energy savings are achieved. This evaluation is aimed at optimizing the process and can be developed during test periods (e.g. t1, t2) in M1 that are characterised by different frequencies (f1,f2). Feedback frequencies can then eventually be

optimised for M2. The percentage of variation for each feedback category *n* is calculated according to the following formula:

$$Percentage\ of\ variation\ n = 100 * [Energy\ use\ (t2, f2) - Energy\ use\ (t1, f1)]/Energy\ use\ (t1, f1)\ [\%]$$

where t1 is a test period during M1 with frequency f1 and t2 is a second test period during M1 with frequency f2.

Following the usability testing protocol (Annex A), questionnaires assessing the usefulness of feedback from the user's point of view shall be provided and addressed to the MOBISTYLE champions (designated person per building, always the same). The content of the questionnaires should tackle the following qualitative aspects:

- **Communication content:** Ideally, this evaluation would require testing different communication content during different test periods, similarly to the indications in the previous paragraph. The timing and set up of the MOBISTYLE implementation in ICT tools probably will not allow to test a large variety of interfaces and communication content. However, the efficacy of communication content should be investigated at least through tailored questionnaires for gathering direct feedback and evaluation from the end users:
  - **Type (numerical, graphical)** - (e.g. "Did you prefer numerical or graphical representations?")
  - **Communication strategy** (prompts, pop-up message, educative advices, serious game, newsletters) - (e.g. "Did you find the advices useful? Did you adopt some of the advices in your daily routine?")
  - **Length (concise/long)** - (e.g. "Do you think the feedback was too short/long?")
  - **Wording and design** (efficacy of the chosen terms in the message) - (e.g. "Is the wording of the feedback too complicated? Are the messages too simple or complex? Is the information easy to understand?")
  - **Content** (antecedent, i.e. announcing the availability of positive or negative consequences; consequent, i.e. providing advices about the action carried out at that specific moment) - (e.g. "Did you find it useful to receive real-time feedback on your actions to save energy and improve indoor environmental conditions? Did you find it useful to receive predictions about the consequences that your behaviour could have on your energy bill or the indoor environment?")
  - **Credibility** (coherency of provided feedback) - (e.g. "Do you trust MOBISTYLE? Did MOBISTYLE provide reliable sources for the received advices?")
  - **Level of detail of communication** - (e.g. "Was the feedback too (un-)detailed? Did advices leave you with open questions?")

- **Tools**: The efficacy of paper-based (poster, brochure) or ICT-based (mobile phone, website, email, room displays) tools should be investigated through tailored questionnaires that allow gathering direct feedback and evaluation from the end users:
  - **Usability** (e.g. "Is the tool comfortably usable in your daily routine?")
  - **User-friendliness, ease of use, barriers** (e.g. "Is the tool easy/comfortable to use? Did you encounter any specific technological problems?")
  - **Reliability** (e.g. "Does the application always work?")
  - **User satisfaction/experience** (e.g. "Are you generally satisfied with the application?")

- **Adaptability for meeting research goals and expected energy savings** (e.g. "Which of the provided tools did you find most useful?")

The efficacy of the tools can be further evaluated by acquiring directly information from the ICT tools that allow for assessing:

- How frequently the users interact with the tools (analytics for sub-tools e.g. number of asked questions through the 'help' sub-tool) and the relation with the time of sending a notification;
- Length of use (number of hours, analytics for sub-tools);
- How many people downloaded the MOBISTYLE application.

3.4 Guidelines for final evaluation (E3)

The final evaluation includes the **same methodological steps (and formulas) as the intermediate evaluation (section 3.3)** and is aimed at providing a comparative analysis of data gathered in M0, M1, and M2 targeting energy, indoor environmental quality, well-being of the occupant and their behavioural change.

Furthermore, the aim of the final evaluation is to verify if the MOBISTYLE project has achieved its expected impacts, or rather to verify a *"Significant reduction of final energy consumption prompted by innovative ICT solutions clearly quantified and substantiated, and subsequent reduction of CO_2 emission"*[28], which implies that the observed total energy savings in the MOBISTYLE testbeds (i) are of at least 16%. The total amount of energy savings should be identified in each case study according to the following formula:

$$Energy\ savings\ (i) = 100 * \frac{[Energy\ cons.(M2) - Energy\ cons.(M0)]}{Energy\ cons.(M0)}\ [\%]$$

$$The\ MOBISTYLE\ energy\ saving\ goal\ is\ achieved\ if\ Energy\ savings\ (i) \geq 16\ \%$$

Indeed, this implies that in the final evaluation phase, the evaluators should gain a comprehensive picture on the MOBISTYLE outcomes by comparing results achieved in the different MOBISTYLE testbeds. Following the quantitative and qualitative methods provided in section 3.3 for the evaluation in the single case studies, a comparative analysis at the overall MOBISTYLE level including all case studies allows for understanding which ICT tools/feedback provisions were more effective and in which contexts (e.g. offices, residential sector).

The subsequent reduction of CO_2 emissions can be calculated according to section 3.3, the final impact of the MOBISTYLE project should be assessed according to the following formula:

$$Reduction\ of\ CO_{2,eq}\ emissions\ (i) = 100 * \frac{[CO_{2,eq}\ (M2) - CO_{2,eq}\ (M0)]}{CO_{2,eq}\ (M0)}\ [\%]$$

A further expected impact of the MOBISTYLE project is related to the *"Number of energy end-users changing their behaviour documenting why and how changes are an effect of particular measures taken, as well in terms of the sustainability of the behavioural change*"[28]. Some impacts can be monitored, some can be derived from analysing **monitored data** and others rely on answers from **questionnaires** or **interviews**. At this final stage, for each MOBISTYLE testbed, and at an overall level, the final evaluation should indeed report a structured overview on the **number (or percentage) of end users:**

- **Changing their behaviour:** The evaluation of the behavioural change of the occupants relies on the monitored data and analysis of the behavioural patterns (section 3.3) as well as on questionnaires that investigate user experiences and intentions.

- **Understanding information about IEQ, energy and health:** The new level of knowledge and the learning experience of the users is investigated through questionnaires aimed at verifying their post MOBISTYLE understanding of energy, IEQ and health. The questionnaires can be supplemented with focus group meetings and interviews.

- **Actively using the tool and services:** The evaluators should provide an overview on the number of persons that have downloaded and used the proposed ICT solutions (web-based evaluation). If possible, the number of daily interactions with the tools and services should be detected.

- **Finding information services usable and attractive:** The final evaluation should also assess the satisfaction of the users with the MOBISTYLE services through survey-based investigation or conclusive meetings with the focus groups. Remarks from the end users can provide important lessons for future projects.

- **Finding wearable technology meaningful and useful:** If specific case studies (e.g. DEMO case 4) make use of wearable technology, the user experience should also be investigated. Particularly, end users should be questioned if they had any specific technical problems with the devices (battery usage, synchronisation with other devices), if they found the device attractive and comfortable, and if they found the information useful for improving their well-being/health conditions.

- **Embedding services in daily routines:** Initial excitement of the end users over the new services won't necessarily translate into long-term usage. There can be several factors that might lead to a decrease in the daily use of the services over the project duration (e.g. lack of clear use-case, technological issues, finding the service unattractive or similar). The frequency of interaction between the end users and the service should be tracked for the whole monitoring period and lead to conclusive outcomes in this final evaluation phase. This can be supplemented by questionnaires that investigate problems encountered by the users and discussion with the focus groups.

