MOBISTYLE

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

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Executive summary

Due to low cost sensor techniques the amount of data collected from various physical quantities is expanding rapidly. Nevertheless, in some situations this data is easy accessible, available or readable; whereas in other situations the required data can be difficult to obtain.

Several challenges recognized from the practice served to form project's goals and opened research questions that will be tackled inside the MOBISTYLE project. For the first – How and which sensors should be installed in the building to present a cost-efficient solution (presenting interesting data types). A sensoring plan needs to be established for each building. For the second – Currently, most of the data is owned by a manufacturer of a building monitoring system. Therefore, it needs to be studied on how to access the data from different sensor manufacturers (energy, temperature sensors, wearables etc.). Combining fragmented sensoring technology, easy to use APIs, universal standards for communication protocols and centralized network hub (gateway) would help connecting different systems to each other. For the third – Absence of occupant's interest in the building performance knowledge leads to a poor usability of the developed building services. The question arises, how to achieve the end-users actually start using the developed tools and change their behaviour towards a more energy efficient building usage. In order to solve these issues and address the main challenges exposed, the MOBISTYLE objectives were developed.

This task **Framework for systematic data representation** focuses on answering the second research question. The main part of this deliverable reports the development of *definitions for energy and energy related data representation*. This data normally represents all kind of partial energy flows e.g. ventilation, hot tap water, solar radiation, home appliances etc. Therefore, data representation solution will consist of a vocabulary with a number of definitions of partial energy flows including the specification of the numbers regarding accuracy of the measurements (alike ISO/AWI 50008[1]). The framework will be used within MOBISTYLE to promote *data exchange between devices, data storage and calculation models*.

Besides energy related data, MOBISTYLE gathers also *Indoor Environmental Quality (IEQ) related data from building sensors and health data from wearables*. This means that the MOBISTYLE technical information model has to allow also for systematic data representation coming from these sources and not only energy related data. This deliverable therefore also addresses of the technical requirements that need to be satisfied as part of the common MOBISTYLE information model in order to gather data coming from the different sources in a systematic and efficient way.

[1] https://www.iso.org/standard/51871.html

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1. Introduction and objectives for the systematic MOBISTYLE data representation

It is important that people share same definitions and representations for energy related data to promote data exchange and data use between storages and devices. e.g. the air flow as physical quantity a mean of energy use must be described (measurement, units, accuracy) in the same way in all applications. Other examples are temperature differences, local outdoor temperature (i.e. over the building envelope) and domestic hot water flow. Aligning these definitions, the communication about and interpretation of energy related data increases the common understanding and effective communication between end-users, developers, designers and experts.

The scope of D4.4 is to report on the work done during the MOBISTYLE ICT development process that allows for a common definition of (energy) data representation that was collected inside MOBISTYLE. The intermediate version of D4.4 was prepared during the 2^{nd} reporting period as the physical quantities were further elaborated, both on a general level as case specific level. The final version of D4.4 consists of following parts:

1: The MOBISTYLE ICT architecture for building's data representation
This includes a short presentation of the overall concept of the *MOBISTYLE technical information model architecture* allowing efficient data measurement and transfer.
The technical details are further elaborated in the deliverables D4.1 'Applicable hardware and software solutions for sensing technologies' and D4.2 'Applicable platform and database for software and information interoperability'.

2: Data management process and the **MOBISTYLE Expert tool**
This provides a description of the data management process and the identified methodology (i.e., a data analysis toolbox), allowing such systematic data representation.
The *Expert tool* (developed by DMO) allows such a systematic data insight where it has three main goals:

- data access;
- data management;
- easy and efficient export of data.

3: Data analytics and KPI definitions
This part provides a *Vocabulary of definitions and representations of all physical quantities* applied in the MOBISTYLE demo cases (KPI, units etc.). A review is given of existing KPI definitions across EU: EC Directives and initiatives (e.g. EPBD, EED, Ecodesign, Digital Single Market etc.).

4: Future recommendations
Finally, some recommendations are given for future work based on the lessons learnt that could be taken further by European or national institutions for standardization as CEN.

5: Conclusions

2. MOBISTYLE Data information model definition

MOBISTYLE aims to make use of both real-time building energy data, data from IEQ sensors and wearables, smart plugs and smart appliances (see Figure 1). The MOBISTYLE aim is to process it in one integrated environment where afterwards a customized information types are catered in an understandable way to the building user (through an app on the mobile etc.).

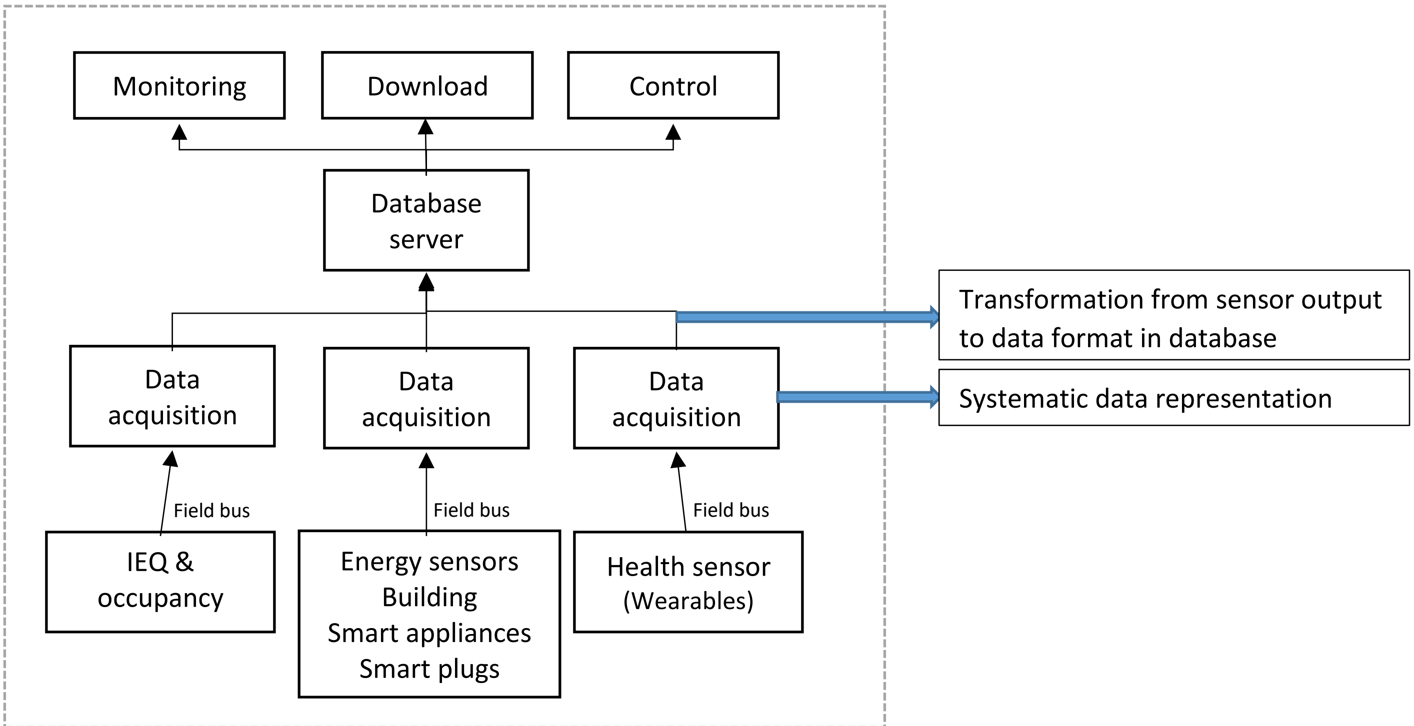


Figure 1: The MOBISTYLE data acquisition model.

