Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

NTNU SINTEF

ICT-ARCHITECTURE APPLIED ON PILOT BUILDING

ZEN MEMO No. 55 – 2024

John Krogstie, Sobah Abbas Petersen, Odne Oksavik, Kristian Stenerud Skeie |
NTNU, SINTEF Community

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Preface

Acknowledgements

This memo has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, AFRY, Asplan Viak, Multiconsult, Civitas, FutureBuilt, Heidelberg Materials, Skanska, GK, NTE, Smart Grid Services Cluster, Statkraft Varme, Renewables Norway and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions.
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design.
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies.
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods.
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system.
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, Mære Campus, Ydalir in Elverum, Campus Evenstad, Ny by-ny flyplass Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Abstract

This memo follows up earlier theoretical reports on a possible ICT architecture for a collection of zero emission neighbourhoods described in ZEN Report 34 – 2021 (ZEN Data Management and Monitoring – Requirements and Architecture).

A case study has been performed, taking the data visualization need for following up the adherence of the building operations to selected ZEN KPI, as described in ZEN-report 44. The case used the ZEB laboratory, which is already heavily instrumented making it possible to capture live data related to a number of the dynamic KPIs on a building in operation. By developing dashboards for the different KPIs, we get insight into the needed underlying data pathways from building sensors to the web.

The focus on the existing work was purely on technical aspects, and we have enhanced this by including all levels in an enterprise architecture, adopting the approach from the +CityxChange project.

As expected, the original architecture was overly general, although the main technical levels (edge, fog, cloudlet, cloud) makes sense also in the case, even if there is no cloudlet-layer here since we have only data from one building and not a full-fledged neighbourhood. Data is captured, processed and made available at different levels, rather than all collected in a cloud to be made generally available for all, which is the general approach e.g. in EU data spaces and the smart building hub project.[1] The case is driven by the need for access to data on the current state, and to some design targets, but not a combination of current data and simulated data of the future, which could be relevant for a building manager.

We see in the ArchiMate enterprise architecture models how one can combine the technical levels and business levels (e.g., showing how some data can go straight from edge to cloud, other is going first to the fog). The movement of data (from real-time, to last recent, to historical must be looked into in more detail. As observed from the dashboards. the dividing line between last-recent and historical data is not clear-cut. One can also more clearly define boundaries of who owns / is responsible for the various parts of the infrastructure using e.g., ArchiMate for depicting the whole Enterprise Architecture, include the ICT architecture.

It was also noted that the current solution did not support the management of meta-data, and there are plans to adopt a standardized meta data schema. Meta-data is both a traditional data-model and a data movement plan (what is done with the data from it is collected to it is used and visualized, and more subtle aspect on a different granularity level (e.g., that some apparatus is not working appropriately in a certain time-period)

Given the large activity nationally and internationally on such ICT and data architecture, it is advised to coordinate further work on this with the SBHub-project, where both SINTEF and NTNU collaborate, which uses the ZEB lab as a case.

The case is simple compared to the scope of ZEN since the focus has been on an individual building as part of a smart neighbourhood, and not a total neighbourhood. Given that, not all KPIs are relevant, thus the next step is to investigate this on an area level. Missing areas in the ZEN KPIs are also identified, e.g. on the quality of the working environment such as air quality that one should have ways of following up. Through energinet[2] one can access additional buildings at Gløshaugen. Still, starting small has given a good testbed providing relevant results both for the ICT Architecture and for the development of the KPIs themselves.

[1] https://www.sintef.no/prosjekter/2023/smart-building-hub/
[2] https://www.energinet.net/building/id/53035

Next, we need additional feedback from those responsible for the different KPI-areas.

- How is it best to represent the different KPIs in a dashboard? A work on representing emission and other data for a building manager will be done in spring 2024.
- How should one investigate the interactions between KPIs?
- How to capture missing KPI-areas
- How to integrate illustrating design targets, historical data, and simulated future data?

For those needing a more holistic view, e.g. from the different entrepreneurs and technology providers questions might be overlapping with the above.

- How should one investigate and illustrate the interactions between KPIs?
- How to capture missing KPI-areas (if any)?
- How to integrate illustrating baselines/reference data, design targets, historical data, and simulated future data?

Similarly, researchers on different areas might want to have tailored views on the overall dataset.

Contents

1 Introduction

ZEN Report 34 – 2021 (ZEN Data Management and Monitoring – Requirements and Architecture) describe considerations and requirements for an ICT architecture and its data management features within a ZEN (Zero Emission Neighbourhood) and smart cities context [1].

This proposal aims to fulfil six goals and describes:

1. how Information and Communications Technology (ICT) architectures can be designed in smart cities.
2. how a data management architecture can be adapted to different ICT architectures in a smart city.
3. how to integrate smart cities' large-scale Internet of Things (IoT) networks in the ICT architecture of the city
4. how a monitoring system can be integrated in the city's ICT architecture.
5. how following up the adherence of the neighbourhood to Key Performance Indicators (KPIs) identified in the ZEN centre can be supported by the proposed ICT and data management architecture.
6. potential extra benefits of the proposed ICT architecture, e.g., developing software services with the use of machine learning (ML) and other Artificial Intelligence (AI) techniques in smart cities.

The findings of this proposal can be beneficial for future smart cities in connection to:

- Designing large-scale ICT architecture including IoT networks in a smart city.
- Organizing and managing obtained city-data from different sources in a smart city, with a focus on IoT-sources.
- Designing a KPI-based monitoring system in smart city utilizing large-scale IoT networks.

Whereas the framework in ZEN Report 34 is mostly a theoretical framework, this report includes the first concrete mapping of the framework to selected detailed ZEN KPIs described in ZEN report 44-2022 (The ZEN Definition – A Guideline for the ZEN Pilot Areas, Version 3.0) [2].

We will first present the existing architecture, before exemplifying this by looking upon the capturing of selected KPI in a ZEB COM building, the ZEB laboratory,

2 Existing work

A description of the main parts of the ICT Architecture in ZEN Report 34 is provided below, focusing on data and software services. In this section, we present it as described in ZEN Report 34 – (ZEN Data Management and Monitoring Requirements and Architecture) [1]. In Section 4, we will highlight the changes based on the learning from the first pilot.

2.1 ZEN Data Types

This subsection presents main types of data and data flow and identified sharing needs between different parties.

Different data types relevant for a ZEN can be broadly categorized as follows:

- Context data: Normally data that has been generated by IoT and sensors or that come from external systems or repositories, such as weather data, environmental conditions, data on the energy system outside the neighbourhood, urban planning data, etc. This type of data supports the interpretation of the core data on ZEN but is not of interest solely on its own.
- KPI data: Data related to the identified KPIs for ZEN. This can be target data (e.g., expected delivered energy from the building), or data from operation of the area captured through monitoring of the neighbourhood in use. This is often compared to a baseline e.g., an existing standard for energy usage

of a building in a reference project. Design targets might be updated over time, e.g., originally based on simulations, but then updated based on experiences from use of (parts of) the neighbourhood.

- Research data: These data types have been generated by third-party applications, such as simulation or planning data, or sensor streams. This data, which has been collected and used, can come from pilots or entities/installations/buildings within pilot areas prototypes from live building and energy data from buildings, and the data types might overlap the KPI-data and context data. Some examples of these types of data are occupant behaviour data and data on actual energy use in a building, but maybe on a finer granularity than what is needed for the following up the performance.

Fig. 1 provides an overview of the stakeholders and roles (including beneficiaries, i.e., user of services provided through the data platform(s)), and types of data sources and the overall dataflow. The figure does not describe how and where the data is stored and processed. i.e. what happens in detail in the data transportantion, cleaning and aggregation. We will describe examples of this in the case discussed later in the memo.