4 Cost-benefit analysis

The MOBISTYLE project views the application at different demo cases level of some personalized ICT solutions to drive behavioural changes in the occupants, pushing on the three issues of energy, indoor environmental quality (IEQ) and health. To support the project, specific standing monitoring systems were designed and installed in the different case studies (see D6.1)[6], in some cases integrating the existing ones. On those infrastructures relies the success of the project, whose evaluation is the main topic of this deliverable. To assess if investments on buildings similar to those proposed in MOBISTYLE demo cases are counterbalanced by positive effects, a net financial cash-flow, counting for costs and revenues/savings, could be performed. However, a financial analysis is not exhaustive of the possible benefits that the application of MOBISTYLE project could generate. Indeed, there could be non-financial effects or outputs that spill over from the direct impact area of the project, resulting in costs or benefits for the society.
Then, the aim of this section of the deliverable is to introduce an economic evaluation tool, namely the Cost-Benefit Analysis (CBA) that is able to assess the MOBISTYLE project social performance. In particular, the following sections introduce the methodological framework for the application of a CBA to the MOBISTYLE demo cases. From a broader point of view, the methodology introduced is a valuable tool in measuring the economic performance of the application of MOBISTYLE solutions in buildings.

4.1 CBA for project assessment

According to the European Commission, “the Cost-Benefit Analysis (CBA) is an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits in order to assess the welfare change attributable to it” [29]. In other words, the aim of a CBA is to assess the convenience for the society of a certain project rather than alternative ones.
In case of specific project assessment, the method is able to judge it, relying on the definition of monetary values for all its positive (benefits) and negative (costs) welfare effects. A discounted economic cash flow is calculated and some economic performance indicators are defined. In particular, the main steps composing the methodology are:

1 - Objectives and context definition;
2 - Time horizon setting;
3 - Future costs and benefits definition and monetization;
4 - Discount rate setting;
5 - Economic performance evaluation;
6 - Sensitivity analyses.

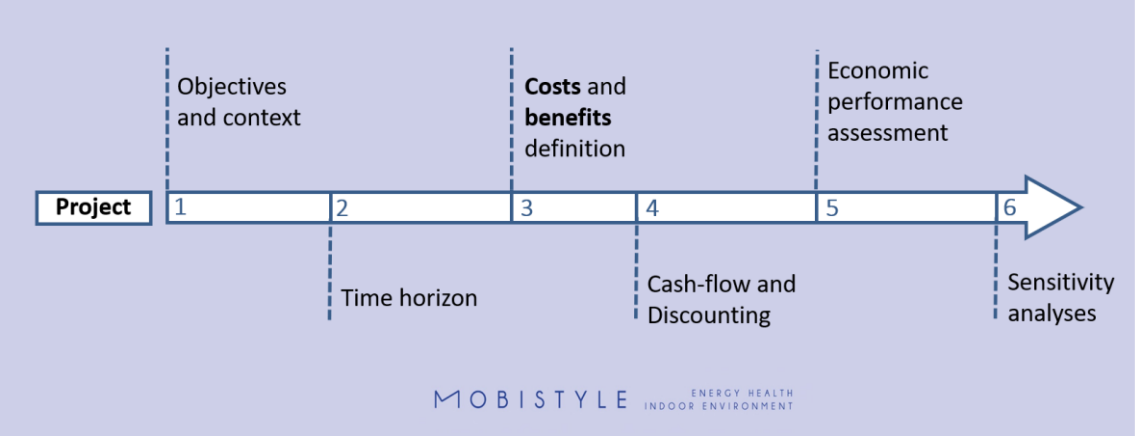


Figure 18: Cost-Benefit Analysis methodological steps.

First, the project description should be framed into the CBA methodology through the identification of the actions envisaged and their beneficiaries.
In this particular application, regarding the actions, to collect data and turn them into meaningful information to the occupants, the MOBISTYLE project relies on some monitoring campaigns, conducted through specific systems (see MAPs in D6.1), and on ICT solutions appositively developed and adopted. Then, for the development of the CBA it is required to collect data about these systems (only the new ones), through their descriptions (type and lifespan) and the specification of the measured parameters (see D4.1)[30].

NB: Since the aim of the CBA is the evaluation of the social performance of MOBISTYLE solutions in buildings, in terms of possible co-benefits produced, ICT solutions could be considered already developed, then only their maintenance costs and benefits should be accounted for in the analysis. The costs and benefits for sensors infrastructure should be accounted for since the installation phase. This is because their design and installation are obliged actions imagining applying MOBISTYLE solutions in buildings.

With respect to the identification of beneficiaries, being the aim of the project the reduction of energy consumptions and the subsequent GHG emissions, the impact area of the project is global. But, according to the minor objectives of the different demo cases, further beneficiaries, typically local, should be defined.

Example: in the Dutch demo case, the reduction of GHG emissions due to energy savings has a global positive effect, but the improvement of IEQ that the MOBISTYLE project could achieve affects mainly the students and professionals occupying the office building.

The target groups at the different demo case levels should be characterized (type, number).

Before going deeper in the CBA evaluation steps (1-6), some key issues defined by the EU Guide [29] should be underlined.
Firstly, the method adopts an **incremental approach**, which means that the project under evaluation is assessed upon a counterfactual baseline, which could be the business as usual scenario or the do-minimum one. The former implies conservative activities to maintain the current level of service, the latter a minimal intervention. Inflow and outflow are considered only in the extent they are different from the baseline scenario. In other words, the CBA only consider the difference between the cash flows in the with-the-project and the counterfactual scenario.

Secondly, the projects that the CBA aims at assessing are not analysed based only on financial issues, but on their **social opportunity cost**, representing their contribution to social welfare. Although the CBA shares the "with-without project" and the "in-out cash flow" approaches with financial evaluations, it could be classified as an economic evaluation method and not as a simple financial assessment. Indeed, including co-impacts, as will be explained later, the assumed perspective it is not the one of private investors, whose choices are driven by profit and price mechanism, but the one of the society. A CBA is able to include all the monetary amount of costs and benefits recognized by the society to an investment project.
Furthermore, a **long-term perspective**, different according to the field of the analysis, is assumed.
Finally, (in contrast to other type of evaluation method as Multicriteria Analysis) all the items that compose the inflow and outflow generated by the project should be expressed in **monetary term**, requiring for monetization techniques, as will be explained later. The final judgment will rely on some **economic performance indicators** that allow to compare and rank alternative projects and, more in general, to judge the "social performance" of a project.

The main steps of the evaluation process are described in the following sections. The main reference for these guidelines is the EU Guide [29].

4.2 Objectives and context definition

The first step of the CBA analysis consists in describing the context in which the project is implemented and the objectives of the project in order to define in explicit way the effects of the project itself. In particular, the CBA is used within the MOBISTYLE project in order to assess both costs and benefits (including non-market and external benefits) in the evaluation of the application of MOBISTYLE solutions in buildings. The CBA analysis will be customized to the different demo cases features.