The MOBISTYLE Information model for data exchange components is consisted of the MOBISTYLE database (memory) and the different tools allowing transformation of raw data into useful but reliable information based on the standardized exchange protocols and reliable ICT architecture (intellect).

The bottom-up data collection included data gathering from the MOBISTYLE demonstration cases representing different quantities: energy, IEQ, health data. Nevertheless, to support transparent data exchange among EU building stock, in the last part of the MOBISTYLE project, several relevant stakeholders (forming MCAB board) were contacted by the consortium to support EU wide data collection process. The objective was to investigate whether other data types can be connected with the MOBISTYLE database and give feedback whether this data exchange repository presents a valid business case.

To ensure that reliable information is provided to users, a robust and transparent building information mechanism is foundation for collecting actual buildings energy performance data and providing information to building users, companies and other relevant stakeholders (MCAB).

2.1 MOBISTYLE ICT architecture for building's data representation

According to the Directorates General (DG) for Information Society and Media of the European Commission, ICT will play a significant role to achieve the European Union environmental objectives and to help in accelerating economic growth as well as to improve energy efficiency. A comprehensive approach has been developed to facilitate the cooperation and communication between policy makers, business, and other stakeholders such as citizens.

If it is implemented correctly, ICT tools can achieve various energy efficiency improvements:

- ICT enables saving through intelligent observation, feedback and control.
- Today's ICT architectures allow a wide range optimization through data exchange
- ICT allows advanced monitoring systems that analyze different data besides the plain energy consumption, such as IEQ and health in the MOBISTYLE case.
- ICT helps to structure and visualize the collected data, analyze them and report back for improvement. Furthermore, it gives first hints on where and when they are, and what has caused them. Monitoring is also needed to generate consumption and life style profiles which in combination with knowledge management can aid in forecasting energy demands.
- Advanced data analysis algorithms allow the increase of performance, effectiveness.

Criteria for the ICT architecture to carry out the energy data representation and analysis are developed. The developed criteria are listed as follows:

- Data acquisition, interoperability, management, transfer and exchange requirements: Due to diverse available sensoring techniques and data acquisition possibilities, the MOBISTYLE ICT architecture needs to satisfy certain requirements in order to enable systematic data exchange. Therefore, interoperability among different IT systems, is an important point for a successful implementation of data exchange and management system.
- Knowledge-based intelligent analysis: Information and knowledge coming from different sources have to be structured and formalized in a knowledge base where certain key performance indicators (KPIs) and its benchmarks are evaluated in order to evaluate the performance using quantitative information. Based on evaluation of these KPIs certain performance actions (measures) can be introduced to different target groups. Furthermore, interoperability between IT system and human stakeholders is also important, as well as knowledge sharing among stakeholders. The link between the IT system and humans can be supported by an expert system that works on the knowledge base. In MOBISTYLE this is the objective of the Expert tool.
- Vocabulary and representations. The generation of the systematic data exchange base is an extensive task where the aim is to come to a framework for a vocabulary of definitions and representations of all physical quantities and corresponding units applied in MOBISTYLE.

The *MOBISTYLE Database* (developed by DMO) can gather and categories a range of diverse data coming from Building Management Systems (BMS), individual indoor environmental quality (IEQ) sensors and other third party (European) databases. Directly linked to the database are *statistical analysis tools and algorithms* (AAU, POLITO) that allow elaboration of the chosen MOBISTYLE KPIs based on the measured data allowing *MOBISTYLE Expert tool* (DMO). See section 3, allows data management with functionality allowing external developers and third parties to access to the data for validation and filtering. The second purpose is to enable the expert to calculate basic KPI related to energy and also to IEQ, comfort and health. Analyses of data allow for transformation of data into useful information and knowledge for identified user groups. In order to accelerate knowledge generation process, a learning capability is a key also in MOBISTYLE Information model. When disclosing the information to users for the MOBISTYLE demonstration cases, the *MOBISTYLE Game* (HS), *MOBISTYLE Office App* (HIA) and *MOBISTYLE Dashboard* (HOLX) are available.

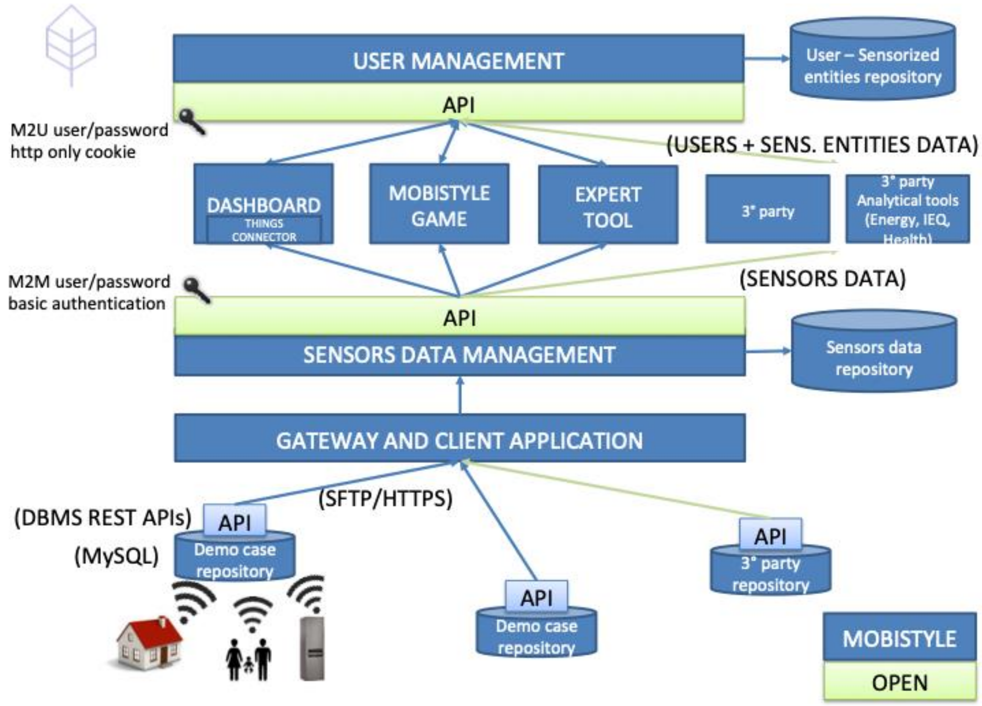


Figure 2: MOBISTYLE data collection flow and MOBISTYLE ICT architecture.

In recent years many buildings in EU are getting equipped with different sensoring systems producing an increasing number of data on energy generation and consumption from various sources (e.g. smart meters, Building Management Systems). This is also the case in the MOBISTYLE demonstration buildings. Collecting reliable data from buildings and making it available is a key challenge for the European Union. Enabling big data for buildings is key to achieving the EU targets. More and better data can lead to enhanced consumer information, contribute to an effective management of energy grids and support the creation of innovative energy services, new business models and financing schemes for distributed clean energy. Data is also a key enabler for reliable and effective policy impact assessments. The collection and analysis of building data, through data analytics tools, will produce statistics, business intelligence and predictive models that will enable reliable and effective policymaking.

The reference architecture should ensure compatibility with existing dataset formats across EU, allow integration with legacy architectures, encourage replication and scale-up and be compliant with applicable EU standards (e.g. privacy, security, intellectual property). The data architecture should be modular in order to accommodate data from various sources including dynamic data from Smart Meters, Sensors and other IoT devices, Building Management Systems (BMS), energy market prices, weather data, currency exchange rates, as well as static data from existing databases such as consumer consumption data, Energy Performance Certificates (EPC) repositories and Building Stock Observatory.

