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IoT-based architecture for efficient energy monitoring in existing building structures

To cite this article: A Redlein and L Thrainer 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1122** 012058

IoT-based architecture for efficient energy monitoring in existing building structures

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Abstract. Considering the definition of Environmental, Social and Governance (ESG) criteria, historical buildings in Europe need solutions to be able to be more energy efficient. One approach to identify high energy consumers is data analysis. To enable this approach, the following research questions have to be answered:

1. How can data be captured in a valid and efficient way?
2. How can data be standardized and merged within dashboards?
3. How can data be analysed within these common dashboards?

To answer these questions, results of a mixed-methods-research project [1] were used, to give a view on the impact and use of emerging technologies and to allow the definition of the best suited technology. Based on the results of this step and previous research [2], the relevant tools and the IT architecture was defined. Thirdly, a case study was enrolled, which is based on the previously defined IT architecture, using IoT measuring devices from European production, two different databases and two analytic tools. To cover the ESG-reporting demands, data structure and relevant building structures were defined. The paper also presents the final decision on the database and the analytics tool, both capable to analyse large amount of data and operated as open solutions (enables enlargement at any time and works without license cost).

1. Introduction

In Europe the "EU REGULATION (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088" puts a new and important focus on sustainability as it asks in Article 8 for "Transparency of undertakings in non-financial statements". According to this article all companies of a specific type and size specified in Directive 2013/34/EU have to publish " (a) the proportion of their turnover derived from products or services associated with economic activities that qualify as environmentally sustainable […] and (b) the proportion of their capital expenditure and the proportion of their operating expenditure related to assets or processes associated with economic activities that qualify as environmentally sustainable[…]" in their non-financial reporting. This additional reporting demand and the Green deal of the EU with the goal to improve the flow of money towards sustainable activities across the European Union increases the importance of sustainable actions of companies. As real estate is responsible for around 40% of the CO_2 emissions and also requires a lot of energy during the utilization phase the developers and investors within real estate have to focus on the ESG criteria and carry out the additional reporting and optimization activities.

Therefore, Environment, Sustainability and Governance (ESG) is the hot topic in real estate and becomes more and more important in the near future as these measurements are to be in place in the upcoming year 2022. Most consider it as simple energy and CO2 reduction but it is much more. The 17 sustainability goals of the United Nations give a perfect overview of the related topics. Of these seventeen (17), three are particularly important to the real estate industry and form the focus of most of the ESG priorities and optimization projects:

1. goal #7 Energy efficiency
2. goal #3 Good health and well-being
3. goal #8 Decent work environment

But especially Europe is known for its historical building structure. Certainly, many original structures are not even close to being state of the art in respect to the goals mentioned above. At least since the definition of Environmental, Social and Governance (ESG) criteria, these buildings need solutions to be able to be more energy efficient.
But how can we reach these goals? The first step is the measurement of the relevant KPIs. Drucker stated [3] "If you can't measure it, you can't manage it." In respect to the relevant SDG goals this means, the measurement of the different forms of energy used by the built environment and at least the well-being parameters like room climate. Based on this data energy reduction can be carried out by identifying high energy consumers through data analysis. To enable this approach, the following research questions have to be answered:

1. By the usage of which technologies can data be captured in a valid and efficient way especially focusing on the existing buildings?
2. How and which tools can be standardized and merged within dashboards at a low cost?
3. What tools can be used to analyze the data within these common dashboards, in order to set further steps to decrease energy consumption in existing historical buildings?

In the next chapter the methodology applied to answer these research questions is described. The chapter "results" will give an overview of the status quo of emerging technologies, that can be used to support the necessary processes of data capturing, analysis and to define steps for optimization. It analyses how and which technologies work together to create functioning ecosystems.