According to the CBA methodological framework, the **objective** of a project under evaluation should be quantified though indicators and targets and its relevance with respect to social needs should be argued.
In detail, considering MOBISTYLE project, the aim is to raise consumer awareness and induce behavioural change though personalized ICT-based knowledge services on energy use, IEQ, health and lifestyle and to reach a 16% reduction in energy consumptions. Minor objectives related to specific demo cases (i.e. IEQ and well-being improvement) should be defined and discuss in this phase of the appraisal. As already mentioned, the success in reaching these goals relies on the infrastructure installed in the building to collect data, inform the occupants and drive their behaviour. Indeed, the project deals with the monitoring of many parameters related to the three different fields of energy, IEQ and health to collect data and turn them into meaningful information to the occupants. The monitoring campaigns are conducted in five different demo cases, located in different countries and having heterogeneous functions. Thus, as defined in deliverable D6.1 [6], the monitored parameters are different among the various demo cases and rely on new or pre-existing monitoring or management systems. Furthermore, the target groups are different. They are inhabitants for the Danish and Polish demo cases; people from the university staff in Slovenian demo case; hotel guests and members of the staff for the Italian one; and students, entrepreneur, professionals and professors in Dutch demo case. The success of the project relies also on the ICT solutions developed for these target groups, and then they also differ among the different demo cases.

Due to this heterogeneity, it is of primary importance to define the **context** in which the project takes place. It means to collect data and information relevant with respect to the project objectives and its development.
First of all, since the project deals with the installation of some sensors (basing on the MAPs of the different demo cases)[6], the context definition should describe the *ante*- MOBISTYLE digitalization level of the buildings that constitute the demo cases (see D2.5)[31]. Then, in accordance to the MOBISTYLE objectives, the buildings performance in term of energy consumptions, GHG emissions, IEQ and well-being guaranteed should be assessed though the indicators defined both at overall MOBISTYLE project (see D3.1)[9] and at different demo cases levels (see D6.1)[6].
The information on digitalization level of buildings will fix the picture of the pre- MOBISTYLE monitoring systems, through their description (type, lifespan) and the specification of the measured parameters (see D2.5)[31]. On the other hand, the set of indicators related to the buildings performance are the results of the "benchmark definition" evaluation phase (E1, see section 3.2 of this deliverable). They represent the baseline for the assessment and in this phase of the appraisal could be compared to national and international benchmark values, where available. The latter could be a valuable action in order to contextualize the demo cases.

From a broader point of view, the context definition phase also requires for the description of the specificities of the different countries in terms of: socio-economic-political trends, geographical factors, regulatory conditions, market conditions and technological conditions. Indeed, since the CBA uses to adopt a long-term perspective, benefits and costs should be forecasted, and their forecasting require this kind of information.

Example: the definition of cash flows requires for information related to the energy and technological market at national level.

Example: to assess GHG emissions reduction due to energy savings it is fundamental to know the national energy mix condition.

According to the evaluation needs of the different demo cases, context information should be collected.

Once the context is characterized and the objectives are clear, it is required to fix the reference period of the analysis, namely the time horizon in which all the cash flows produced by the project are expected to occur. The main criteria for its definition are reported in the followings (section 4.3).

4.3 Time horizon setting

As already said, in CBA a **long-term outlook** is assumed. It ranks between 10 and 30 years, depending on the sector considered, and represents the lifespan of the project, within which all cash flows (both costs and benefits) occur. The time of the analysis, called "reference period" or "time horizon", should be proportionated to the project's economically useful life and to the timing of its impacts. According to the Annex I of the Commission delegated regulation (EU) No. 480/2014 [32], in the energy field the appropriate time horizon ranges between 15 and 25 years.
Since the success of the MOBISTYLE project relies on the monitoring systems, their life spans should be considered as criteria in the definition of the reference period of the analysis. Indeed, it is preferable not to foresee large replacement costs close to the end of the time horizon and, if it happens, it is

suggested to shorten the reference period to match the end of the life of the components that would be necessary to replace. In fixing the life span of the monitoring systems, the technological obsolescence should be also taken into account. Another criterion to consider in the definition of the reference period is the timing according to which the potential benefits of the project are expected to be expressed.
According to those issues, a 15-year time horizon is proposed for the MOBISTYLE project appraisal.
Defined the reference period for the analysis, the subsequent step consists in the identification of the costs and benefits produced by the project, as reported in section 4.4.

4.4 Future costs and benefits definition and monetization

The definition of the costs and benefits of a project and their monetization is the key step of a CBA. In particular, in the CBA methodology both direct and indirect costs and benefits are considered. The former, also called internal, are the ones related to investors; the latter, also called external, are costs and benefits produced by the project that are relevant for the whole society.
According to the EU Guide [29], a **financial analysis** evaluating the direct impacts should be assessed as a starting point for the economic analysis, where direct costs and benefits will be translated from market prices to shadow prices (reflecting their social opportunity) and non-market impacts (direct or external) will be included.
Thus, to assess a CBA it is firstly required to define, calculate and monetize all the direct costs and benefits related to the project and to the counterfactual scenario (namely, the without-the-project scenario) according to the **discounted cash flow financial method (DCF)**. This method implies the evaluation of all the cash flows produced by the project having a financial nature, it means all the assets for which a market (and then a price) exists.

The costs to be considered are:

- Investment costs;
- Replacement costs;
- Operational and maintenance costs (O&M);
- Residual values.

They are all cash outflows, a part for the residual value. The latter represents the residual serving potential of those systems whose economic life is not ended in the last year of the reference period (time horizon), as will be mentioned later.

On the other hand, the direct benefits to be included in a financial evaluation are the one that produce a monetary cash flow, namely:

- Revenues (or savings).

The adopted monetization technique provides for **market prices** use, to be defined at national level as input data to the appraisal model. All the analysis has to be carried out considering market prices fixed at the base-year. Prices should be considered net of VAT and the discounting of the cash flows should be carried out according to a **financial discount rate (FDR)** expressed in real term. The latter should be defined at national level as input data to the appraisal model (see section 4.5 of this deliverable). The financial analysis shares with the CBA the incremental approach: only the difference between the cash flows in the with-the-project and the counterfactual scenario are considered.

In this framework, the financial evaluation of the MOBISTYLE project consists in the identification of the costs of the activities on which the project success relies (namely the development of standing monitoring campaigns and the adoption of ICT solutions and behavioural influence activities) and of their direct benefits, defining the counterfactual scenario as the business as usual (BAU) one.
The BAU scenario includes costs related to investment, replacement, operation and maintenance (O&M) of potential pre-existing (*ante*- MOBISTYLE) monitoring systems (see D2.5) as describe in the context definition (section 4.2). Their eventual residual values are the only cash inflows in the BAU scenario. Energy consumptions of the building, whose reduction due to behavioural changes represents the main objective of MOBISTYLE project, is monetized as energy bill and represents a further cash outflow.
The project cash flows assessment includes only the incremental costs and benefits with respect to the BAU scenario. Thus, pre-existing monitoring systems do not require to be accounted for in the appraisal, since they are already part of the counterfactual scenario. Conversely, a variation in energy consumptions (then in energy bill) is expected as a result of the project implementation as described in the project's objectives definition (section 4.2). By the comparison between BAU scenario and with-the-project scenario, it is clear that the only direct financial benefit of the project is the energy saving achieved. Indeed, the latter is the only potential benefit for which a market exists, since it produces a saving in money. It should be monetized as money saved in energy bill (energy prices are considered fix at the base-year, as mentioned above). Dealing with negative impacts of the project, costs for new monitoring systems design and installation should be accounted for as initial investment; their eventual replacement should be considered according to these systems lifespans; O&M costs of monitoring systems and of ICT solution have to be assessed. ICT solution development costs are not included in the initial investment assessment, since they can be considered already existing, as said before (section 4.1). The only inflow of the project would be the eventual residual value of the installed systems in the end-year. It represents the residual serving potential of those systems whose economic life is not ended in the last year of the reference period. For its calculation, refer to the Commission delegated regulation (EU) No. 480/2014 [32].
In summary, the financial evaluation of the MOBISTYLE project requires to quantify the new monitoring systems installed, the ICT solutions adopted and the energy saved in their proper units of measure. The former results in investment, O&M and replacement costs; the second implies O&M costs; the latter represents an annual benefit to be monetized as saving in the energy bill. Starting from the quantification, the monetization depends on national market (to be defined in the context description), since market prices of technologies and energy carriers should be considered (see also D4.1 for sensors prices)[30].
Further direct costs and benefits related to minor objectives of the project should be defined at single demo cases level following the approach reported in this section.