For the five MOBISTYLE demonstration cases (see the deliverables D4.1 ‘Applicable hardware and software solutions for sensing technologies’, D4.2 ‘Applicable platform and database for software and information interoperability’ and D6.1 ‘Detailed final monitoring, awareness and information campaigns’) data acquisition systems are established allowing transfer of data from the demonstration buildings to the MOBISTYLE database. The requirements for data acquisition needed to be met at the building site to allow sufficient transfer and reporting of data that is then stored at the common MOBISTYLE database coupled with real time analysis and trend analytics when needed.

3. The MOBISTYLE Expert Tool

3.1 Introduction

A preliminary description of the Expert tool was already provided in chapter 5 of D4.1 'Applicable hardware and software solutions for sensing technologies'.

The Expert Tool is first used by the MOBISTYLE experts in WP3 and WP6 in order to be able to access sensors data from the different demonstration cases. With these data the experts will perform data analysis and evaluation on energy, comfort and health.

The Expert Tool is built as part of the RE Monitoring, software application integrated in the commercial software package RE Suite developed by the consortium partner DMO.

The Expert Tool has 3 main purposes:

1. Data management: the expert has access to the data for visualization, filtering and validation purposes.
2. KPI calculation: the expert will be able to visualize and download KPIs on energy, comfort and health.
3. Support the needs of third parties tools: the expert will be able to export the data in the most suitable format. This functionality guarantees the interoperability between the Expert Tool and the other software programs used by the expert for evaluation and analysis purposes.

3.2 Main functionalities of the Expert Tool

The expert tool aims to supply experts (WP3 and WP6) with the dataset(s) they need. Its purpose is not high-level analysis, but rather offering experts access to data for use in their own tools.

As such, a simple retrieve-and-save-to-disk operation would fulfil the basic theoretical requirements. However, this method will quickly prove insufficient. Therefore, following questions should be considered:

- What if an expert only needs part of the set?
- How will an expert know if the result matches their expectations?
- Must they dive into the dataset's depths and do a preliminary analysis?
- How will they even know what to query if they do not know what a dataset looks like?

To answer these questions, the Expert Tool offers dataset constraints through the use of filtering conditions. It offers quick verification through visualisation of dataset summaries. It must offer insight in data sources and their current status. And finally, it must export a verified dataset in some format that is useful to the expert's tools.

The Expert Tool is a client application with an interface. It connects to an API back-end on the data server with access to all MOBISTYLE Data.

The base retrieve-and-store functionality is implemented as follows:

- A download button retrieves data from the server into the tool.
- An export button writes data loaded into the tool into a file.

3.3 Data management

For data management purposes the following functionalities have been implemented in the Expert Tool:

1. Data retrieval
2. Data filtering
3. Data visualisation
4. Data export
5. Sensor status validation

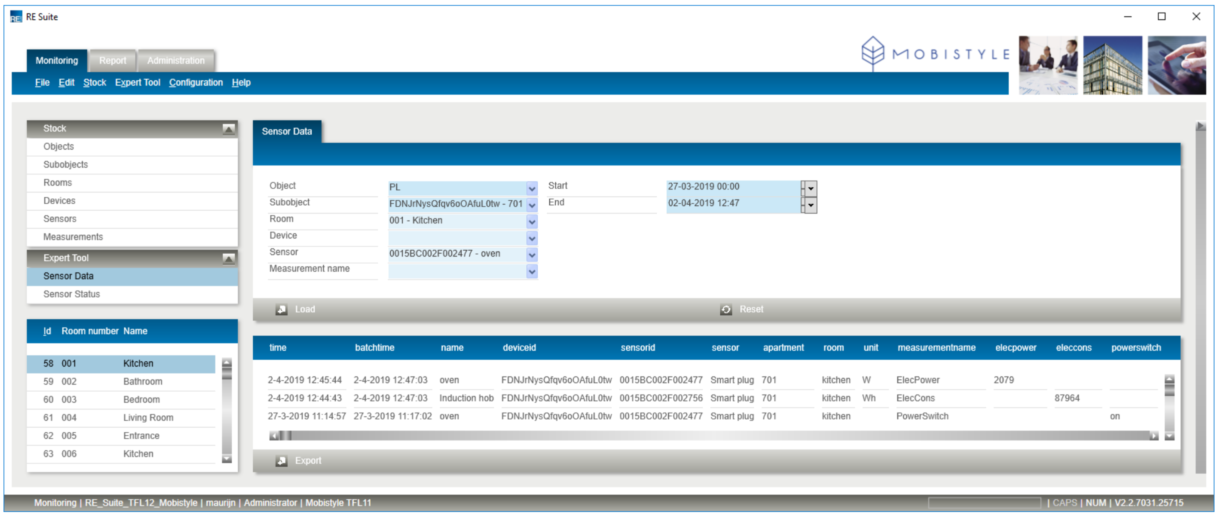


Figure 3: Expert tool interface

3.3.1 Data retrieval

The Expert Tool is a client interface application, communicating with a data server. Through custom APIs the expert tool requests the server to extract and build the data set required before passing it on to the client.

However, data sets are large and building those takes time. Especially if an expert is uncertain if the requested dataset will meet their needs, waiting for a multi gigabyte data set to be compiled and transferred is inefficient. Thus, in the future, the Expert Tool will be extended with summarizing functionality. This will allow requesting a dataset summary, retrieving only the necessary data for proper visualization, plus statistics on data set volume and estimated processing time. Only if the user affirms, will the true dataset be built.

3.3.2 Data filtering

Before retrieving a dataset the user can select filter conditions. This instructs the server to constrain the dataset, filtering out irrelevant data and reducing overall size. Note that this operation executes on the server as to prevent communication overhead. The following filter conditions are supported:

- Case/Apartment/Room/Device/Sensor/Measurement
  The semantic hierarchy constraint according to the metadata definition.
- Start/End
  The time constraint for data points of interest.

Example

To retrieve the electricity consumed by the oven in the kitchen of Polish apartment 701 in the month of March 2019, specify the following filter conditions:

- Case: Polish (PL)
    - Apartment: FDNJrNysQfqv6oOAfuL0tw (701)
        - Room: 001 – Kitchen
            - Sensor: 0015BC002F002477 – oven
                - Measurement name: ElecCons
- Start: March 1st 2019, 12 am
- End: April 1st 2019, 12 am

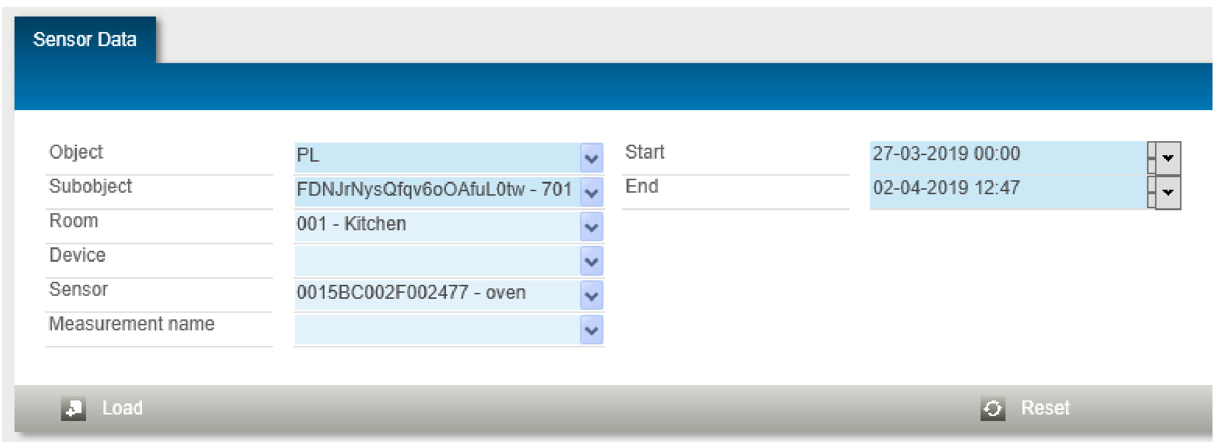


Figure 4: Zoom on filtering interface

3.3.3 Data visualization

After retrieving a dataset, the (structure of the) data is displayed in the RE Suite. The purpose of this visualisation is gaining immediate high-level insight into the structure and content of the data. Answers that should be immediately evident are:

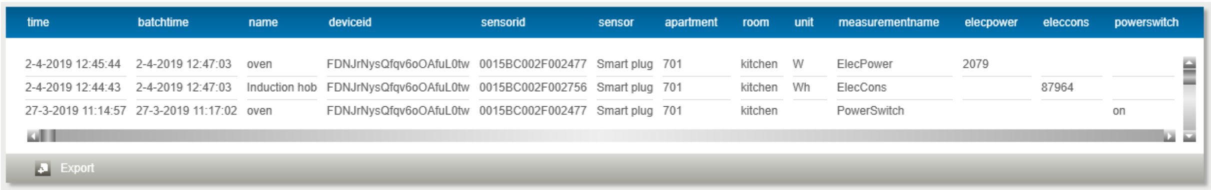
- Is the dataset empty?
- What is the structure of the dataset?
- Roughly, what is the data?

Ideally, visualisation should also answer:

- What are the minimum and maximum values?
- What timestamps are present?
- What is the time-based progress of the data?

Currently, (part of) the data is displayed in a tabular format. This makes empty or sparse datasets immediately evident. Secondly, the columns indicate the structure of the dataset that will be produced without requiring actual exporting. Because values are displayed simple questions become answerable immediately. For example: what was the sensor value at specific time X is visible without requiring external tools to read an exported dataset.

In the future, plotting of data in graphs will be supported to gain insight into value changes over time, answering the remaining questions listed above.



time	batchtime	name	deviceid	sensorid	sensor	apartment	room	unit	measurementname	elecpower	eleccons	powerswitch
2-4-2019 12:45:44	2-4-2019 12:47:03	oven	FDNJrNysQfqv6oOAfuL0tw	0015BC002F002477	Smart plug	701	kitchen	W	ElecPower	2079		
2-4-2019 12:44:43	2-4-2019 12:47:03	Induction hob	FDNJrNysQfqv6oOAfuL0tw	0015BC002F002756	Smart plug	701	kitchen	Wh	ElecCons		87964	
27-3-2019 11:14:57	27-3-2019 11:17:02	oven	FDNJrNysQfqv6oOAfuL0tw	0015BC002F002477	Smart plug	701	kitchen		PowerSwitch			on

Export

Figure 5: Zoom on data visualization

In addition, the Expert Tool is used for the management of the metadata, as described also in chapter 4 and 5.2.3 of deliverable D4.1 ‘Applicable hardware and software solutions for sensing technologies’.
The top task bar contains the main commands and configuration option. On the top left, are indicated the main categories: Objects (demonstration case), Sub-objects (Apartments), rooms, devices, sensors and measurement types. By clicking on each category, the detailed information and content is available in the main screen. Here it is possible also to visualize the relation between the elements.

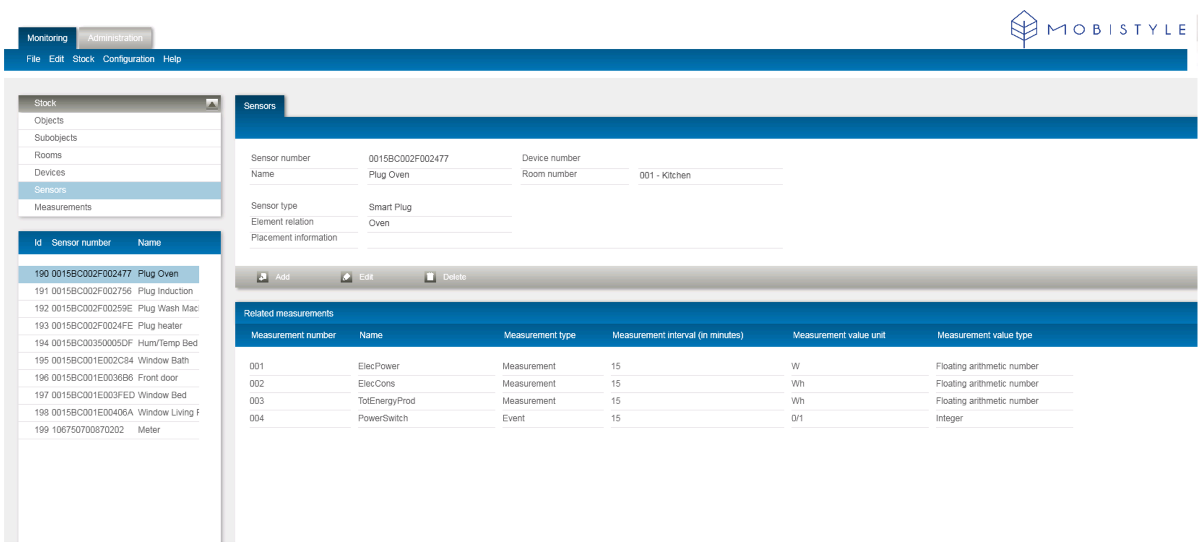
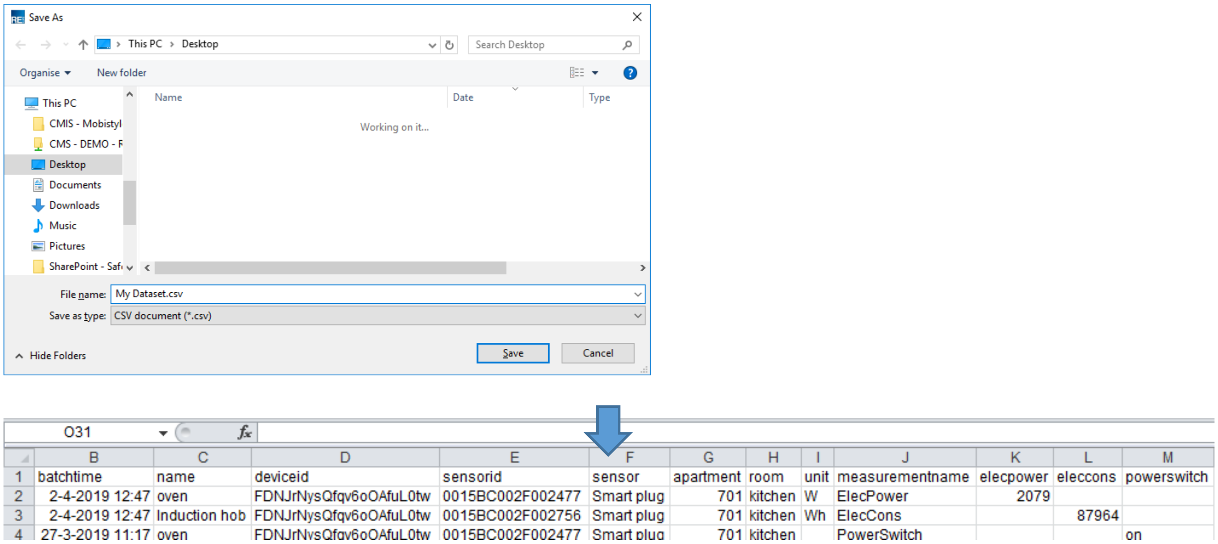


Figure 6: Metadata interface. Example for the PL case

3.3.4 Data export

Data is exposed by MOBISTYLE APIs through JSON as it is compact and very machine-readable, thus well suited for data exchange. However, many tools prefer data in some kind of tabular format, such as popular spreadsheet applications. For this purpose the Expert Tool allows exporting of its dataset to a Comma Separated Values-file, or CSV. This is a very popular format, supported by most applications with a data import function. Many conversion applications also exist, so by including them in the tool chain, maximum interoperability is achieved.