2. Methodology

To answer the questions from above the results of a research project about the availability, usage and interrelation of emerging technologies conducted through mixed methods research (see [2] and [4]) can be used.
A mixed methods research approach was used, which integrates quantitative and qualitative aspects. Qualitative and quantitative research methods each have particular strengths and weaknesses. By combining these two methods, the researchers are able to profit from the strengths of each method while minimizing the weaknesses of both. The mixing of methods also allows for more breadth and depth in the research, leading to a fuller understanding of the subject by providing richer answers to the research questions [5].
The research was structured in two main phases, each applying the appropriate research method for the task at hand. Based on a preliminary literature review analyzing which emerging technologies were considered to be already used, expert interviews with 50 German speaking facility managers were conducted to define the technologies in focus. This qualitative step was used to gather as much information as possible. Therefore, unstructured interviews were used to give the participants room for their input. This happened in 2017.
Based on the results of this first qualitative phase, the quantitative part of the research was started. The researchers have been collecting international use cases in the chosen emerging technologies. Use cases were primarily found in publications like IEEE spectrum, MIT technology review, Harvard Business

Review and strategy documents of well-established consultancies like McKinsey, CBRE, JLL, Gartner Group, EY, PwC and Deloitte. Many of these publications referenced scientific journal articles, which were used as further input. Overall, 955 use cases were collected from 2017 to 2022. These cases were primarily published in the years from 2015 to 2021.
The use cases collected were not limited to usage in the area of real estate and facility management in order to include innovation from other industries. By doing this, the researchers were able to broaden the scope of the research considerably, while simultaneously ensuring validity of the results. The goal was to collect as many meaningful use cases as possible, while being able to infer assumptions for the real estate industry.
The published use cases were analyzed using grounded theory to ensure that the results were replicable and meaningful [6]. The written descriptions of the use cases were analyzed for two types of anchors for coding and conceptualization:

1. the emerging technologies applied
2. the facility services they were applied in.

For the categorization of the emerging technologies on the top level called “Class Level” (table category in figure 1) in the first step the listing of Schwab [7] and the input of the qualitative phase (literature review and expert interviews) was used. Examples of the entries at the Class level are AI, IoT, Big Data etc. In addition, the explicit technologies named in the article were also coded and gathered in the table technology case as the “Base Technology”. In this way a distinction was made between Artificial Intelligence (AI), AI Deep Learning, Machine Learning (ML) etc. in the area of AI. The entries of the list were enlarged based on the literature analyzed. Each new base technology was subsumed to a technology of the top level.
To better analyze the data, a middle level called Category was created, where individual base technologies, which made an extensive contribution to their class, were singled out (e.g. ML). This allowed for a more detailed analysis of the emerging technologies, applied by the use cases without overextending the level of detail. For the analysis in this paper the researchers primarily used the “Category level”.
For the categorization of the services the definition of the individual services given in the EN15221:4 [8] was used. The application of grounded theory ensured that the coding and categorization of the services and technologies was consistent for all individual use cases.