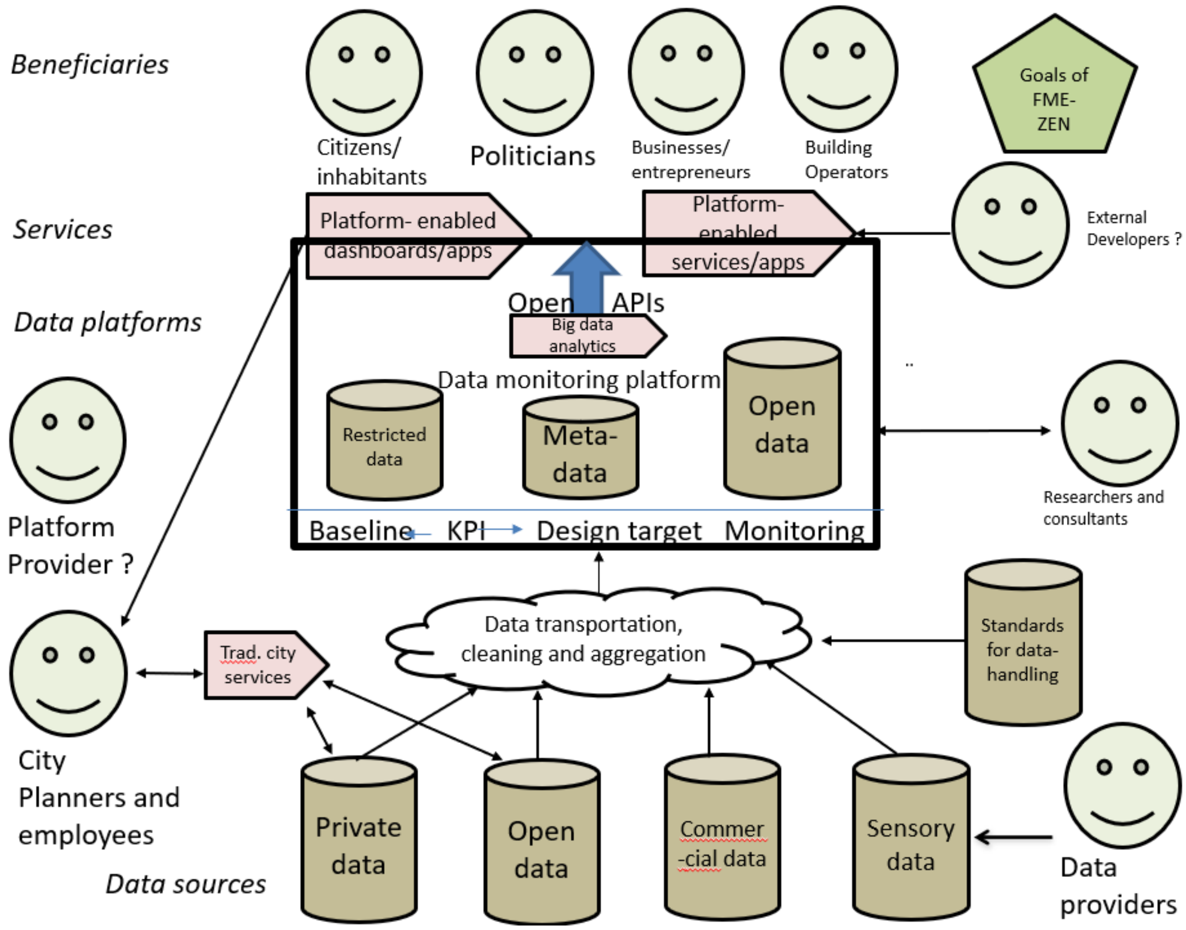

Figure 1 Overall model of roles, tools and data sources

A number of KPIs have been defined for ZEN, and the latest overview is described in Table 1, based on ZEN-report 44. The KPIs are defined according to categories and assessment criteria. There is also a preliminary weighting proposed for each KPI, shown in the column labelled “Points”. KPIs are either dynamic or static, as shown in the column “KPI Type”. A selection of KPIs will be described in the following sections.

Table 1 ZEN assessment criteria and Key Performance Indicators (KPIs)

Category	Assessment criteria	KPI	Points	KPI type
GHG	Emission reduction	*GHG1.1 Materials (A1-A3, B4)*	11	static
		GHG1.2 Construction (A4-A5)	2	static
		GHG1.3 Use (B1-B3, B5)	1	static
		GHG1.4 Operational energy use (B6)	12	dynamic
		GHG1.5 Operational transport (B8)	19	dynamic
		GHG1.6 End-of-life (C1-C4)	1	static
	Compensation	*GHG1.7 Benefits and loads (D)*	4	dynamic
ENE	Energy efficiency in buildings	*ENE2.1 Energy need in buildings*	8	dynamic
	Energy carrier	*ENE2.2 Delivered energy*	8	dynamic
		ENE2.3 Self-consumption	2	dynamic
		ENE2.4 Net load profiles	1	dynamic
		ENE2.5 Colour-coded carpet plots	1	dynamic
POW	Power performance	*POW3.1 Peak load*	6	dynamic
		POW3.2 Peak export	2	dynamic
		POW3.3 Energy stress	6	dynamic
		POW3.4 Representative days	2	dynamic
	Load flexibility	*POW3.5 Delivered energy difference*	1	dynamic
		POW3.6 Operational cost difference	1	dynamic
		POW3.7 Energy stress difference	1	dynamic
		POW3.8 Peak load difference	1	dynamic
URB	Density and land use mix	*URB4.1 Population density*	2	static
		URB4.2 Block density	1	static
		URB4.3 Land use mix	2	static
		URB4.4 Access to a diversity of amenities	2	static
	Building layout	*URB4.5 Dwelling type*	1	static
		URB4.6 Multifunctional building roofs	1	static
		URB4.7 Active frontages	2	static
	Street network	*URB4.8 Street connectivity*	3	static
		URB4.9 Street intersection density	1	static
		URB4.10 Walkable and bikeable streets	1	static
	Green open space	*URB4.11 Share of green open space*	2	static
		URB4.12 Share of green permeable area	2	static
		URB4.13 Preserving and planting trees	1	static
MOB	Access	*MOB5.1 Access to public transport*	3	dynamic
		MOB5.2 Travel time ratio	3	static
		MOB5.3 Parking facilities	3	static
		MOB5.4 Vehicle ownership	3	static
	Travel behaviour	*MOB5.5 Mobility pattern*	3	dynamic
		MOB5.6 Passenger and vehicle mileage	3	dynamic
	Logistics	*MOB5.7 Freight and utility transport*	2	dynamic
ECO	Life Cycle Costs (LCC)	*ECO 6.1 Investment costs*	6	static
		ECO6.2 Operating costs	6	dynamic
	Cost benefit	*ECO6.3 Overall performance*	8	static

In this pilot, we have first of all, focused on ENErgy-KPIs, although one can transform this to be able to follow up also GHG-KPIs. Also, data for calculating POW-KPI are available in the pilot building.

We can look upon the three types of ZEN data with a topological model as shown in Figure 2, which constitutes the overall levels of the ICT architecture. The context data can be relevant on all levels (including micro (building/building-part), meso (neighbourhood), and macro (city/country)), e.g., weather data may be relevant for all levels. The research data mainly exists on the meso and macro levels, e.g., simulations or planning are often conducted at the building or a neighbourhood level. Lastly, in a similar way to the context data, the KPI data is potentially available in all three levels (micro, meso, and macro), e.g., energy data or emissions levels could be measured at the building, neighbourhood and city levels.

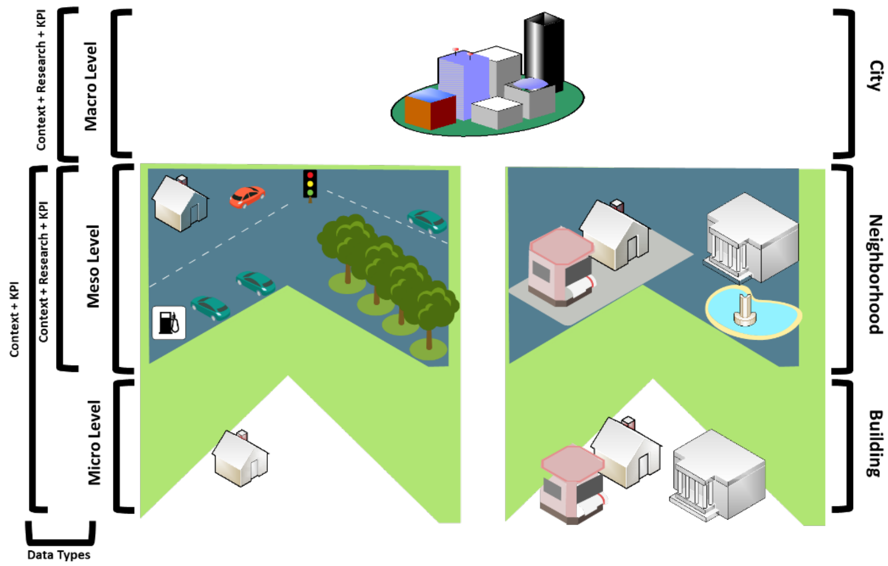

Figure 2 Data types in ZEN centre through the ZEN topological models

2.1.1 Tailoring Smart City Data Types to ZEN Centre Data Types

From a temporal point of view, there are three main data types in the smart cities, including real-time data, last-recent data, and historical data. These smart city data types are described in relation to the three levels in the ICT architecture:

- Micro Level: the real-time data produces near the end-users in the city by physical data sources (such as sensors). Also, the real-time data can act as "context data," "research data", and "KPI data".
- Meso level covers both real-time (physical data sources on the neighbourhood) and last-recent as described below:
  - Real-time data: there are several physical data sources on the neighbourhood level in addition to building sensors (such as vehicular network, traffic lights, etc.) at the meso level. Therefore, these data sources generate real-time data in the meso level. Also, the real-time data can be matched with the "context data" and "KPI data".
  - Last-recent data is located between real-time and historical data. Moreover, the last-recent data can be tailored to be appropriate as "research data" and "KPI data."
- Macro level: the macro level includes the historical data. Moreover, the historical data can be tailored to fit the definition of the "research data" and "KPI data" for the ZEN centre.