	B	C	D	E	F	G	H	I	J	K	L	M
1	batchtime	name	deviceid	sensorid	sensor	apartment	room	unit	measurementname	elecpower	eleccons	powerswitch
2	2-4-2019 12:47	oven	FDNJrNysQfqv6oOAfuL0tw	0015BC002F002477	Smart plug	701	kitchen	W	ElecPower	2079		
3	2-4-2019 12:47	Induction hob	FDNJrNysQfqv6oOAfuL0tw	0015BC002F002756	Smart plug	701	kitchen	Wh	ElecCons		87964	
4	27-3-2019 11:17	oven	FDNJrNysQfqv6oOAfuL0tw	0015BC002F002477	Smart plug	701	kitchen		PowerSwitch			on

Figure 7: Export function

3.3.5 Sensor status validation

The Expert Tool exposes data collected by the MOBISTYLE Data Collection Service. However, this is merely a reflection of the true data sources: the sensors themselves. Insight into the platform data would be incomplete without insight into the sensor status. For this purpose an overview visualises which sensors are performing well and which sensors expose less data points than expected.

The origin of this is an independent application, the “AutoCheck”, used for gaining insight into malfunctioning sensors during the development process. At that time, it helped detect discrepancies between the data collected and the data that was exposed. Currently, the results are shared with all demonstration cases on a weekly base.

The procedure creates a tabular format containing the number of data points received per sensor per day. Basic detection of malfunctioning sensors occurs by highlighting intersections without data points in red. More advanced analysis highlights data point counts below an acceptable threshold in orange. This threshold is dynamically calculated, and set to 75% of the median of the non-zero counts available.
As an example, let a sensor produce 5 data points on a particular day. If it always produces 6 values, it will be marked in green. If it normally produces 16 values, it will be marked as orange.

		Id			Thu 28 Feb	Fri 1 Mar	Sat 2 Mar	Sun 3 Mar	Mon 4 Mar	Tue 5 Mar	Wed 6 Mar	Thu 7 Mar	Fri 8 Mar	Sat 9 Mar	Sun 10 Mar	Mon 11 Mar	Tue 12 Mar	Wed 13 Mar	Thu 14 Mar	Fri 15 Mar	Sat 16 Mar	Sun 17 Mar	Mon 18 Mar	Tue 19 Mar	Wed 20 Mar	Thu 21 Mar	Fri 22 Mar	Sat 23 Mar	Sun 24 Mar	Mon 25 Mar	Tue 26 Mar	Wed 27 Mar	Last measurement
					Measurements per day																												
1		9/1/53	KNX RF+ Socket with active power measurement	printer	0	0	0	0	0	753	1071	243	1095	1304	137	250	904	1530	1725	1597	1077	138	510	886	983	827	1746	1217	137	1088	1521	1012	Thu, 28 Mar 2019 06:53:27 GMT
2		9/1/54	KNX RF+ Socket with active power measurement	PC	0	0	0	0	0	89	134	135	136	135	138	136	134	136	128	135	137	137	113	103	112	99	115	110	137	135	131	137	Thu, 28 Mar 2019 06:53:14 GMT
3		9/1/73	KNX RF+ Socket with active power measurement	printer	0	0	0	0	0	108	143	110	100	144	143	143	142	142	143	142	144	143	143	134	125	132	115	143	144	139	144	143	Thu, 28 Mar 2019 06:52:35 GMT
4	RECEPTION	9/1/74	KNX RF+ Socket with active power measurement	PC	0	0	0	0	0	106	137	139	141	141	143	142	139	143	138	142	140	142	117	103	117	102	120	110	144	141	135	142	Thu, 28 Mar 2019 06:54:18 GMT
5		9/2/12	SchneiderCO2, humidity and temp. sensor		0	0	0	0	0	64	96	96	95	96	95	96	95	96	97	95	96	96	96	97	96	95	96	95	96	95	95	96	Thu, 28 Mar 2019 06:52:52 GMT
6		9/2/2	SchneiderCO2, humidity and temp. sensor		0	0	0	0	0	64	96	95	95	96	94	95	96	95	97	94	95	96	93	97	94	94	96	94	95	95	95	94	Thu, 28 Mar 2019 06:49:15 GMT
7		9/2/22	SchneiderCO2, humidity and temp. sensor		0	0	0	0	0	64	94	94	95	95	94	95	95	94	97	95	95	94	95	96	96	94	95	95	95	95	94	96	Thu, 28 Mar 2019 06:47:41 GMT
8		2/0/1	magnetic switch / BMS		0	0	0	0	0	23	8	7	25	17	0	12	22	19	1	23	102	44	25	18	13	11	18	7	0	3	2	23	Wed, 27 Mar 2019 16:34:18 GMT
9		2/2/1	magnetic switch / BMS		0	0	0	0	0	3	2	0	2	4	0	0	3	0	1	0	15	4	6	4	2	4	0	2	0	0	0	0	Sat, 23 Mar 2019 10:03:58 GMT
10		4/2/1	Attuatore		0	0	0	0	0	13	3	4	9	5	0	6	13	11	1	10	21	7	11	12	8	6	7	4	0	4	2	10	Wed, 27 Mar 2019 16:34:55 GMT
11		5/0/1	Termostato ABB TUX/U 1.1		0	0	0	0	0	10	13	2	2	13	0	0	3	2	2	1	6	1	13	3	6	4	0	3	1	1	0	1	Wed, 27 Mar 2019 06:32:09 GMT
12		5/1/1	Termostato ABB TUX/U 1.1		0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	Tue, 19 Mar 2019 08:38:11 GMT
13		7/2/1	Attuatore		0	0	0	0	0	4	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	Tue, 19 Mar 2019 08:34:30 GMT
14		7/3/1	Attuatore		0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	Tue, 19 Mar 2019 08:34:57 GMT
15	Room 01	9/0/1	KES-KNX Energy saver (floor distribution board)		0	0	0	0	0	85	144	144	144	144	143	144	144	144	143	144	144	144	144	144	145	144	144	144	143	144	143	144	Thu, 28 Mar 2019 07:00:00 GMT
16		9/0/16	KES-KNX Energy saver (floor distribution board)		0	0	0	0	0	114	155	151	147	146	143	143	146	160	149	149	149	158	165	190	170	188	169	164	165	163	165	166	Thu, 28 Mar 2019 06:52:04 GMT
17		9/1/51	KNX RF+ Socket with active power measurement	TV	0	0	0	0	0	151	107	14	76	272	167	326	52	217	398	365	273	176	165	102	138	109	122	18	0	2	1	33	Wed, 27 Mar 2019 16:27:23 GMT