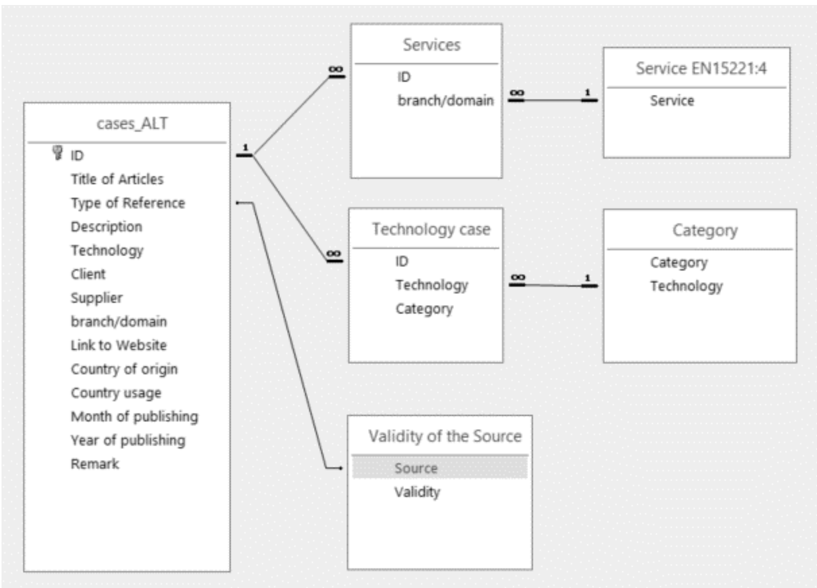

Figure 1. Data collected and relationships within the database

The use cases were entered into a Microsoft Access SQL database. The structure of this database and the type of data collected can be seen in figure 1. In order to ensure the results' validity, the type of source was also recorded for the individual use cases. We assigned grades based on significance and ensured that less creditable sources like newspapers or companies' press reports were not overrepresented compared to peer reviewed scientific reports and articles. For a more detailed description of the methodology used and the architecture of the database the researchers kindly refer to [1].
Using the described methodology and this database the emerging technologies applied in the use cases and the FS are applied in were analyzed. The 955 use cases analyzed in this way provide a valid overview of the status quo of the utilization of emerging technologies in the facility services industry.
Based on the results the relevant technologies were identified and an IT architecture combining the tools was defined. Also, in this step the best practice represented in the use case database was used. To validate the approach two prototypes using different databases and analytic tools were implemented and tested in real life. The databases and the analytic tools were selected based on their usage and on the costs related to the usage. So, the license costs and the needed hardware was taken into consideration in the selection process. Based on the feedback of the users of the usability of the prototypes the database and the analytic tool was finally selected.

3. Results

3.1. Relevant technologies

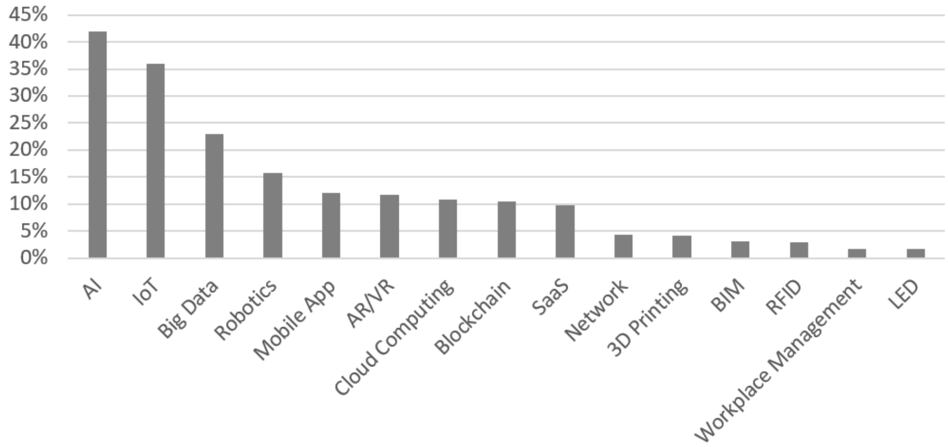

Figure 2. Technology Classes as percentage of overall use cases (955) (comp. [9])

Figure 2 shows the emerging technologies applied by the use cases grouped by Technology Class. AI is most widely spread, followed by Internet of Things (IoT) und Big Data. This figure also includes some enablers. Technologies which are enabling the use of other technologies like IoT and AI. Cloud Computing and Software-as-a-Service are these enablers. They make the application of the other technologies easy and cost efficient. Both service models do not ask for great investment into hard- and software as centrally provided and hosted. Hard- and software can be employed on a pay per use model. Providers like Amazon Web Services (AWS) and Microsoft Azure provide computing and storage as a cloud service. You can rent out 15 Terabyte of Memory for 1 day and only for this usage you have to pay, which is much cheaper than buying the hard- and software and setting up the environment. These services also provide IoT interfaces and Big Data as well as AI tools, which only need to be customized to the requirements of the use case. In some cases, even pre-configured solutions are offered. These make a feasibility test and also operation much easier and cost efficient. That is the reason, why we call these two approaches enabler for the other emerging technologies.

Overall, 343 out of 955 use cases in the database use IoT technology. IoT technology is used in smart homes, factories, buildings and even cities [10]-[13]. Sensors can automatically gather data and trigger certain actions, like measuring energy usage and room climate [14], adjusting thermostats, which makes our lives more comfortable and in the same way more energy efficient [15]. Data gathered from smart devices gives valuable insights into work processes within the building usage and operation. They help to improve operations by providing solid data for decisions and even enables forecasting machine failures [16]. Sensors can provide information on how we use space [17], which is the basis for space optimization. They can help us to lead healthier lives [18]. These examples should give an overview on how far reaching IoT technology has become over the last years. There are just some of the best practice use cases included in the database.

84% of these IoT use cases apply at least on one other form of technology. This is to be expected, since IoT technology, especially in regards to sensors, is used as part of an IoT ecosystem, consisting of many layers. IoT sensors create huge amounts of data, which have to be transmitted, analyzed and in some form made available to the end user. IoT is most powerful when embedded in a well-designed system.