The relations among the three levels in the ICT architecture, the ZEN data types, and the smart city data types are shown in Figure 3.

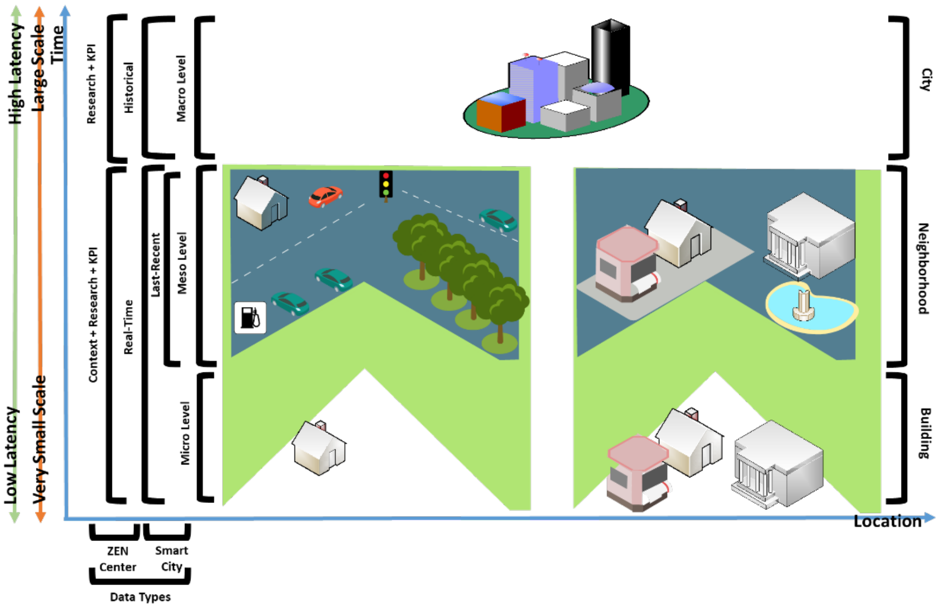

Figure 3 Different data types in smart cities and ZEN centre

2.2 Large-Scale ICT management for ZEN centre and beyond

ZEN Report 34 proposed a distributed and decentralized ICT architecture including Fog, cloudlet, and Cloud technologies. The Fog layer forms the lowest layer of the ICT architecture, the cloudlets form a middle layer while the top layer consists of Cloud technologies. An ICT architecture composed of these technologies is relevant for ZEN and the pilots for the following reasons:

- Scale: The architecture must handle at least seven distinct pilots and cities in Norway. To store all data in a common cloud is not necessary and may not be feasible since this might result in unnecessary security and privacy challenges.
- Flexibility: The architecture must be responsible for distinct ranges of policies in each cross-layer from edge to cloud technologies within city management policies and ZEN business models requirements. An example of a policy is checking data quality, applying data security, and updating data collection frequency mechanisms.
- Complexity: Several complexities may be addressed through the ZEN requirements (identified in ZEN Report 34) [1], e.g., varieties of data types and formats, mixing obtained data, different underlying building automation systems, etc.

To sum up, we have earlier proposed an ICT architecture for the ZEN centre, as shown in Fig. 4. The ICT architecture has three different architectural layers from edge-to-cloud. The left-hand side of the architecture in Figure 4 presents that a bottom-up ICT architecture is planned to model a city based on a very small scale to a large scale, from building components to neighbourhoods. The proposed architecture shows that the bottom Fog-Layer has a minimum desirable latency level for the network communications, and their bandwidth and the resource capacities are restricted in processing and storage capabilities. Going up to the higher layers, gives a potentially undesired latency level for the network communications, although a main reason for the levelling has to do with handling the data diversity and privacy/security. On the other hand, the processing and storage capabilities are increased by multilevel technologies within the upper layers, e.g., Cloud technology. Finally, the security vulnerabilities are high at the bottom layer of the architecture, and the higher layers provide more facilities for treating obtained data and data resources.

2.2.1 Data Management Architecture

In this subsection, we intend to present the effective data management architecture for the ZEN centre and their related pilots. This data management architecture must provide several capabilities to meet the requirements of the ZEN centre, as shown below:

- The architecture must cover all conceptual levels of the ZEN pilots.
- The architecture must support different data types in different pilots in the ZEN centre.
- The architecture must manage both IoT- and non-IoT data sources.
- The architecture must deal with several distributed repositories across multiple geographical locations in Norway.

We assume that the hierarchical architecture provides a flexible number of layers according to the city structure or the business model requirements. Accordingly, a recommended ZEN data management architecture consists of four layers of architecture (namely Edge-layer, Fog-Layer, cloudlet-Layer, and Cloud-Layer). In principles, one might have more or fewer layers in connection to a neighbourhood. Regardless of the number of levels, one must have clearly defined boundaries of who owns / is responsible for the various parts of the infrastructure i. Edge, fog or cloud processing layers may be necessary to ensure safety-critical operations etc. and support access to data at different aggregation levels to support different actor's needs. However, it is recommended to have as few layers as possible, to do things as simple as possible.

Also, several data repositories across the ZEN centre pilots are shown in Fig. 4. The Fog-Layer is responsible for managing IoT and real-time data sources by using Fog technologies in all the pilots. The cloudlet-Layer is a middleware platform available for organizing non-IoT and last-recent data sources and combining them with IoT and real-time data locally in the same pilot as IoT-data sources. Finally, Cloud is a place to organize and access all the pilots' historical data sources, along with other relevant data, e.g., relevant contextual data sources concerning the business and data privacy requirements.

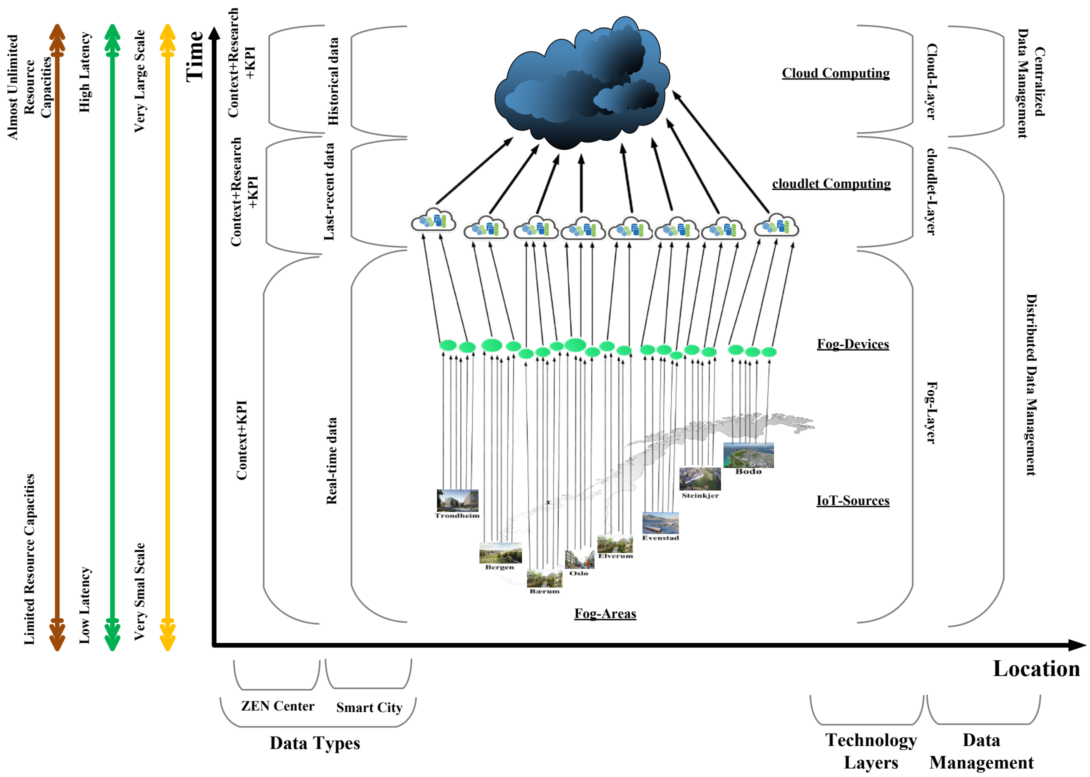

Figure 4 The data architecture through the smart city scenario

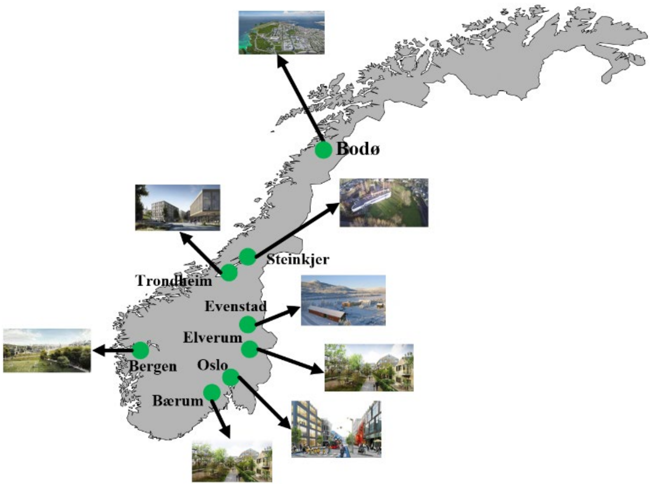

Figure 5 The ZEN pilots city location

2.2.2 Software Services Architecture

We also want to provide facilities for various software services that are predicted to be created for the ZEN centre and their related pilots as shown in Fig. 6. The ZEN software services may then be launched through various city-data sources and types within a multilevel data management architecture, as shown in Fig. 6. Contrary to the traditional cloud-centric model in Fig. 1, services can reside on several levels, not only as a part of a central cloud.