NB: costs of pre-existing monitoring systems should not be accounted for in the analysis, since they are also part of the counterfactual scenario and then they are not incremental costs. On the contrary, it is not required to distinguish the benefits relying on pre-existent systems from the one attributable to the new ones. Indeed, the EU Guide [29] *states that if a project integrate pre-existing services, both additional and new contributions can be taken into account to calculate the projects revenues. The same principle is here applied to the determination of the positive impacts of MOBISTYLE project (i.e. energy saving).*

The project net cash flow could be obtained as the difference between discounted costs and benefits.

The analysis here set needs to be included in a CBA, but it is not exhaustive of the benefits that the project could generate. Indeed, there could be non-financial effects or outputs that spill over from the direct impact area of the project, resulting in costs of benefits for the society.

Precisely, the main strength of a CBA lays is its capability to include **non-market impacts** of a project, assessing its convenience for the society. They are impacts that cannot be expressed directly in monetary term, since there is not a market and, then, there is not an observed price for them. Then, it is necessary to move from a financial assessment to an **economic analysis**. For this purpose, the methodology proposed by the UE Guide [29] includes many steps:

- **Definition of direct non-market impacts:** a project could have impacts relevant for the society for which a market price does not exist. They are defined direct since they affect the beneficiaries of the project.

  Example: a project aiming at optimizing the management of ventilation could improve indoor air quality (IAQ). Since it does not exist a market for IAQ, the IAQ improvement is an output of the project that does not have a market value. However, it is relevant, and it directly affects the beneficiaries of the project. Then it could be defined as a direct non-market impact.

  Since all the items that compose the inflow and outflow generated by the project should be expressed in monetary term, **monetization techniques** for the evaluation of these co-impacts that do not have financial values are strongly required. In particular, the CBA methodology asks for the definition of shadow prices, namely estimated prices that represents the value recognized by the society to items that do not have a monetary nature. A method for shadow prices estimation is the **willingness-to-pay** (WTP) evaluation. WTP measures the maximum amount users are willing to pay for a unit of a given outcome of the project.

  Example: the improvement of comfort in a hotel room could be monetised by asking to the guests how much they are willing to pay in order to rent a room with a high level of comfort rather than a room in poorer comfort condition.

  There are different techniques to empirically estimate the WTP, namely revealed preference, stated preference and benefit transfer methods (see Annex VI in [29]).
  If the WTP could not be estimated directly, an accepted and common practice consists in the calculation of the avoided cost, it means the money saved by the users to have the same good or service from an alternative source.

  Example: in the energy filed, the increase of exploitation of renewable energy sources could be monetised as the avoided cost of alternative generation technologies.

  Shadow prices are also used as data input instead of the market prices in the direct impact evaluation when market prices are not considered representative of the social opportunity costs of the assets. The methods to convert input market prices in shadow prices are sundry, but they share the approach of multiplying the market prices for specific conversion factors (see Annex III in [29]).

- **Definition of indirect non-market impacts (externalities):** when non-market impacts do not occur between the producer and the direct users of the good/services delivered by the project, but they fall on third parties, that impacts are called externalities. They are typically the effects of a project on the environment.

  Example: a project aiming at improving the energy efficiency of a building results in a reduction of GHG emissions related to energy consumptions. GHG emissions have well-known effects on climate change that is a global phenomenon. This make the GHG emission reductions an output that spills over from the project towards third parties. Variation in GHG emissions is then considered an externality of that project. Equally, pollutants' emission reduction due to lower energy consumptions has a positive impact on society at local scale.

  Their evaluation also asks for monetization techniques. Again, the willingness-to-pay (WTP) approach could be included in this part of the analysis to monetise the externalities. Furthermore, there are some studies that provide reference unit price for some already recognized externalities, like for example the unit cost for carbon emissions [33] or for pollutants [34]. If that parametric values are provided for the externalities under evaluation, their assessment results in the estimation of their volume to be multiplied by the proper unit price.

In this framework, the economic evaluation of the MOBISTYLE project consists in going beyond the energy saving objective of the project (-16%), through the identification of all the positive non-market effects that MOBISTYLE solutions in buildings can generate (see Figure 19). It means to think about all the possible direct and indirect effects that the digitalization of a building with concurrent provision for personalized ICT-based knowledge services can bring. If not all the positive non-market effects can be identified, at least the ones related to the focus of each case study (i.e. IEQ, energy, health) should be included in the appraisal.

Figure 19: Cost-Benefit Analysis definition.

As shown in Figure 20, the International Energy Agency (IEA) provides an overview of possible benefits related to energy efficiency project in the publication "Capturing the multiple benefits of energy efficiency"[35], exhorting to adopt a wide perspective in their identification.

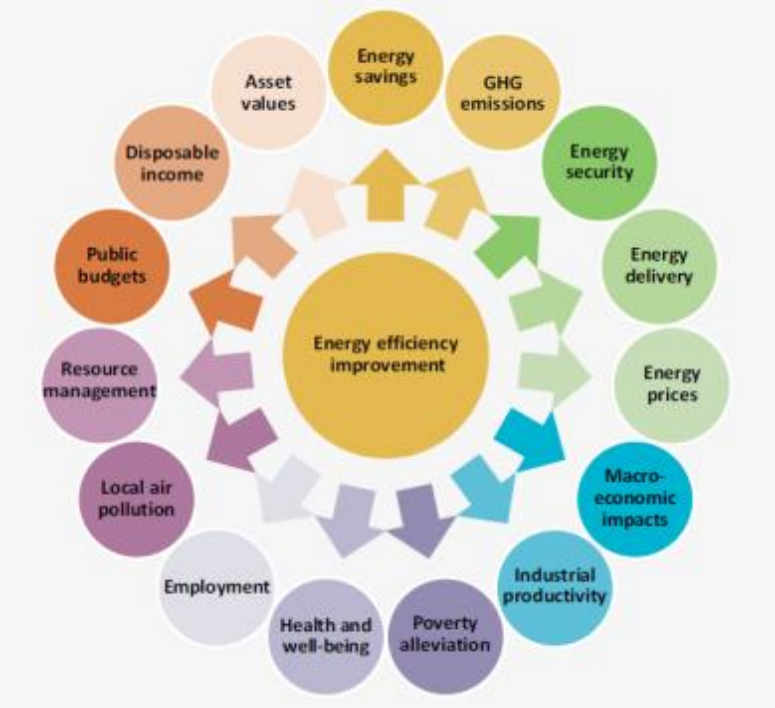


Figure 20: The impacts area of energy efficiency. Source: IEA, 2014, p. 20 [35]

A part for GHG emission reductions due to energy savings that could be considered an externality produced by the project having a global impact, of particular interest for MOBISTYLE project would be the positive non-market impacts on comfort, well-being and health. They are all benefits affecting directly the occupants and their inclusion in an economic assessment can significantly influence the results. In particular, there are four classes of comfort (thermo-hygrometric well-being, indoor air quality, visual well-being and acoustic well-being) to be controlled in order to guarantee high IEQ in buildings. In MOBISTYLE project, the potential benefits on comfort would be mainly related to thermal environmental quality and indoor air quality (IAQ) improvements. Better IEQ conditions could increase the productivity in working space [36], as well as reduce sick leave and, more in general, lower the incidence of sick building syndrome symptoms [37]. Well-being and health improvement include reduced symptoms of respiratory and cardiovascular conditions, rheumatism, arthritis and allergies [35].