Over the last years, several attempts have been made to standardize the layers used for IoT architecture. In its most basic form IoT architecture consists of three levels: hardware to collect data, middleware for storage and analysis and finally a presentation layer with visualization tools to present the data to the end user [19].

The United States National Institute of Standards and Technology (NIST) suggests a five-layer architecture, consisting of building blocks called “primitives” [20]. These primitives are 1) physical sensors with data output, 2) aggregators to help manage the data, 3) communication channels to transmit data, 4) external utility, which can be a software, hardware, a product or service and 5) decision trigger to create the final results. In addition to these 5 primitives, 6 elements are to be considered: geographic location, owner, environment, cost, device ID and snapshot or instant in time.

These layer suggestions are reflected in the results of the use cases analyzed. 38% of IoT use cases apply one other technology, 29% apply two more, 11% apply three additional? non-IoT technologies, and 4% use 4 or more technologies in addition to IoT. A more detailed analysis of which secondary technologies support IoT can be seen in Table 1 [4].

Table 1. IoT in combination with other Technology Categories [4]

Category	combined with IoT only	combined with IoT and one other Tech Category	combined with IoT and 2 other Tech Categories	combined with IoT and 3 or more other Tech Categories
3D Printing	0,3%	0,3%	1,7%	0,7%
AI	3,7%	7,7%	3,0%	3,7%
Autonomous Vehicles	0,7%	1,3%	0,0%	0,0%
Image Classification	0,3%	1,3%	1,0%	1,0%
AR/VR	2,0%	3,0%	2,3%	3,0%
Big Data	4,3%	6,3%	4,0%	2,0%
Big Data Advanced Analytics	4,0%	4,3%	2,7%	1,7%
BIM	1,0%	1,0%	0,3%	1,0%
Blockchain	2,0%	1,0%	1,0%	0,3%
Chatbot	0,0%	0,7%	0,3%	0,7%
Cloud Computing	1,0%	5,7%	3,7%	2,0%
Drones	1,0%	0,7%	0,7%	0,7%
LED	1,0%	0,7%	1,0%	0,3%

ML	4,0%	4,7%	3,7%	2,3%
Mobile App	3,0%	4,0%	4,0%	2,7%
Network	2,0%	2,0%	0,3%	1,0%
RFID	2,7%	1,7%	1,0%	1,0%
Robotics	2,3%	3,3%	1,7%	1,3%
SaaS	2,7%	3,7%	1,3%	2,0%

Table 1 shows the number of IoT Technology Class use cases in combination with one, two, three, and four or more other technologies (as Categories) in percent of overall IoT use cases (300) (comp [4]). Data is collected by sensors, which account for 45% of all IoT use cases. The data gathered by these data acquisition tools is then processed. About one in three IoT use cases employs Big Data for storage and analytics. 37% of IoT cases employ some form of artificial intelligence for further analyzing the data, including ML and image classification solutions. This is often achieved by using computer systems like IBM Watson.
Mobile apps are used in one out of six IoT use cases to access and visualize data. Cloud computing, including Software-as-a-Service (SaaS), supports a fifth of all IoT use cases. Cloud computing and SaaS are the technology enablers of the whole process. They support the linkage of the IoT devices into the rest of the ICT network, the data import, storage and analysis. Figure 3 shows this observed typical workflow. Out of all these layer suggestions and the result of the use case analysis we see a flow from data generation and collection to data storage and to manual or automated analytics shown in figure 3.

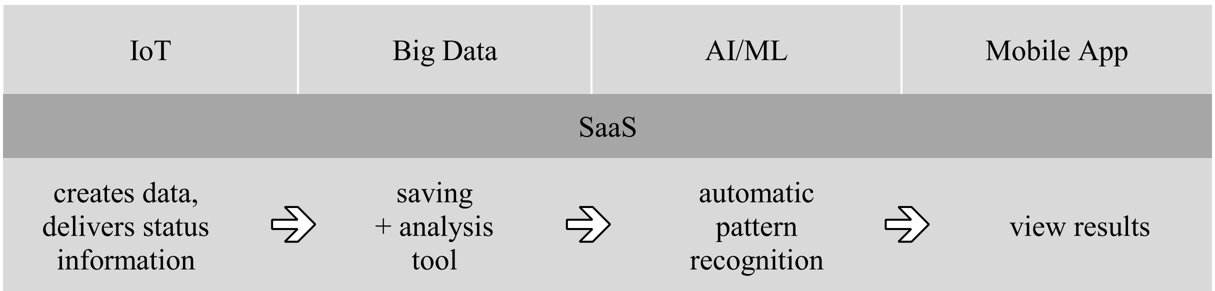

Figure 3. Typical IoT use case workflow (comp. [4], based on [19])