As displayed in Fig. 6, we describe the software services management on the right-hand-side of the figure. The service architecture follows the levels of the data-architecture and consists of two distinct layers: local and historical software service layers, and these concern data privacy and user requirements, as described below:

- Local Software Services layer: Developers can work with the locally stored data across the Fog-Layer at the edge of the network to build the required software services for each, pilot taking data privacy requirements into account. Also, various software services may be built on the cloudlet layer(s), including critical and private services:
    - Critical Software Services: Critical services may be launched inside a pilot, at the cloudlet- and Fog-Layers of the data management architecture. Some examples of critical services are healthcare and emergency services. The critical software services may be launched in this software service layer, through the lowest network communication level, to adhere to requirements for low latency and high bandwidth.
    - Private Software Services: Private and privacy-aware services can be built by utilizing private/ locally stored data in the Fog- and Cloudlet-layers of the data management architecture, near the pilot's-data sources and citizens. So, we can improve data privacy issues through such private software services for the pilots.
- Historical Software Services layer: This layer handles the largest scale of collected pilot or city-data, on cloud data storage platforms from all the pilots. This layer can also connect to other non-city data sources to build public software services for all relevant stakeholders.
- Combined Software Services layer: This layer allows developers to utilize all obtained city-data sources to create software services.

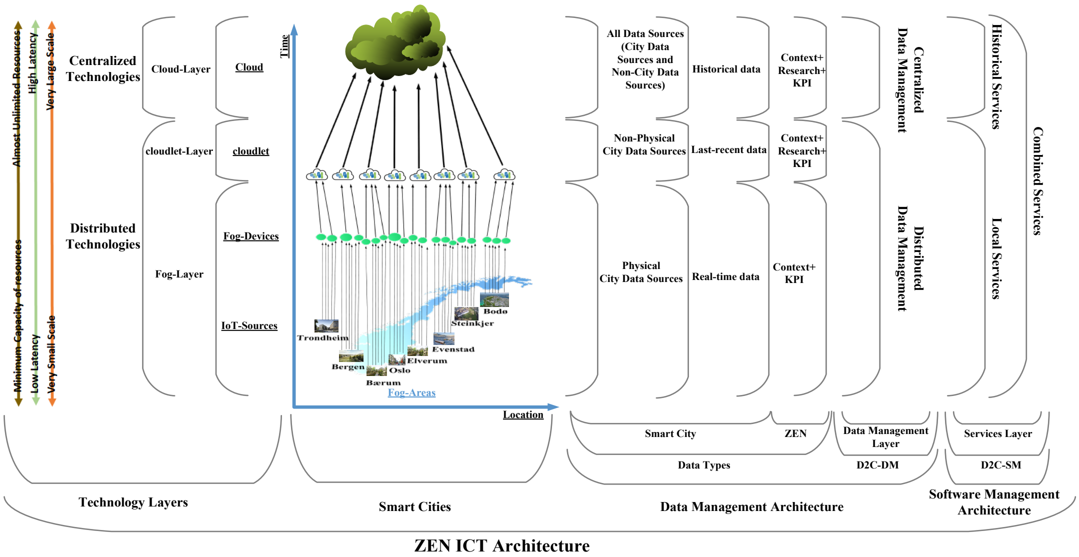

Figure 6. Providing software service through the ICT architecture for ZEN [3]

2.2.3 Monitoring system and their related ICT controller

The architecture must be responsible for the management of data/database, resources, network communication, and software services in smart cities. As shown in Fig. 7 the architecture includes an ICT "Integrated and Intelligent Control and Monitoring of IoT" box at the cloudlet layer to handle all the main management blocks across the multilevel layer of edge-to-cloud orchestration. We decided to position the box in the cloudlet-layer because the cloudlet is in the mid-layer, between the edge to the cloud platform and available to an entire city (or a several pilots). Therefore, we imagine that we can manage all city and cloud resources from city-scale to centralized scale concerning the user and business demands. Finally, the IoT box gives data discovery opportunities and data monitoring mechanisms from distributed to centralized schema on the city-scale.

This may manage all city requirements through different ICT KPIs, including network traffic and performance, resource performance, data age, data location, and cost calculator. Brief explanations of potential ICT related KPI’s for a ZEN data management architecture are provided below:

- Network traffic and performance: This category estimates network traffic cost and their related latencies through a set of parameters across multilevel layers of the architecture for data discovery purposes in large-scale IoT networks of smart cities. This shows how fast it is possible to find the relevant city-data sources through different edge-to-cloud layers. The result of network traffic and performance are relevant to different management blocks of resource, data, and network communication.
- System Performance: This category estimates different performance issues, e.g., CPU usage, across multilevel layers of our architecture. The result will determine the most suitable accessible resource that may help manage resources and software services.
- Data Age: This category finds relevant city-data sources based on the produced data time, including real-time, last-recent, and historical.
- Data Location: This category explores the city-data sources based on the requested data’s location across multiple layers of edge to cloud. These actions may be useful for the management of data and resource blocks in smart cities.
- Cost: This category intends to measure the cost of data within several different parameters such as data access, data price, etc. through different layers of the architecture. For instance, some of the produced city-data may not be free and also has special access permission (commercial data and private data in Fig. 1).

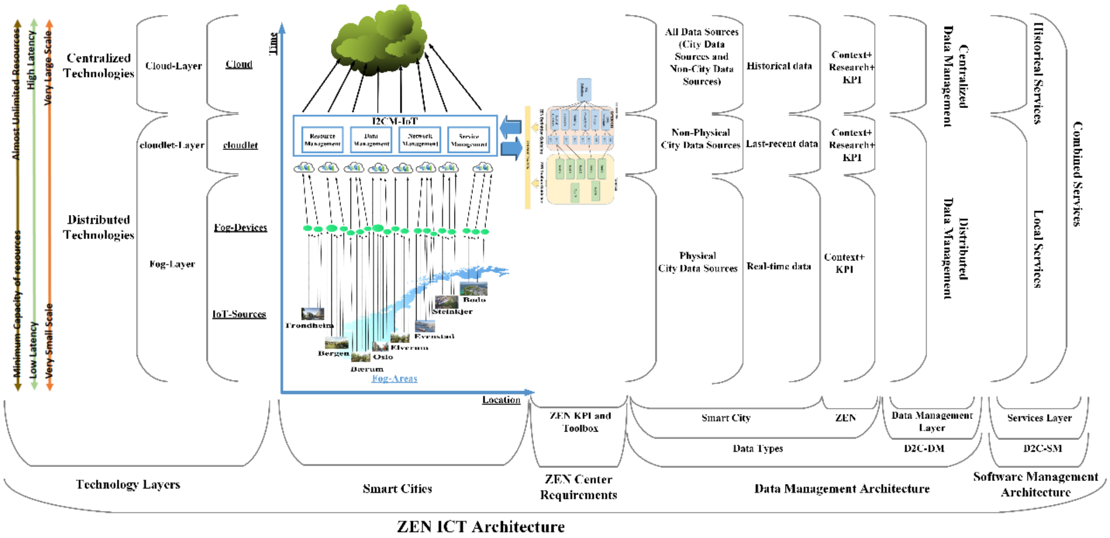

Figure 7. The proposed monitoring system and related Management Block

2.3 Architecture for ICT ecosystems

The abundance of data, data types and data sources relevant for ZENs could be considered as an ICT ecosystem, that encompasses many stakeholders and ICT applications, as shown in Fig. 1. The concept of Enterprise Architecture is an approach that has been considered by many projects similar to FME-ZEN, such as the Positive City Exchange (+CityxChange) project [4]. The term Enterprise Architecture was coined to focus on aligning the business and technical strategies of organizations, to ensure that the technical infrastructure supports the strategic business goals [5]. The Open Group defines that Enterprise Architecture is about understanding all of the different components that go to make up the enterprise and how those components interrelate. Such components include the enabling technical infrastructure of any organization. In the case of the FME-ZEN project and ZEBs or ZENs, the data infrastructure and the ICT components for managing the data are important enabling technical infrastructure.