A non-exhaustive list of possible non-market benefits (both direct and external) for different functions is provided in the followings.

Residential:

- Emission avoided
- Reduced sicknesses
- Effects of comfort
- User empowerment
- Increase of real estate market value
- …

Hotel:

- Emission avoided
- Reduced sick leave
- Effects of comfort
- Increased service price
- …

Offices:

- Emission avoided
- Reduced sick leave
- Effects of comfort
- Improved productivity
- …

Once the possible non-market benefits are identified, a monetary value should be estimated though the techniques mentioned above (section 4.4 of this deliverable). To do so, benefits have to be firstly quantified in physical units before their translation into a monetary value. In summary, the process consists in identifying, quantifying and monetizing benefits. The table below (Table 1) is structured following this process. The benefits-related physical indicators, the related monetary indicators and the most used appraisal methods for their assessment in CBA are reported. While above they were classified according to different buildings functions, here benefits are subdivided according to their impact category and sub-category.

Category of impacts	**Sub-category of impacts**	**Physical indicator**	**Monetary indicator**	**Appraisal method**
Comfort and well-being	Thermal comfort	Temperature	Energy cost	Energy price
Health	Outdoor air pollution	Avoided cases Avoided hospital admissions Restricted activities days Years lived with disability Disability-adjusted life years (DALYs) Quality-adjusted life years Years of life lost	Costs of illness/cost per avoided case (in avoided costs approach) Value of a lost year and value of a statistical life (VSL) (in WTP approach)	Revealed preferences: avoided costs approach Stated preferences: willingness to pay through contingent valuation method
	Indoor air pollution			
Productivity	Performance of individuals	Increase in labour productivity	Per unit labour costs	Market price of labour
Environment	Global worming	GHG emission	CO_{2eq} cost	CO_{2eq} price
	Local pollution	PM emission	PM cost	PM price
Economy	Real estate (Residential)	Market value	Selling/renting cost	Revealed preferences: hedonic pricing method

	Business (Hotel)	Market value	Renting cost	Revealed preferences: hedonic pricing method Stated preferences: willingness to pay through contingent valuation method

Table 1: Physical and monetary metrics and possible methodologies for the quantification of some benefits of interest to MOBISTYLE. Part of the table (the first three categories) comes from [38].

The tricky part of benefits assessment is in the calculation of numerical values of the physical indicators and of the related monetary indicators properly selected. While for the latter there are the already mentioned techniques, benefits quantification (e.g. avoided kg of CO_{2eq}, % increase in working performance, day of sick leave, etc.) should be based on their link with some physical phenomena. In literature, some examples could be found in this sense. Indeed, dealing with comfort, health and well-being, many studies highlight the relation between some indoor parameter with the benefits previously mentioned: ventilation ratio can affect the occurrence of sick building syndrome [37]; indoor temperature affects the working performance according to statistically-determined rules [36]; and ventilation ratio impacts on working performance [36], illness and sick leave according to calculated functions [39]. See Annex C for an example.

When market prices are adjusted, and non-market impacts are assessed, costs and benefits related to the project should be distributed over the time horizon and discounted, in order to calculate some economic indicators. The next two sections deal with the discount rate identification (section 4.5) and the economic performance evaluation in term of calculations of proper indicators (section 4.6).

4.5 Discount rate setting

The discount rate reflects the opportunity cost of capital and it is adopted in order to evaluate the present value of future cash flows. The Commission delegated regulation (EU) No. 480/2014 [32] recommend using a **4%** discount rate in real terms. Member States are encouraged to fix their own reference value (see also Annex I in [29]).
While the Financial Discount Rate (FDR) is used in the financial evaluation, in economic appraisal like the CBA, a **Social Discount Rate (SDR)** is adopted. It represents how future costs and benefits would be valued by the society against present ones. The Commission delegated regulation (EU) No. 480/2014 [32] recommend using a 5% discount rate in Cohesion countries and a **3%** for the other Member States, which are encouraged to fix their own reference values (see also Annex II in [29]).
All annual costs and benefits should be discounted according to the following formula.

Discounting formula:

$$V_a = S_t \times (1+i)^{-t} = \frac{S_t}{(1+i)^t}$$

Where: V_a is the present value, S_t is the balance of cash flow at time *t* and *i* is the discount rate.

Discounted cash inflows and outflows can be so assessed, and specific economic indicator can be calculated.

In the following section, these indicators are reported and described.

4.6 Economic performance evaluation

As already mentioned, once market prices are adjusted and non-market impacts are assessed, costs and benefits related to the project should be distributed over the time horizon.

Then, annual flows are calculated and discounted to be comparable at present moment (see also section 4.5). The discounted cash flow of the investment represents the difference, year by year, between benefits and costs. Basing on these assessments, three different economic indicators can be calculated to provide a final judgment to the performance of the project.

- **Economic Net Present Value (ENPV):**

$$ENPV(C) = \sum_{t=1}^{n} a_t S_t = \frac{S_1}{(1+i)^1} + \frac{S_2}{(1+i)^2} + \cdots + \frac{S_n}{(1+i)^n}$$

Where $a_t = \frac{1}{(1+i)^t}$ represents the discounting formula. S_t is the balance of cash flow at time *t* and *i* is the discount rate.

- **Economic Rate of Return (ERR):**

$$0 = \sum \frac{S_t}{(1+i)^t}$$

Where: S_t is the balance of cash flow at time *t* and *i* is the discount rate.

- **Benefits over costs ratio (B/C):**

$$B/C = \sum_{t=1}^{n} \frac{a_t B_t}{a_t C_t}$$

Where $a_t = \frac{1}{(1+i)^t}$ represents the discounting formula. B_t is the benefits at time *t* and C_t is the costs at time t.

NB: in this application n (time horizon) is equal to 15 year and i (discounting rate) is the economic one and it is equal to 3% (or 5% in Cohesion countries).

The **economic net present value** (ENPV) is calculated as the difference between the benefits cash-flow and the costs cash-flow, both actualized at the present moment and summed. If ENPV is major than zero the benefits produced by the investment overcome the relative costs, meaning that the project under assessment can produce an increase in welfare. The ratio between the two cash-flows, namely benefits and costs, represent the indicator **B/C**. The more the indicator is high, the more the benefits overcome the costs. Finally, the **economic rate of return** is the rate that produces a zero ENPV. It should be compared with a threshold of acceptability to be analysed. The more the rate is equal to the threshold, the more the project risks to fail in producing the expected benefits in term of welfare.