3.2. Prototype
Out of these theoretical results we set up a prototype to test technical feasibility and user acceptance. The sensors selected measure:

1. Electricity usage
2. Gas or district heating consumption
3. Room climate of office space

The first two parameters were selected to cover the ESG reporting demand regarding energy usage, the third one to cover the Social perspective of well-being and decent workplace. The main costs are generated by the energy measurement as we use standard stored program controllers (SPC) that are already available at the buildings. As alternative solution we used other existing MQTT clients providing us with the relevant data. This was mainly used in the area of the room climate. In a lot of buildings, intelligent lighting systems or easy to add self-sufficient IoT room climate sensors are available at almost no cost. These send the data via MQTT either to the SPC or a Raspberry-PI (RPi), which acts as MQTT broker gathering the data, manipulating it and sending it to a database. Both systems, the SPC and the RPi, have enough computing power for these tasks.

We tested two different databases: an InfluxDB and a MySQL database. Both databases are available as an open source software. The InfluxDB has the advantage that it is optimised to store and manipulate time series. As analytic tool we first used PowerBI, as it is also a common tool and widely spread in the real estate industry. After using the system for several months, we recognised the amount of data generated by the IoT devices was so large, that the analytic tool came to its limits. As a next step Grafana (version v8.4.4, OSS edition) was used, which showed a much better performance with limited hardware resources needed.

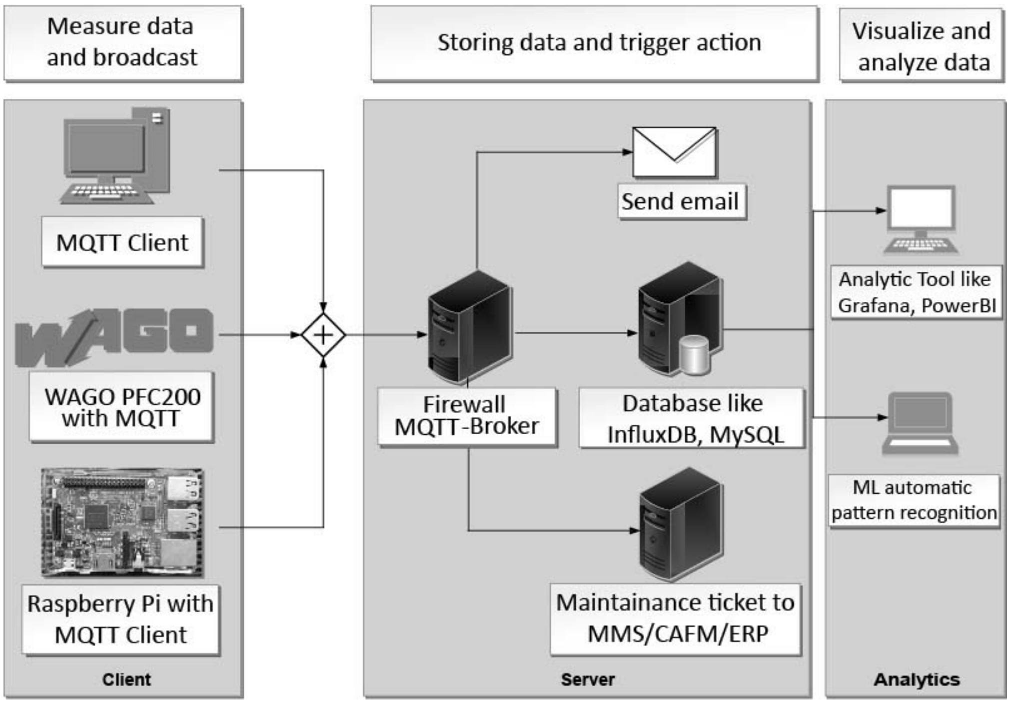

Figure 4. Setup for ESG monitoring prototype (cmp. [2], [8] and [15])

In addition, the concept enables us to directly interact with the service staff either via email or by triggering an event in the existing MMS/CAFM/ERP system (cmp. [2]).