A neighbourhood, or a city, could be considered similar to a complex organization, or an enterprise, where a number of services are offered and that uses a variety of data and ICT systems, where these systems are essential for providing value added services to their numerous stakeholders. The benefits of the Enterprise Architecture approach in designing the data management ICT architecture in the FME-ZEN project could be summarized as follows:

- bridges the value-adding services to the ICT ecosystem.
- provides a structured approach to co-creating and describing services and ICT systems, which can facilitate dialogue and a common understanding among the project partners and stakeholders.
- provides a structured approach to designing and developing services and ICT systems.
- can support better access to information, data, services and potential business collaboration partners.
- can support innovative services and business models.
- can support blueprinting of services, which can act as reference architectures to support replication of services across ZENs.

2.3.1 Enterprise Architecture Approaches

The first Enterprise Architecture approach, the Zachman Framework, was presented as a taxonomy, identifying the different organizational stakeholders' perspectives or views and the different aspects of the entity they may be interested in [5]. Drawing inspirations from the construction industry, the Zachman Framework highlights that the views of a building that are of interest to a building owner, the designer and the builder are not the same, although they may all be looking at the same building, Hence, it is essential to consider the views of all the stakeholders. The main ideas and concepts that define Enterprise Architecture frameworks are the perspectives of different stakeholders and considering the alignment of the ICT developments with the needs of non-IT stakeholders as equally important. Common to these frameworks is reducing complexities by considering disparate views and organizing various aspects in ways that make an entity understandable.

Several Enterprise Architecture frameworks and modelling concepts have been proposed. They include the Zachman Framework [5], The Open Group Architecture Framework (TOGAF) [6] and the Industrial Data Space Reference Architecture Model (IDS-RAM) [7]. TOGAF takes a layered approach and provides a methodology for continuously aligning the business and the IT strategies and managing change. It considers an organization to consist of three layers, each with three distinct types of architectures:

1. Business Architecture,
2. Information Systems (Application and Data) Architecture,
3. Technology Architecture.

The IDS-RAM framework takes a data-centric approach to support the increase in the availability and access to data (e.g., from sensors and other sources) and Big Data. This is a paradigm shift in the way we think about data and how to leverage on the data that is available. By "bringing the analytical capabilities to the data" versus the traditional processes of "bringing the data to the analytical capabilities through staging, extracting, transforming and loading", which could contribute to reducing the cost of moving data [8]. The general structure of IDS-RAM is shown in Fig. 8. The model is made up of five layers: Business, Functional, Process, Information and System layers. Directly related to the five layers are three cross-sectional perspectives: Security, Certification, and Governance. These are an integral part of the RAM in order to make sure that these three major core concepts of the IDS are implemented across all five layers. The Industrial Data Space at the top is defined as a "virtual data space leveraging existing standards and technologies as well as accepted governance models for the data economy, to facilitate the secure and standardized exchange and easy linkage of data in a trusted business ecosystem. It thereby provides a basis for smart service scenarios and innovative cross-company business processes, while at the same time making sure that data sovereignty is guaranteed for participating data owners" [7].

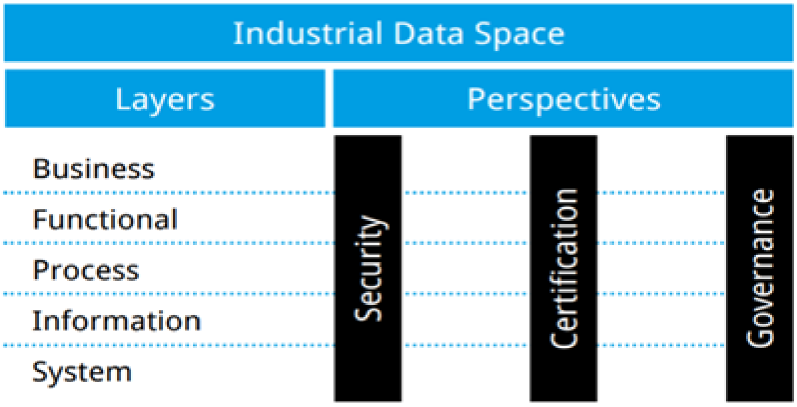

Figure 8 The general structure of IDS-RAM [7]

2.3.2 The Positive City Exchange Enterprise Architecture Framework

Taking inspirations from the literature on Enterprise Architecture frameworks, an architecture for Positive Energy Districts was developed in the Positive City Exchange (+CityxChange) project. The +CityxChange Enterprise Architecture Framework was used to describe the ICT ecosystem for the different demonstrator scenarios that were developed for Positive Energy Districts, which are described in [9]. This is a layer based architectural framework, which also focuses on the data, data sources and the ICT applications developed using the data. Furthermore, it also integrates the users' and stakeholders' needs and the services as well as the collaborations that contribute to the realization of the services. At the heart of this Enterprise Architecture framework lies the +CityxChange Data Space which connects the higher layers with the lower layers. The higher layers correspond to what has been identified as the business and services layers and the lower layers correspond more to the technological infrastructure [7]. The different layers are shown in Fig. 9.

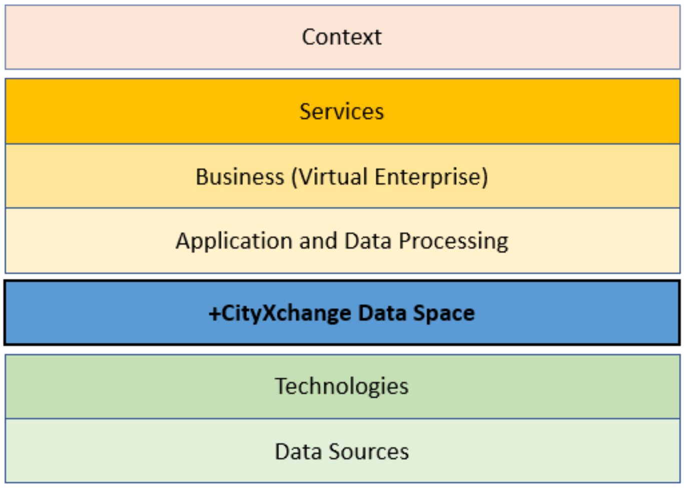

Figure 9 The layers in the +CityxChange Enterprise Architecture Framework

The layers of the +CityxChange Enterprise Architecture Framework are described below:

- Context layer describes the needs of the stakeholders and the drivers for the services, which may in our case also include the KPIs.
- Service Layer describes the value-added services that are offered to users and stakeholders, which bring together a number of service providers, data and applications.

- Business Layer describes the different actors and processes that are involved in providing the service.
- Application and Data Processing Layer describes the different applications that support the services. Applications may support processing or analytics of data that are relevant for the service or other purposes such as searching and navigating the information space, visualisation of information or others.
- +CityxChange Data Space provides a means to bridge the lower levels of the Enterprise Architecture, such as supporting technologies, and the higher levels of the Enterprise Architecture, such as the (data-based) services. Furthermore, this layer will also serve as a common "platform" for the lower layers to facilitate access to data for the higher layers. This layer can be used to describe the data that is available in the ZEN, which could be used by various entities to provide services.
- Technologies Layer describes the different technologies that support the Data Space and the higher layers of the Enterprise Architecture. Technologies include hardware (e.g., servers and community grid) and basic applications such as databases.
- Physical Infrastructures Layer identifies the sources that provide the data, such as energy sensors, metering devices, IoT devices, mobile phones and social media. This layer is important for supporting transparency and integrity of data, and for adhering to regulatory frameworks such as GDPR.

2.3.3 Enterprise Architecture approach for ZEN

The +CityxChange Enterprise Architecture Framework could be adapted to describe dashboards and other services related to the ZEN KPIs for multiple stakeholders. An example of how this could be done is illustrated in Fig. 10.

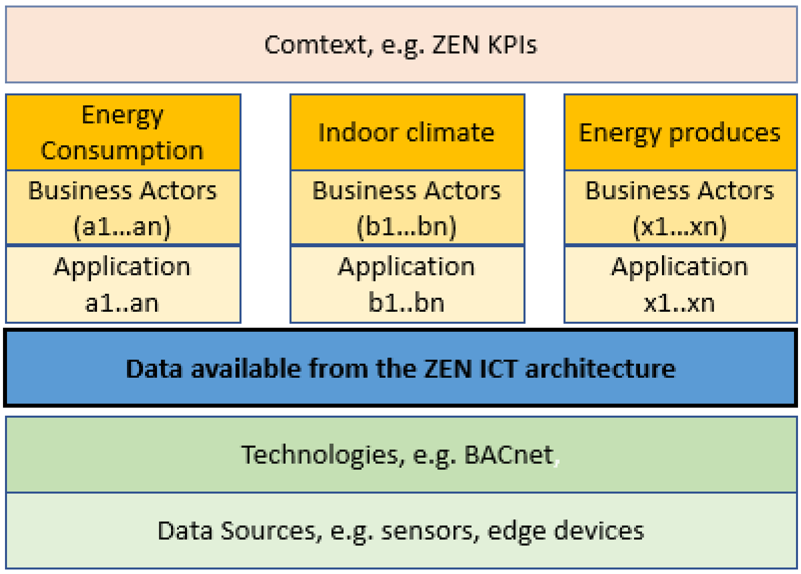

Figure 10 +CityxChange Enterprise Architecture Framework adapted to ZENs.