Figure 8: Example AutoCheck IT case

3.4 Assessment of usability by demonstration case holders

In line with the protocol for MOBISTYLE solutions testing implemented in **D4.3 Software modules for user interfaces on mobile devices** based on the System Usability Scale (SUS) testing and evaluation questionnaire, the demonstration case holders, as main users of the Expert Tool have provided feedback on their experience with the Expert Tool (at M36). Unlike the SUS questionnaires used for the end-users MOBISTYLE Tools (i.e. Dashboard, Game, App), for the evaluation of the Expert Tool, the demo case holders have briefly covered the following aspects of the tool:

- Effectiveness: the ability of users (i.e. managers/experts) to complete tasks using the tool and the quality of the output of those tasks;
- Efficiency: the level of resources consumed in performing tasks
- Satisfaction: user’s subjective reactions to using the system)

IRI University of Ljubljana for the Slovenian demonstration case

In terms of efficiency and effectiveness (data transfer functionality):

- The tool works very slowly; this might be however related to the remote access functionality;
- When choosing a date from the drop-down menu, the month and year are written in black on a dark blue background (i.e. very poor visibility);
- When you select all the criteria and press the **Load** button, it would be great if you could see that the function is executing, because it happens, that you cancel the task too quickly not aware if there is no data or you are too fast and you can continue;
- With respect to the weekly AutoCheck file, this functionality is very valuable as it triggers the manager/owner to start investigating for example when data flow interruptions are occurring;
- Overall, I am positively surprised by the Expert tool. I managed to figure out how to get the data needed quickly. I like that in addition to the data, a graph is also drawn.

AAU for the Danish demonstration case

For the Danish demonstration case the tool has primarily been used to download the data and analyse that outside of the Expert tool environment. Therefore, only this feature of the tool has been evaluated.

- In general the tool has a clear structure, which is user friendly and easy to navigate. However, for downloading purposes it lacks a function for simultaneous download of data from many parameters. In the existing situation, the user must do it separately for each parameter, not even the sensor, which is every time a consuming activity. The logic behind is fully understandable, namely that by downloading individually the user has a better control of the data amount. etc. However, similar as in SQL database you could call for all data from a particular apartment with a single download action.
- The built-in functions for different aggregation options for the data are very useful and saves editing/coding time after data download.
- Choosing the start and end time of the data needed could also allow for user to type in the period and not only select it from the calendar;
- Visualization of each parameter for specific purposes are handy.

POLITO (Cristina Becchio) for the Italian demonstration case

The experience with the Expert tool as Italian demonstration case holder is mainly related to the following actions:

- Checking on sensor status to identify possible sensors disconnected;
- Downloading of raw data for the assessment of data quality;
- Downloading of raw data for the evaluation of the outcomes of the project;
- Computation and downloading of preliminary KPIs for evaluation purposes;
- Visualization of some parameter trends for different purposes (e.g. visualization of actual active power of printer to identify peak and standby power in order to define rules for the implementation of new suggestions in the Dashboard deployed at demo side).

In leading other activities within the project (i.e. proposal of KPIs for the MOUP; definition of personalized Cost-Benefit Analysis methodology per each demo case) the tool was also deployed to understand available data at each demo case level.

Based on the above mentioned activities the following has been experienced:

- navigation in its different parts and filtering tools are intuitive;
- check on sensor status is useful;
- With respect to the filtering function organized as drop-down list, it is easy to understand which variables are available per each sensor and which sensors are associated to the different rooms (even if understanding of the meaning of the variables requires sometimes direct knowledge of the demo case);
- Functionalities are useful and formatting of downloaded data suitable for the analysis.

Some criticalities that make the tool not always handy in the usage are:

- refresh button does not allow to save some of the filtering options;
- scrolling of the calendar to look for dates of interest uses the refresh all the *times* it has opened, slowing the user down;
- retrieving of data sometimes is not efficient in terms of speed.

Based on the experience with the tool, the following has been identified with respect to possible improvements for exploitation:

- concerning the pre-visualization of data, popping up of a window when the cursor is positioned on the graphs showing x and y values (i.e. numerical value and time) would be particularly useful to understand visualized data, especially when a long data series is displayed;
- concerning the contents, documentation page to explain how the proposed KPIs are computed would be beneficial, especially for an external user.

3.5. Next steps

The expert tool was developed within last year of the project (M30-M42) based on the following functionality objectives:

1. Related to the first purpose of data visualization:
    a. Raw data will be visualized in graphs and icons;
    b. KPIs will be visualized as well;
    c. A summary of the dataset will be made available.
2. Related to the second purpose of KPI calculation:
    a. Simple KPI algorithms will be implemented in Expert Tool. The list of KPIs will be provided by WP3 (POLITO);
    b. Filtering functionality for KPI type;
3. Related to the third purpose of interoperability:
    a. Export of KPIs in the most convenient format will be guaranteed. The export format will be discussed also with WP3 partners, in order to allow full compatibility of the Expert Tool with other analytical tools used within the project.

4. MOBISTYLE vocabulary of definitions and representations of all physical quantities applied

4.1 Fundamental definitions in MOBISTYLE: data, information, knowledge

The words data, information, and knowledge are often used to represent the same thing in ICT world. Nevertheless, in MOBISTYLE distinction is done between these terms due to their objectives. The following definitions are proposed

Webster's dictionary defines data as follows:
"*Data are factual information (as measurements or statistics) in forms of sets of symbols which are used as the basis for reasoning, discussion or calculation*."

Bauer et al. defined information as follows:
„*Information is an interpretation of data in a context*."

Data become information if meanings are given to them in forms of relations, and they are interesting, meaningful, and understandable for a human. In MOBISTYLE, this was ensured by adopting people centric approach where information provision was based on the outcomes of the focus groups (see D2.2 for more information). Information is gained from data through interpretation of data based on a reference system.

Knowledge represents the structure, meaning, application, interpretation and other functional characteristics of data. In this work the following definition is used: "*Knowledge is a quantity of all interpreted and evaluated information which is integrated as a whole inconsistent and unambiguous manner. The structure of knowledge allows formulating the future events based on previous events that have already occurred and has been saved. In general, knowledge symbolizes the know-how coming from previous experiences*."

The relation between definitions of data, information, and knowledge can be summarized as shown in Figure 9 [2].

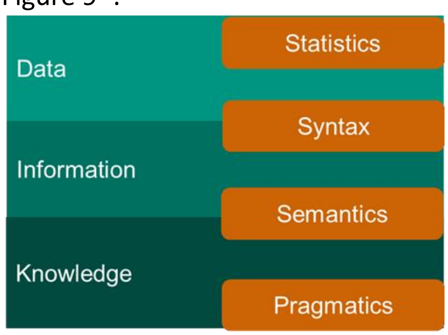


Figure 9: Relation between definitions of data, information, and knowledge.

[2] An Integrated Method for Information and Communication Technology (ICT) Supported Energy Efficiency Evaluation and Optimization in Manufacturing, H. Wicaksono, 2016

4.2 Basic principles and position of sensors for energy use and IEQ parameters

In building installations there is a distinction in two main building types: non-residential buildings and residential buildings (i.e. dwellings) due to their main characteristics of the climate installations. The figures 10 and 11 show the main basic principles for energy and IEQ monitoring to evaluate the energy balance understanding energy use of the building and energy use by user behavior for residential (i.e. dwellings) and non-residential buildings (i.e., cellular offices).