4.7 Sensitivity analyses

A very important step of the CBA consists in performing some sensitivity analyses. They are developed starting from the identification of some variables included in the appraisal model and consists in varying that variables to observe how the results in term of performance of the project change. Those parameters that varying by +/- 1% bring a difference in the ENPV higher that the 1% are considered critical and have to be closely verified and monitored, since wrong assumptions on them could compromise the appraisal. The approach to the sensitivity analysis is defined “what if”.
In this application at least two sensitivity analyses should be performed varying the discount rate and the energy price.

5 Conclusion and remarks

This deliverable presented the research activities within WP3 during the second year of the MOBISTYLE project, which focused on defining a methodological evaluation framework for assessing the project’s outcomes, impacts, and process. This report is a guideline for the evaluators of the implemented engagement campaigns in the MOBISTYLE testbeds for effectively planning monitoring phases and evaluation steps. The proposed guidelines **shall be adapted and tailored to the specific characteristics and needs of the individual case studies**. The main contents of this report tackled the following key aspects:

- Definition of three monitoring phases: M0 – Initial monitoring (without feedback), M1 – Feedback provision, and M2 – Optimized feedback provision;
- Definition of three evaluation steps: E1 – Benchmark definition, E2 – Intermediate evaluation, and E3 – Final evaluation;
- Planning of monitoring periods and evaluation steps over time;
- Investigation of alternative strategies: Testing behavioural persistence and testing feedback in selected target groups;
- Aim and duration of monitoring periods;
- Aim of the evaluation steps and description of comparative analyses of parameters targeting energy, indoor environmental quality, well-being and health of the occupants, and behavioural patterns and change;
- Guidelines for quantitative and qualitative evaluation;
- Guidelines for the development of a cost-benefits analysis, aiming at assessing both costs and benefits, including non-market and external benefits, in the evaluation of the application of MOBISTYLE solutions in buildings.

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Annex A – Usability testing protocol (developed by IRI-UL)

Protocol for MOBISTYLE solutions testing

1. General recommendations

Please keep in mind that the whole process, including preparations and analysis, should not take you more than one workday (8 hours) of one person. Note that the meeting with participants should not take more than hour and a half. It is important to select a right person to conduct the testing and facilitate the debate. Most importantly, the person in charge of facilitating the testing should be communicative and ready to accept different perspectives of participants.

2. Preparation

This is a general guideline for conducting the testing and making all necessary preparation activities. If necessary, adapt the preparations to your local situation.

- Invite 5-7 people to the testing. If possible, establish a contact with the people who are already familiar with the project or use the following guidelines[1] when recruiting new participants.
- Prepare a quiet and comfortable room with available PCs or laptops (at least one per group, ideally one per person) where you will be able to show the products and their functionalities.
- Try out in advance if the solution actually works on the location. Check the internet availability if you need it. Have a backup.
    - Dashboard is available via http://MOBISTYLE.demo.holonix.biz. Use the right location an user specific login credentials (manager and user).
    - Mock-up of the game is available via https://share.axure.com/[2].
- Print out enough paper copies of the *System Usability Scale* (SUS) test (see point 3.2. in this document). Before printing them out, translate the 10 questions and 2 remarks above the scales (“Strongly disagree” and “Strongly agree”) to your local language.
- Prepare printed versions of MOBISTYLE advices and recommendations. Print out each advice on a small piece of paper (or simply print all of them on one piece of paper and cut them out). Prepare the same list of 10-15 advices for each participant (see point 3.4. in this document).
- The testing should be carried out in your local language. IRI UL expert will provide you support via video call, if necessary.

[1] Recruitment of participants in the ethnographic study, Instructions for the MOBISTYLE project partners

[2] HS needs to allocate you permissions

- Audio record the full conversation (for example with you smartphone or any other appropriate audio recording device) after obtaining the permission of the participants. Most probably, the participants have already signed the informed consent[3] for MOBISTYLE study, but please check. Have few printed copies prepared. Make photos of the process.

3. Process

3.1. Introduction

- Each participant of the testing event introduces him/herself. Ideally, make a quick round of introductions, especially if participant do not know each other. The leader of the event should start.
- Briefly present the objectives of the MOBISTYLE[4] project.
- Present the purpose of the testing, i.e. collecting user feedback on the current stage of the solution; keeping users involved in the design and development process.
- Tell them about the timeframe of the meeting (not more than 1.5 hours).

3.2. Quantitative measurement by System Usability Scale

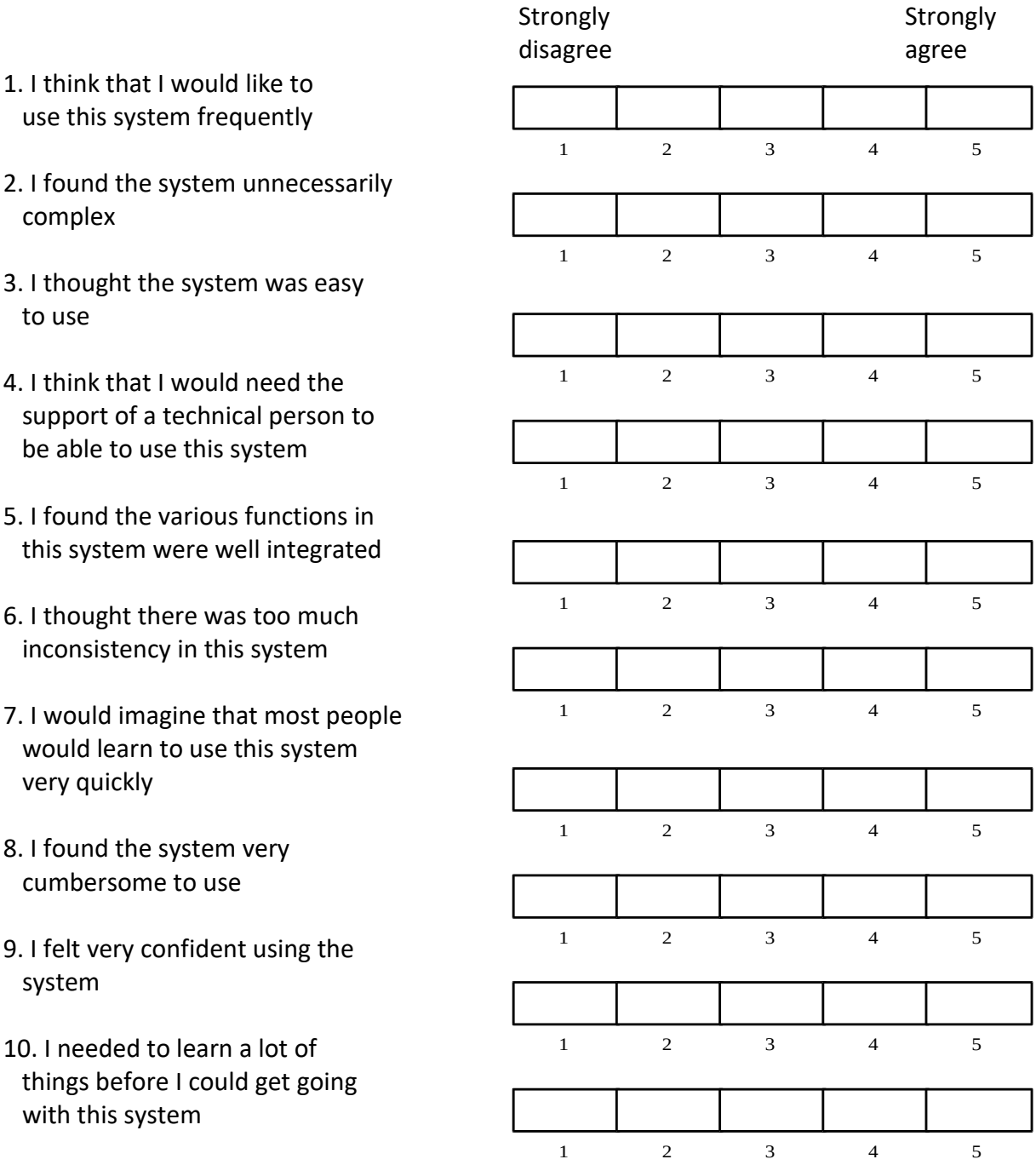
After the users are presented the solution and interact with it for few minutes, start the testing by presenting to the participants the *System Usability Scale* (SUS) test. The questions should be provided on paper for all participants. Take approx. 5 minutes to finish the test.