The contents of the layers of the +CityxChange Enterprise Architecture Framework are described below:

- Context (Goals): the goals to achieve (regardless of levels). A core goal is to reach selected KPI-goals for the neighbourhood.
- Services: business services to fulfil goals (and to monitor the achievement of goals).

- Business actors: With access to resources at different levels. E.g., Siemens and Vegdekke as entrepreneurs (with contractual goals on e.g., power production for solar panels and performance of heat-pumps).
- Application and data processing: Data processing done on one or more levels with specialized or general-purpose tools, including an overview of data in tools such as Grafana.
- Data space: Different data sources stored at different levels of the ZEN ICT Architecture.
- Technologies: to gather data and being used for intermediate data processing along the data pipeline.
- Physical infrastructure: including sensors on the edge in the physical buildings and premises.

3 Pilot Case – ZEB Laboratory

In the first pilot case, we have started with one single office building that is designed to be ZEB-COM. Including only a single building limits the KPI-types that are relevant. The reason to start with this single building case is to be able to thoroughly investigate a highly instrumented building with its own production of energy using different technologies (both solar and thermal) with local energy storage possibilities.

3.1 Research Infrastructure: ZEB Laboratory

The ZEB Laboratory is described in more detail in https://zeblab.no/. Highlights of the different parts and functionality are provided below. The building is a living laboratory, which is highly instrumented and is constantly monitored through the data available through multiple sources. Pictures of the building are shown in Fig. 11.

Figure 11 Building and energy sources.

The top right part of the figure shows the building before completion and the left side shows the building from the outside, after its completion.

The focus of the pilot has been, in particular, on how to represent the ENE-ergy KPIs.

3.2 Application of the case

The case has looked at concrete reporting dashboards available for the ZEB laboratory building, to be able to follow up selected ZEN KPIs, and the overall data-architecture supporting the provision of such KPI data from a building in operation.

We will first show some of the relevant dashboards, and then illustrate the underlying architecture. Then, we will present ideas for a more generic architecture and finally how this can be mapped to the aspects we have described in the current ZEN-architecture.

An overall dashboard might be built according to the following structure:

- A start page where one selects the building/area e.g., using a map interface.
- An overview page with, e.g., a spider-diagram, as shown in Fig. 12, together with information about the building/neighbourhood.
- The possibility to select one thematic area and analyse in detail, an area of interest (e.g., ENE or energy related KPIs).
- Further, drilldown to a single dashboard as exemplified below, to look at values in the operational phase, alone, and in combination with the design targets in the different proceeding phases.

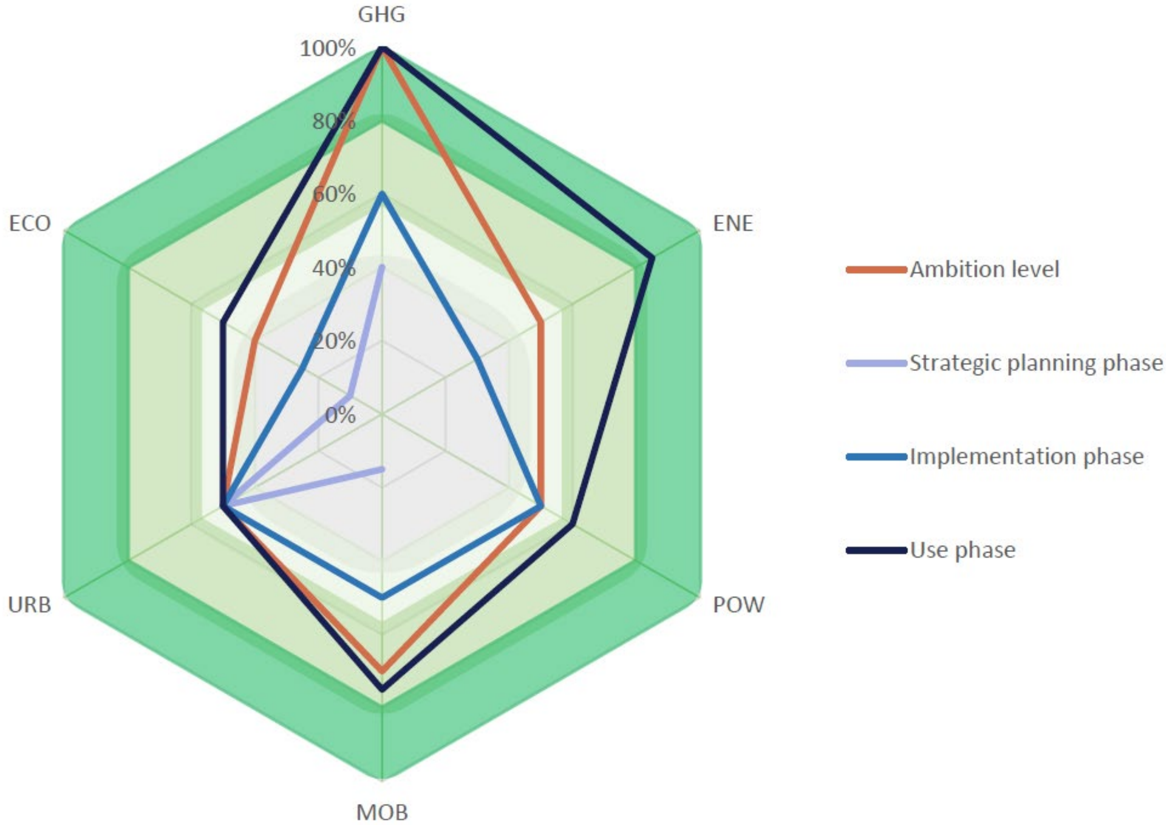

Figure 12 Example of KPI Spider-diagram

In the prototype, we have started with creating dashboards for the ZEN KPIs ENE 2.1, ENE 2.2 and ENE 2.3, which are described in the following way in ZEN Report 44 [2]. As we can see, the focus in ZEN so far is on calculating these values, rather than measuring these KPIs in the use phase (production of energy) and comparing to the designed target values, which have influenced the work reported in the ZEN Report 44.

ENE2.1	**Energy needs in buildings**
Objective	To increase the energy efficiency of the building envelope by reducing the energy demand of buildings as much as possible. More energy efficient buildings use less energy and have peak load requirements which will reduce GHG emissions from GHG1.4 Operational energy use (B6) and by reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related emissions as well as other environmental impacts.
Description	Specific total energy needs for all buildings within the building assessment level calculated per kWh of m^2 heated floor area (HFA) per year in the ZEN pilot area and in the reference project.
Method	The energy demand in buildings should be calculated at an hourly or sub-hourly level for a period of one year according to *SN-NSPEK 3031:2020*. This can be calculated using the tools PROFet [10] or building energy performance simulation tools. The energy demand should be calculated per energy services, with a minimum resolution of splitting the energy demand for thermal energy services and electric energy services.
Points available	8 points
ZEN KPI assessment	The KPI will be assessed based on the percentage (%) reduction in energy demand in the ZEN pilot area compared to the energy demand in the reference project (acting as a baseline). The limit and target values will be developed in future ZEN work.
Best practice	– New buildings are constructed as passive house buildings with low U-values and low energy demand. – Existing buildings are upgraded to the current building minimal.

ENE2.2	**Delivered energy**
Objective	More energy efficient buildings use less energy and have peak load requirements which will reduce GHG emissions from *GHG1.4 Operational energy use (B6)* and by reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related emissions.
Description	The delivered energy (imported energy) should be calculated as an hourly or sub-hourly mismatch between energy use and energy generation and is collected from the net load duration curve for each energy carrier. The net load profile and net load duration curve are calculated or measured at the neighbourhood assessment boundary level, per energy carrier, with hourly or sub-hourly resolutions. For this KPI, delivered energy should be reported as annual totals for all energy carriers at the neighbourhood assessment level for the ZEN pilot area and the reference project.
Method	The load duration curve for each energy carrier can be calculated using for example building performance simulation tools, energy generation tools and PROFet. It may be necessary to combine several tools. In the user phase, measurements can be used.
Points available	8 points
ZEN KPI assessment	The KPI will be assessed based on the percentage (%) reduction in delivered energy in the ZEN pilot area compared to the delivered energy in the reference project. The limit and target values will be developed in future ZEN work.
Best practice	– New buildings are constructed as passive house buildings with low U-values and low energy demand. – Existing buildings are upgraded to the current building minimal standard (or better). – Using heat pumps and/or non-electric heating will reduce the electricity use. – Solar panels reduce the demand for imported electricity

ENE2.3	**Self-consumption**
Objective	To increase the self-consumption of local electricity production. Introducing local electricity generation from renewable sources will reduce the need for imported energy and GHG emissions from *GHG1.4 Operational energy use (B6).*
Description	The self-consumption KPI is calculated for electricity on an hourly or sub-hourly resolution at the neighbourhood assessment
Method	Self-consumption is derived from hourly load profiles of electricity generation and electricity use in the ZEN pilot area. Hourly load profiles can be generated using building energy performance simulation tools, PV-generation tools and PROFet (it may be necessary to combine several tools). Where hourly measurements are not available, the self-consumption calculations can be complemented or substituted with simulations.
Points available	2 points
ZEN KPI assessment	The KPI will be assessed on the percentage (%) value for self-consumption of electricity in the ZEN pilot area. 1 point if self-consumption is 25 < 50 % 2 points if self-consumption is > 50 %
Best practice	– Storage solutions (electricity) and optimal control can increase the self-consumption by shifting electricity use to hours of electricity production. – The orientation of PV can be adjusted to better fit with the energy use of the neighbourhood.