4.2.1 Residential buildings

Typical for residential buildings is that, especially in well-insulated buildings, the energy use of DHW can be higher than for space heating. So a need can be noticed for measuring heating separately form DHW. In NZEB residential buildings also electricity use for building-bound appliances, especially for fans, can be dominant in relation to space heating. IEQ measurements will be mainly performed in the living room (CO_2), (master) bedroom (CO_2) and bathroom (RH). From the Dutch TKI TRECO projects[3] it can be shown that peoples behavior shows independent profiles regarding heating, DHW and electricity use for household appliances. Therefore, the need for independent sensoring these energy flows.

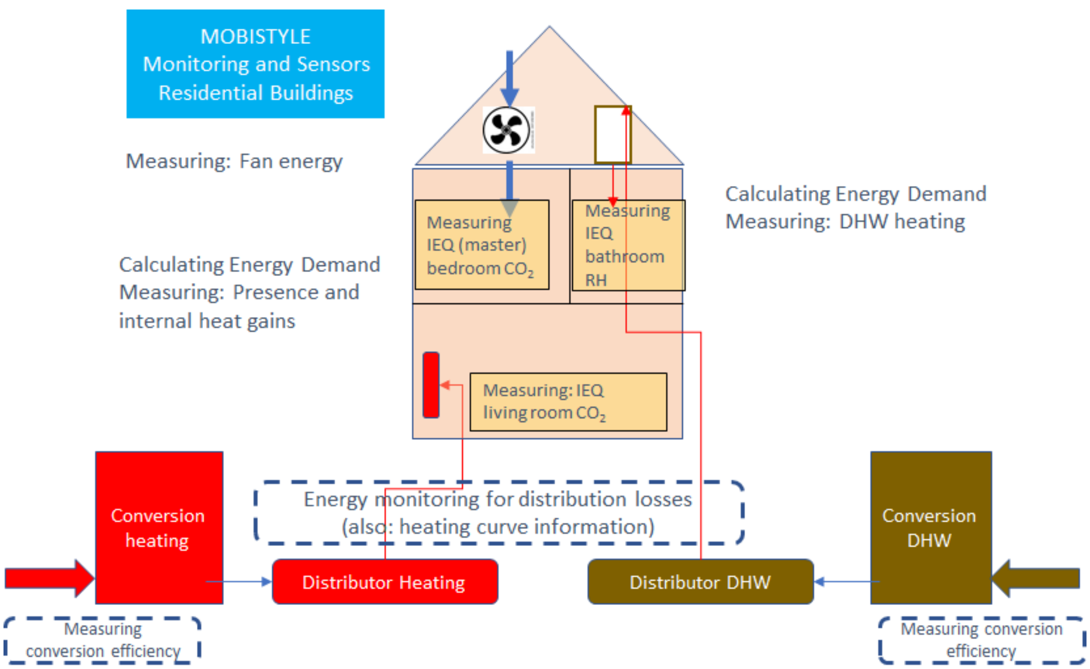


Figure 10: Positioning monitoring sensors for IEQ, conversion and distribution efficiencies and energy use in dwellings

4.2.2 Non-residential buildings

As the consumption of DHW in offices is neglectable, it does not make sense to measure/monitor energy use for DHW. From the other hand, energy use for cooling (if applicable) can be dominant, especially in offices with relative high heat gains (solar radiation, office equipment, lighting). The number and the positioning of sensors for energy and IEQ monitoring in non-residential buildings, or more specifically in

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[3] TKI TRECO Home, Towards Real Energy performance and Control by predicting, monitoring, comparing and controlling' for Homes, final report, June 2018
TKI TRECO Office, Towards Real Energy performance and Control by predicting, monitoring, comparing and controlling' for Offices and Public Buildings, final report, March 2018

offices, depends on the type of offices (open plan versus cellular offices) and the type of climate control (central versus individual climate control), as explained in the figure 11 and deliverable D2.6, section 3.1.

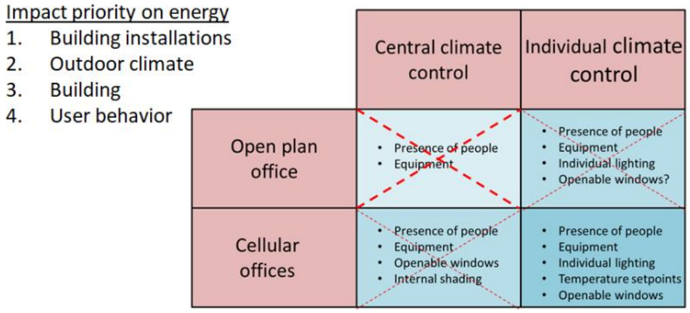

Figure 11: Sensoring recommendations for different type of offices (open plan versus cellular offices) and the type of climate control (central versus individual climate control), as explained in this figure from deliverable D2.6, section 3.1.

In open-plan offices employees have little or no influence on energy usage caused by central climate control. Since in open-plan offices no individual control mechanisms are present (can't open windows, adjust thermostat, only open/close blinds), user behaviour is not so influential on total building energy use. So, in these types of offices sub-metering of office spaces does not make much sense. IEQ measurements (CO_2) can be performed on floor level.

Employees in a cellular office having individual climate control can have a greater impact on energy use. In these cases, it make sense to have sub-metering systems for electricity use on room level (or clusters of rooms levels) as well for IEQ (CO_2) measurements.

Hence, it is important to distinguish between different office typologies having different occupancy schedules in order to choose appropriate monitoring techniques and information feedback.

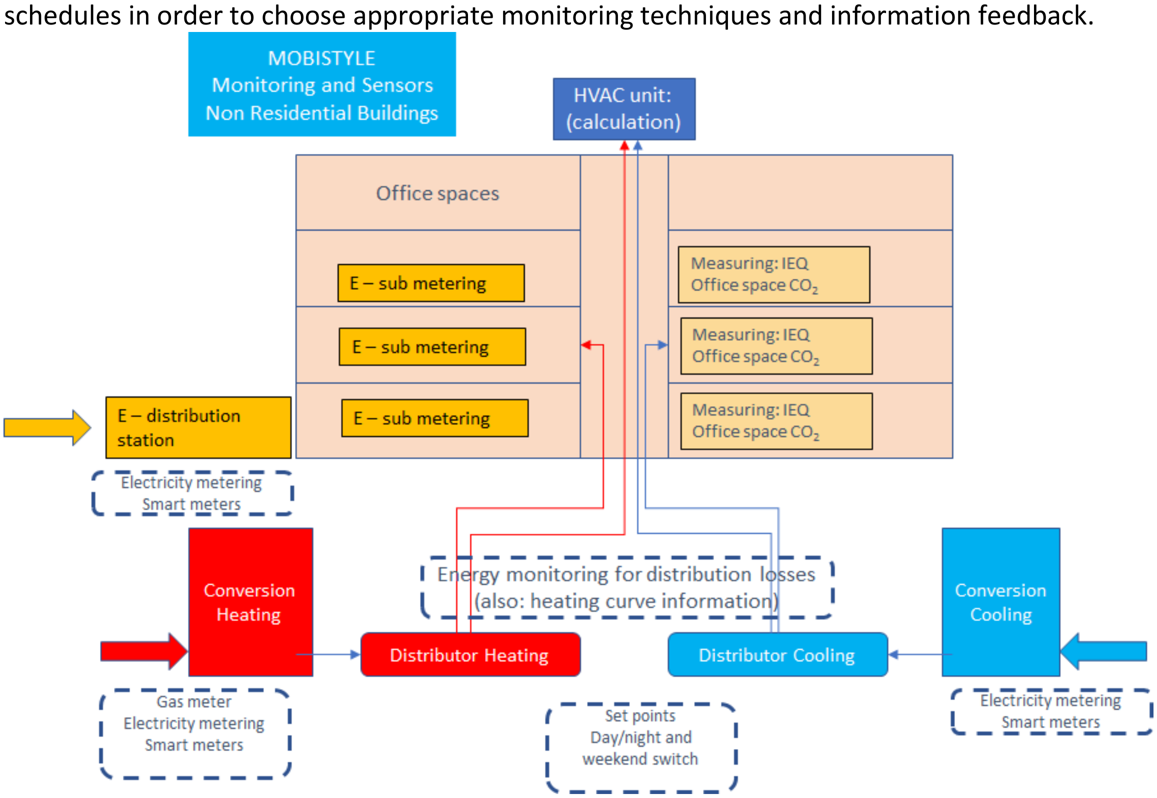

Figure 12: Positioning monitoring sensors for IEQ, conversion and distribution efficiencies and energy use in cellular offices.