[3] Examples of questionnaires are available here.

[4] https://www.MOBISTYLE-project.eu/en/MOBISTYLE/project/objectives

System Usability Scale

© Digital Equipment Corporation, 1986[5]



3.3. Questions addressed

After the SUS test, continue with the debate. While showing the participants the MOBISTYLE solution, focus on the following topics and adapt your questions accordingly:

[5] Accessed 25.7.2018 https://hell.meiert.org/core/pdf/sus.pdf

1. **Intuitiveness and simplicity** of the graphical user interface (GUI): How do you find the design of the solution? Can you recognise the main features? What do you think of the symbols used on the screen?
2. Possible **channels of content distribution**, e.g. public screens and other ICT devices in the building that could be used for motivating them to change their existing practices: Where would you like to use the MOBISTYLE solution? Do you know any good place in the building where it could be shown to others?
3. Relevance of **advices, recommendations and tips**: Which advices do you like the most? Which are the least relevant for you? Why?

3.4. Testing advices and recommendations

After the last question, put some additional attention to MOBISTYLE health, energy and wellbeing related tips and recommendations. Arising from activities in T3.4, the recent list of possible statement can be found on Sharepoint here. Select the most appropriate and relevant tips for you demo case and print them out on small pieces of paper. Keep in mind that their purpose of the tips is to influence behaviour of people and to establish new habits.

- Provide a deck of 10-15 advices per participant. They should all get the same deck.
- Let them have a look of the questions (1-2 min).
- Ask them about the wording used. Let them comment and suggest better or even new tips, which would work best for them.
- Ask them to choose the 3 best tips (the ones they like most or find most useful in their own case) and 3 worst tips.
- After they pick 3 tips, ask them to explain their selection (1-2 min per participant).

Example texts used in SI demo case:

- *It seems you have left the window open for X hours, and outdoor conditions are not favourable.*
- *Open the window, it is warmer/colder outside.*
- *Reduce the temperature and boost your brain!*
- *Want to lose some weight due to increased metabolism? Reduce the heating in your office!*
- *If you feel cold, put on some clothes!*
- *Ventilate the room! CO_2 has been above X ppm for X minutes, you might get a headache and your productivity might decline.*
- *The outdoor conditions are excellent for letting some fresh air in!*
- *Ventilate the room! There is a risk of mould growth that can be hazardous to your health.*
- *Why waiting for the elevator? Use the stairs, save time, get fit and live longer.*
- *Turn off your computer and monitor.*
- *Its sunny outside, do you really need the light on?*
- *Turn off the light and equipment if there is no one in the room.*
- *Do you really need hot water for washing your hands?*

- *If you feel cool, put on some clothes!*
- *If you feel hot, you should cool yourself and/or move to another room.*
- *If you do X sit-ups, you will feel warmer and more focused.*

Below are images from testing the tips in Slovenian case.


3.5. Conclusion

Finally, thank the participants for their time and contribution and inform them that the MOBISTYLE team will keep them posted about the outcomes of the project.

4. Follow up

After you conclude the testing, analyse it and prepare a short report. First, analyse received SUS by using standard model to get numerical score for each participant. A table is provided here.

Use the audio recording to prepare a report of the qualitative part of the testing. First, include the metadata of the focus group (Title, Date, Type, Recorder/Facilitator, Duration, Location, Prepared by) and include your short comment at the beginning, explaining if there were any special circumstances or issues which affected the procedure. After that, prepare a list of participants' names and their initials, which are used in the report. Prepare a list of keywords, i.e. the main topics of the discussion. Describe each topic (add a subtitle above the paragraph(s) with a new topic) and explain what do people think about the user interface, how do they perceive the used symbols, how do they find the MOBISTYLE tips and advices (which are the most and least relevant for them), etc.

Finally, prepare some general recommendations coming out of the testing, which can be used to improve the MOBISTYLE solution and tailor it to your own local case. The recommendations can include your personal impression about the positive and negative aspects of the MOBISTYLE solution and about possibilities for improvement. Example of a report is available here[6].

[6] Focus group in Slovenia demo case (UL FKKT FRI) – testing the solution design.

Annex B – Evaluation questionnaires/interviews: Examples

A. (NEW) PERCEPTION OF COMFORT

How satisfied are you generally with the surrounding environment in terms of: (E1, E2, E3)

1) **Temperature**

Very unsatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied

Please specify and describe causes of your dissatisfaction related to the thermal environment:

_____
_____
_____

2) **Air quality**

Very unsatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied

Please specify and describe causes of your dissatisfaction related to the indoor air quality:

_____
_____
_____

3) **Amount of light**

Very unsatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied

Please specify and describe causes of your dissatisfaction related to the visual environment:

_____
_____
_____

How much do you agree/disagree with the following statements? (E2, E3)

The MOBISTYLE services helped me to improve the thermal environment in my home/office.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

The MOBISTYLE services helped me to improve the indoor air quality in my apartment/home/office.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

The MOBISTYLE services helped me to improve the visual environment in my apartment/home/office.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

B. (NEW) PERCEPTION OF ENERGY

How much do you agree/disagree with the following statements? (E1)

I think I am aware of how my daily routines and actions affect building energy use.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

I would like to improve my behaviour in order to reduce energy consumption.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

I would like to improve my behaviour in order to reduce energy costs.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

I would like to improve my behaviour in order to reduce my impact on the environment.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

How much do you agree/disagree with the following statements? (E2,E3)

The MOBISTYLE services gave me important hints on how my behaviour affects building energy use and the environment.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

The MOBISTYLE services helped me to reduce energy consumption and my impact on the environment.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

The MOBISTYLE services helped me to reduce energy costs.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

C. (NEW) PERCEPTION OF HEALTH

How much do you agree/disagree with the following statements? (E1, E2, E3)

I think that the indoor environment has a negative impact on my health.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

Please specify and describe why:

_____

_____

_____

I think that the MOBISTYLE services helped me to adopt a healthier lifestyle.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

Please specify and describe why:

_____
_____
_____

D. PERCEPTION OF FEEDBACK PROVISION AND MOBISTYLE PROJECT

How much do you agree/disagree with the following statements? (E1)

I am aware of the objectives of the MOBISTYLE project.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

I think that the objectives of the MOBISTYLE project are important.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

Please specify and describe why:

_____
_____
_____

I want to know how my behaviour affects building energy use/costs/indoor environment/my health.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

I would like to change my behaviour in order to reduce energy use and save energy costs.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

I would like to change my energy-related behaviour by adopting a healthier lifestyle.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

A healthier lifestyle can help me to reduce energy consumption.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

How much do you agree/disagree with the following statements? (E2,E3)

The MOBISTYLE services provided understandable information and feedback.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

Comments:

_____
_____
_____

Please describe the feedback* that you found **most useful and why.**

_____
_____
_____

Please describe the feedback* that you found **least useful and why.**

_____
_____
_____

*examples of implemented feedback in the specific case study can be provided

E. INTENTION TO CHANGE ONE'S BEHAVIOUR IN A LONG-LASTING MANNER

The MOBISTYLE services helped me to change my behaviour.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

Comments:

_____
_____
_____

I will adopt the learnt behaviour also in future.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

Please specify which behaviours* you will adopt/not adopt after the MOBISTYLE project.