1. Email information:
   This email contains the individual ID of the sensor, therefore allowing the recipient to easily identify where an action has taken place. It immediately alerts the personnel responsible and also gives information about why this action has been triggered by the system by telling the recipient whether the temperature, humidity or energy usage are too high or too low.
2. Triggering and existing MMS/CAFM/ERP system:
   In this case, a ticket is created. Like the email, this action informs maintenance personnel of where and what has occurred. The IoT setup thereby seamlessly integrates with existing in-house or outsourced IT solutions for maintenance operations.

The described setup was tested in several historical buildings and proved to provide the necessary data and analytics. As the tools used for analytics are quite widely spread, the time to train people was rather short. The users were capable to adapt the reports and generate additional ones in a short time frame.
In this way the prototype using emerging technologies in an ecosystem, that was derived out of the literature research, enables to fulfil the new demands of the EU directive in existing buildings in a cost-effective way, as it only asks for small "upgrades" in the switchboards and the installation of self-sufficient IoT sensors. These devices capture the necessary data in a valid and efficient way, especially focusing on the existing buildings.

Big Data systems, either on premise or in the cloud, standardized and merged the data. In a second step, analytic tools like PowerBI or Grafana can provide the dashboards at low cost, which enable the identification of the main energy consumers and to set action to reduce the energy consumption in existing historical buildings. The room climate data helps us to identify the reasons for the misusage of energy and space. It also helps us to safeguard the well-being and prevents overshooting action through a single focus on energy consumption.

4. Practical Implication

As described above, the proposed solution is easy to implement, as it only asks for small upgrades of the existing infrastructure. The unique value proposition of the solution is, that it not only delivers the necessary energy and space usage data to gain adequate insights for an optimization of the energy usage in a cost-efficient way, but also provides the data for the non-financial reporting according to the EU taxonometry. Therefore, several developers and owners of historical buildings are already using the system for their properties as a reporting and monitoring tool based on solid usage data. One example of energy monitoring in Vienna takes place at the Hofburg (a former imperial palace, whose building structure dates between the 13^{th} to the 20^{th} century). These use cases provide feedback on the usage of the solution and areas for optimization, which were already included in the prototype presented in the paper.

The Hofburg use case also showed some limitations to the solution: thick walls limited the range of the WLAN and switchboards made out of steel made the access of the IoT devices impossible. So, the availability and access to a WLAN network is one of the requirements limiting the application of the IoT devices. Therefore, 5G and LoRaWAN are analyzed on the capability of these technologies to help to overcome these shortcomings. Furthermore, setting up the solution with the on-premises database and the analytic tool turns out to be quite complicated. In a next step a spin-off is planned to set up a Software-as-a-Service solution to make the implementation even easier and more cost efficient.

5. Conclusion and Discussion

Based on an extensive literature research about availability of emerging technologies, the usage fields of these technologies and the interrelation, the authors developed an IT architecture and a prototype to cover the new demands of the EU taxonometry directive especially in existing and historical buildings. This directive asks for an elaborated reporting of the energy usage within buildings and a permanent optimization of the consumption. The prototype consists of an MQTT broker that gathers data from the different IoT devices, standardizes it and sends the data to a central Big Data system. There the different data sources are stored and put into relation. An analytic tool provides the necessary dashboards for reporting and to define actions for optimization.

The usage of cheap, self-sufficient IoT sensors that can easily be installed as an add-on to the existing environment, reduces the implementation costs and time within the building. The application of cloud-based software tools which are already configured and asks for no or only small license fees, make the implementation of the Big Data and analytic part very effective. Therefore, this solution is very easy to be implemented in existing buildings and can cover the new requirements of the EU taxonometry.

Further research and prototyping are necessary in two main areas. The first question is, what granularity of data is necessary to enable in-depth analysis in the area of optimization and to use the data also for preventive maintenance. The second question deals with the analysis of the gathered data. The amount of data generated points in the direction of ML as a tool for automatic analysis. Also, the application of ML to derive automatic measurements to derive optimization tasks should be analyzed more in the future.

IOP Conf. Series: Earth and Environmental Science 1122 (2022) 012058 doi:10.1088/1755-1315/1122/1/012058

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