3.2.1 Dashboards in Grafana

The current dashboard-prototypes are developed using a tool called Grafana, based on time-series data on electricity usage and production stored in a no-SQL temporal database. We have pragmatically used Grafana because it was available and has been used for other dashboards based on the same data in the ZEB Laboratory. Grafana seems appropriate for this type of dashboard but is less suitable for the map-oriented front end indicated for a more comprehensive system.

The relevant Dashboards made as part of the open data portal connected to the ZEB-lab available from the following links:

- https://zeblab.sintef.no/grafana/d/CwdTscX4z/zen-ene-2-1?orgId=1 - ENE 2.1
- https://zeblab.sintef.no/grafana/d/DNfedcXVz/zen-ene-2-2?orgId=1 - ENE 2.2
- https://zeblab.sintef.no/grafana/d/LNYuscXVz/zen-ene-2-3?orgId=1 - ENE 2.3

These dashboards are meant to be used by a building manager that follows up on the different parts of the energy usage and other aspects of sustainability of the different parts of the building, over a period of time.

In Fig. 13, the current (August 2023) version of ENE 2.1 is shown where all detailed area is hidden.

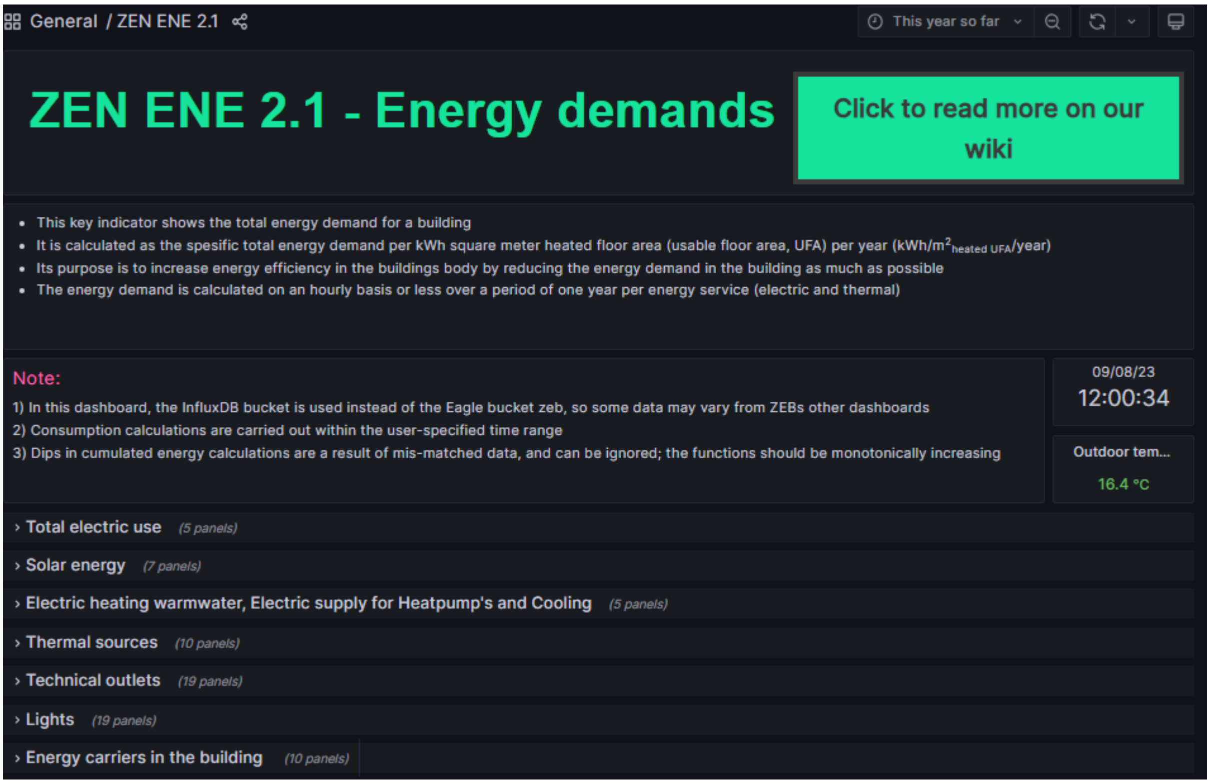

Figure 13 Top-level of ENE 2.1 dashboard

In the top left, the possibility for choosing a time period is found, with the possibility to choose a specific date or a previous period (from last 5 minutes to last 5 years). Data for last minutes and hours can be regarded as last-recent data, whereas data for previous months and years can be looked upon historical data); see Fig. 14. Notes to provide context both in general (as here) and also on specific data is important to be able to support.

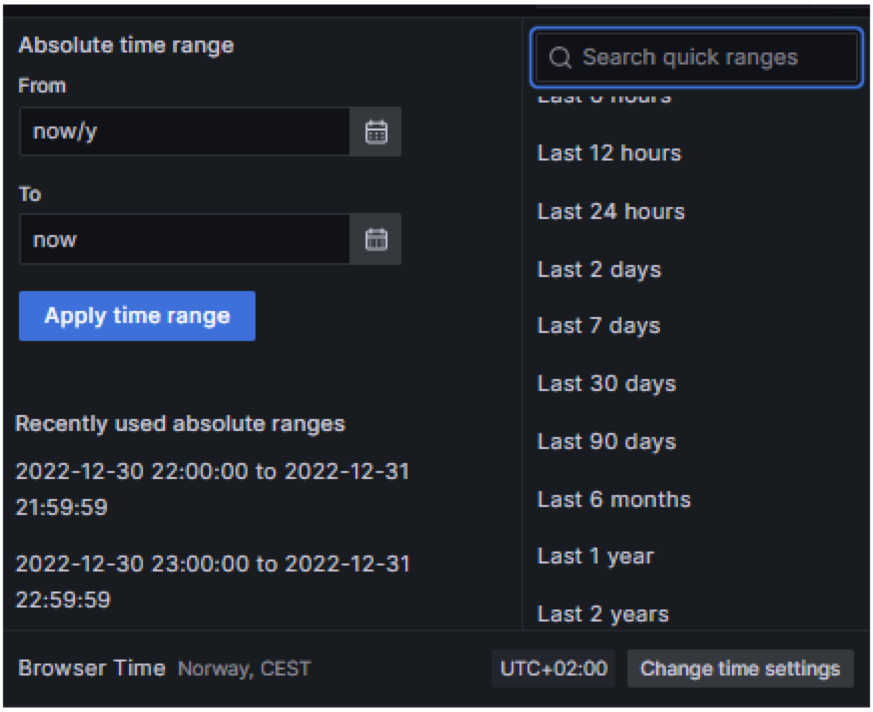

Figure 14 Available time-ranges

The two first panes how energy usage compared with the energy (solar) produced. 5 shows the energy usage for the last two years. As for comparison, this is not so useful as we can see, since usage data is only available from the last year.