4.3 Definitions and representations of all physical quantities applied in MOBISTYLE.

By performing measurements and communication about it, it is important to align the definitions of quantities and units. In next table a first inventory is given of possible physical parameters and quantities that can be measured in the five MOBISTYLE demonstration cases. In deliverable D6.1 ‘Detailed final monitoring, awareness and information campaigns for the five cases’ this is further elaborated, both on a general level as case specific level.

Measured by sensors		**Symbol**	**Units**
Alternative: weather stations/apps	Outdoor temperature	Tout	^{0}C
	Outdoor CO2-concentration	Cout	ppm
	Indoor temperature	Tin	^{0}C
	Relative humidity	RH	%
	Indoor CO2-concentration	Cin	ppm
	Exhaust temperatures fancoil units	Tex	^{0}C
	Space heating	Qh	kWh
	Air velocity	v	m/s
	Domestic hot water use	Qhw	kWh
	Space cooling	Qc	kWh
	Electricity for domestic use	Eh	kWhe/h
	Monthly electricity for domestic use	Emon	kWh/month
Data manually collected			
	Number of people per household	N	-
	m2 Net Floor Area (NFA) per dwelling	NFA	m2
	Day of the week	D	-
Health data measured by wearables			
	Heart rate		Beats/pm
	Physical activity		
	Sleep quality		-
	Skin temperatures		^{0}C
	Micro climate test subject (temperature)		^{0}C
	Micro climate test subject (RH)		%
	Blood pressure		mmHg
Interactions			
manual	Number counting	-	n
	Specific:		
	Window opening	-	n
	Door opening	-	n

Can be sensorised as well	Mechanical ventilation	-	n
	Ventilation grilles	-	n
	Solar shading	-	n
Functioning of appliances (measured by sensors)			
	Building services		
	Water temperature (supply) boilers, heat pumps	Tsup	^{0}C
	Fan position in combination with electricity use	Efan	W
	(Smart) Household appliances		
	Washing machines ➢ This is typically appliance specific, see the specifications of the Whirlpool washing machines in MOBISTYLE		
	Smart plugs in combination with appliances	Eappl	W
Calculated by sensor data			
	Mean monthly productivity level	MMP	??
	Energy use per deltaT (indoor-outdoor)	Qspec	kWh/grC
	Heatcurve Q = a(DetaT) + Ttreshold	Q	kWh/grC
Time related additions			
	Hour	.h	/h
	Day	.day	/day
	Month	.mon	/mon
	Year	.yr	/yr

Furthermore, based on data coming from the Whirlpool washing machines, following parameters can be gathered:

Specific parameters for MOBISTYLE Whirlpool washing machines			
Description	**Normalized list of parameters**	**Symbol**	**Units**
Water temperature set for the cycle	WaterTemp	Twat;set	^{0}C
Options selected by user	Optional PreWash	opt	
Remote control	Remote Control (False/True)		
selected cycle type	Cycle		
Duration of the cycle in minutes	Duration	T	min
Water hardness level set	degree General Hardness	dGH	DH
Spin speed set for this cycle	Spin	Sp	Revolves/min

5. Recommendations

Nowadays, both residential and nonresidential buildings are equipped with monitoring and smart metering systems. This leads to an increase of availability of automatically collected data of multiple sensors, hourly or daily, over long-term periods whereas in the past only yearly data by manual meter readings were available.

These energy data can provide insight in the total performances of buildings in use:

- Energy related data on the function of the building and building services.
- User lifestyle related aspects e.g. occupant behavior and interaction with installations.
- Qualitative aspects like thermal comfort and indoor air quality.
- Optional, health and wellbeing of occupants by using wearables.

Moreover, these data can provide information with the building (as a total 'system') with the ambient conditions such as weather and microclimate, which influences particularly the energy use for climatization, but also in the way of occupants behavior (i.e., adapting to outdoor circumstances).
Yet, the main drivers for energy use for heating (and cooling) are indoor temperature and indoor CO_2 concentration. Therefore, it makes sense to compare energy use by ΔT, and with the same average indoor CO_2 concentration. Concerning accuracies of sensors:

- Temperature sensors need to have high quality, i.e. an accuracy of +/- 0,2 K.
- CO_2 sensors do not require a high accuracy; +/- 100 ppm is acceptable.

Although it is important to collect hourly and daily data for analysis of the building installations and behavior, evaluating and comparing energy use due to behavior changes and applying useful feedback to users only makes sense on a monthly time scale (see also D2.6 'Catalogue of personas/user profiles', the impact area matrix in section 3.2).

Comparing in shorter time stamps implies energy changes are strongly influenced by time constants of heating and cooling down buildings, weather changes, solar radiation and irregular user behavior on a daily basis. For residential buildings, especially single-family houses, behavior is subject to monthly changes with a weekly rhythm. Other KPI's can be evaluated and compared directly based on sensorized (instant) values.

Differentiating between weekday and weekend is not directly useful for residential buildings, but it can be depending of the occupant profiles (see D2.6). Nevertheless, behavior shows in general a weekly rhythm, i.e., it will not be likely to change attitudes in the weekends, as occupants tend to keep the same lifestyle. For non-residential buildings such as offices and schools differentiating between weekday and weekend is of course useful (occupied and non-occupied hours). The monitoring of the energy related aspects of user behavior are more elaborated in the MOBISTYLE demonstration cases.

6. Conclusions

One of the main conclusions is that there should be consensus and compromises among stakeholders on definitions of the physical quantities of the (partial) energy flows and other energy related data.

When it comes to technical ICT system, such system needs to be able to connect different sensoring equipment measuring different datatypes and should ensure compatibility with existing dataset formats across EU, allow integration with legacy architectures, encourage replication and scale-up and be compliant with applicable EU standards. The data architecture should be modular in order to accommodate data from various sources.

This is also why for MOBISTYLE purposes the Expert Tool was developed having three main functionalities:

1. Data management: the expert has access to the data for visualization, filtering and validation purposes.
2. KPI calculation: the expert will be able to visualize and download KPIs on energy, comfort and health.
3. Support the needs of third parties tools: the expert will be able to export the data in the most suitable format. This functionality guarantees the interoperability between the Expert Tool and the other software.

The “AutoCheck” application was proved to be useful add-on for gaining insight into malfunctioning sensors during the development process. For demonstration cases this allowed easy and quick detection of discrepancies between the data collected and the data that was exposed. During the tool’s application at the demonstration sites, some errors were noticed that needed to be improved before final version of the tool is ready for the market application.

Within MOBISTYLE demonstration demonstration the targeted TRL was for the development and testing at TRL7 which had been reached. Further exploitation of the MOBISTYLE Expert tool should lead to a development and implementation TRL8. See the D5.4 for the Expert tool developed business model introduction.

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