I will adopt:

_____
_____
_____

I will not adopt:

_____
_____
_____

*examples of trained behavioural change actions can be provided (case-specific)

I will try to influence people close to me to adopt the learnt behaviours as well.

Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree

Comments:

_____
_____
_____

Annex C – Example of benefit monetization

As already mentioned in section 4.4, once the possible non-market benefits are identified, a monetary value should be estimated though the techniques mentioned above (section 4.4 of this deliverable). To do so, benefits have to be firstly quantified in physical units before their translation into a monetary value. In summary, the process consists in identifying, quantifying and monetizing benefits. The tricky part of benefits assessment is in the calculation of numerical values of the physical indicators and of the related monetary indicators properly selected. While for the latter there are the already mentioned techniques, benefits quantification should be based on their link with some physical phenomena. In the following an example in this sense is reported.

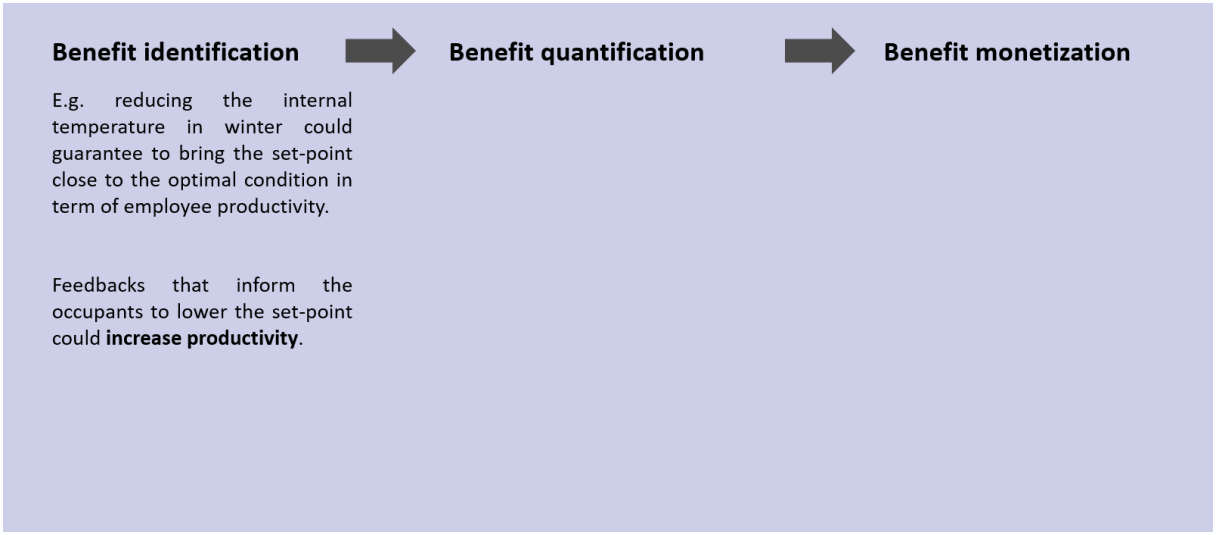


Figure 21: example of benefit identification

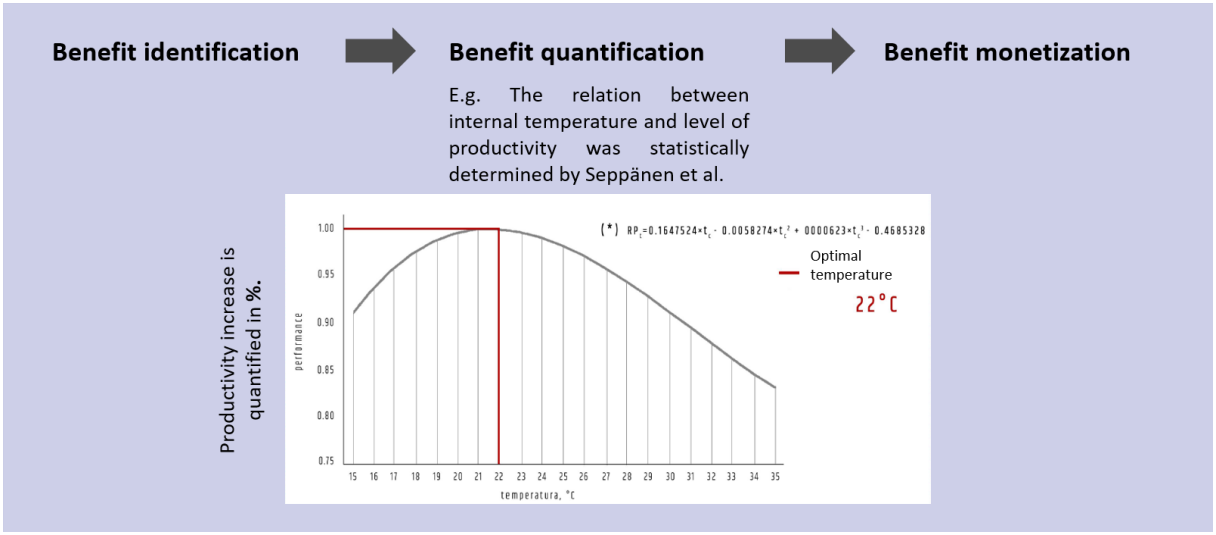


Figure 22: example of identification of a metric for benefit quantification

Benefit identification → **Benefit quantification** → **Benefit monetization**

E.g. The relation between internal temperature and level of productivity was statistically determined by Seppänen et al.

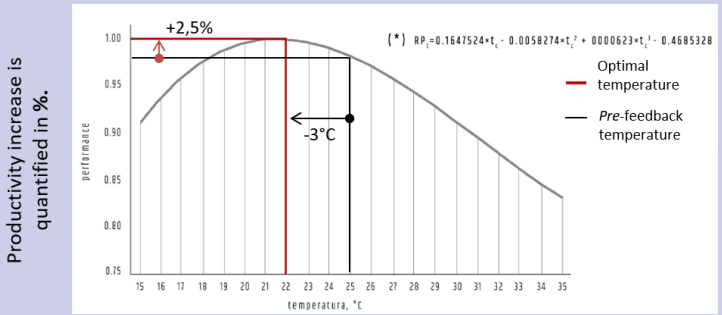


Figure 23: example of benefit quantification

Benefit identification → **Benefit quantification** → **Benefit monetization**

E.g. Relating the employee productivity to their medium salary, the increase in productivity can be monetized as variation in salary.

Medium salary= 16,83 €/h (*)

Benefit monetization=

16,83 x 0,025 = 0,42 €/h

(*) Medium Italian salary (Istat).

Figure 24: example of benefit monetization using market price of labour method