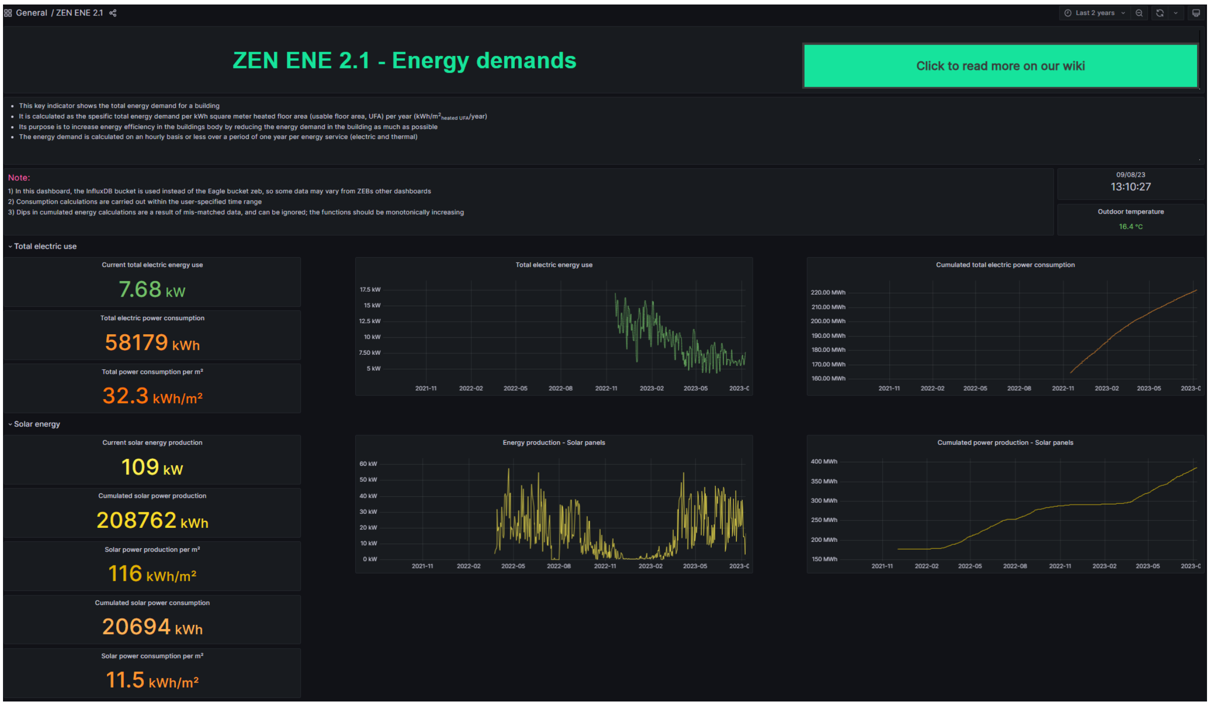

Figure 15 Total energy used and solar power produced.

Zooming in, we also see some irregularities, i.e., the low production July 2023. Here, there was an error in the solar power production system, and one thus lost 3 weeks of production in the summer. This is the kind of context information that it is useful to be able to store in addition to the recorded data, especially when comparing the solar production over many years.

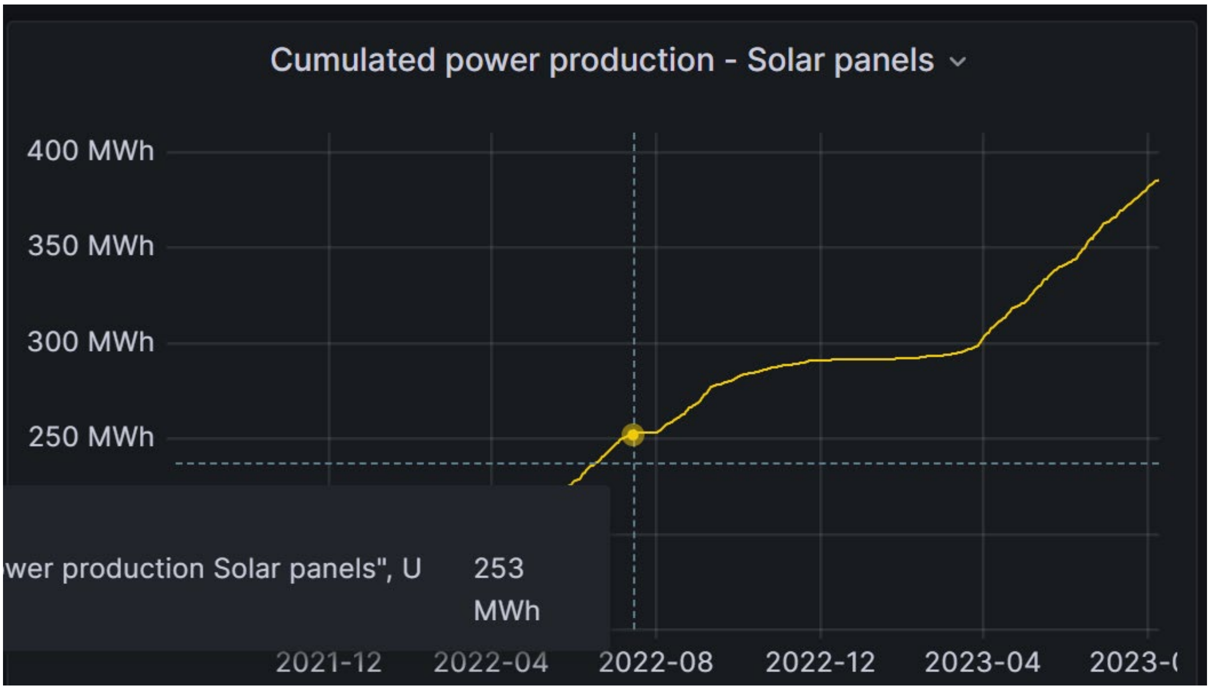

Figure 16 Example of unexpected production

A more useful view for comparison is the below in Fig. 17 (year to date) since both consumption and production data is available for the whole period. Note another anomality, the dip in the cumulated data on solar production. Here, this is not a production error, but a data error, which is also warned about in the general note on the top of the dashboard. This illustrates the need to smoothen curves.

Figure 17 Errors in readings

Figs. 18-21 show the additional panels for looking at aspects of energy consumption in more detail (all is year to date (August 9)).

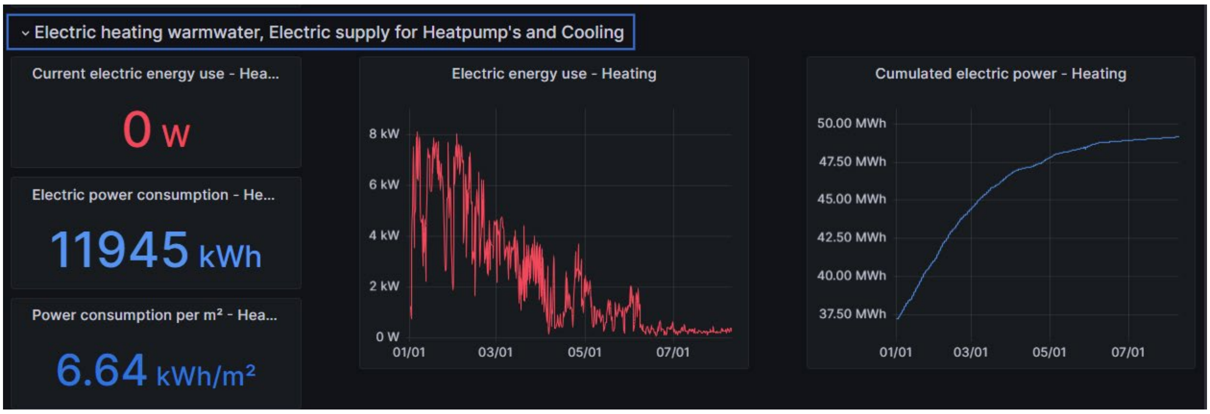

Figure 18 Cumulative electric heating

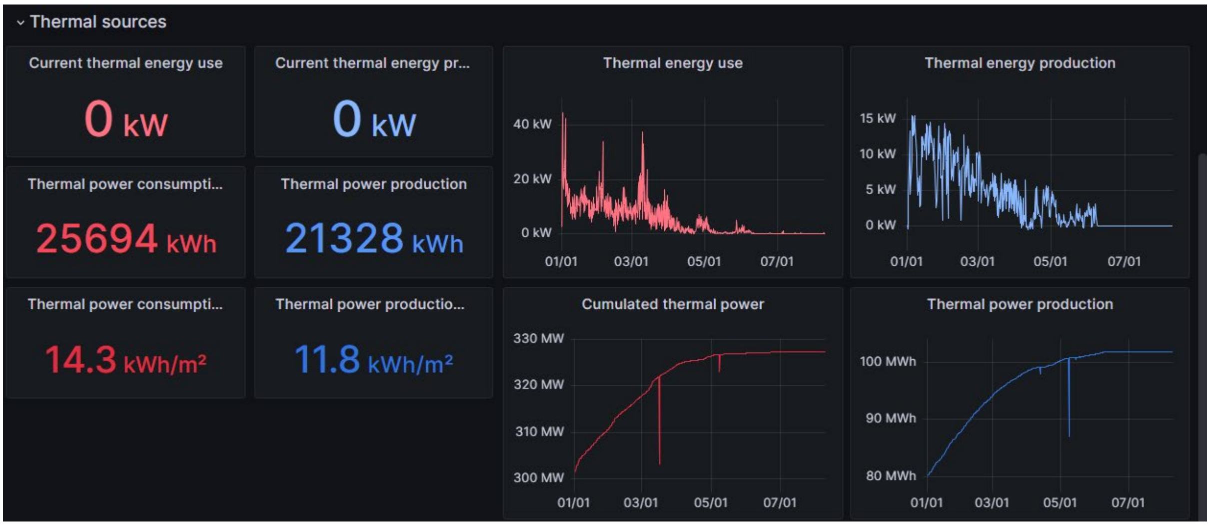

Figure 19 Cumulative thermal production

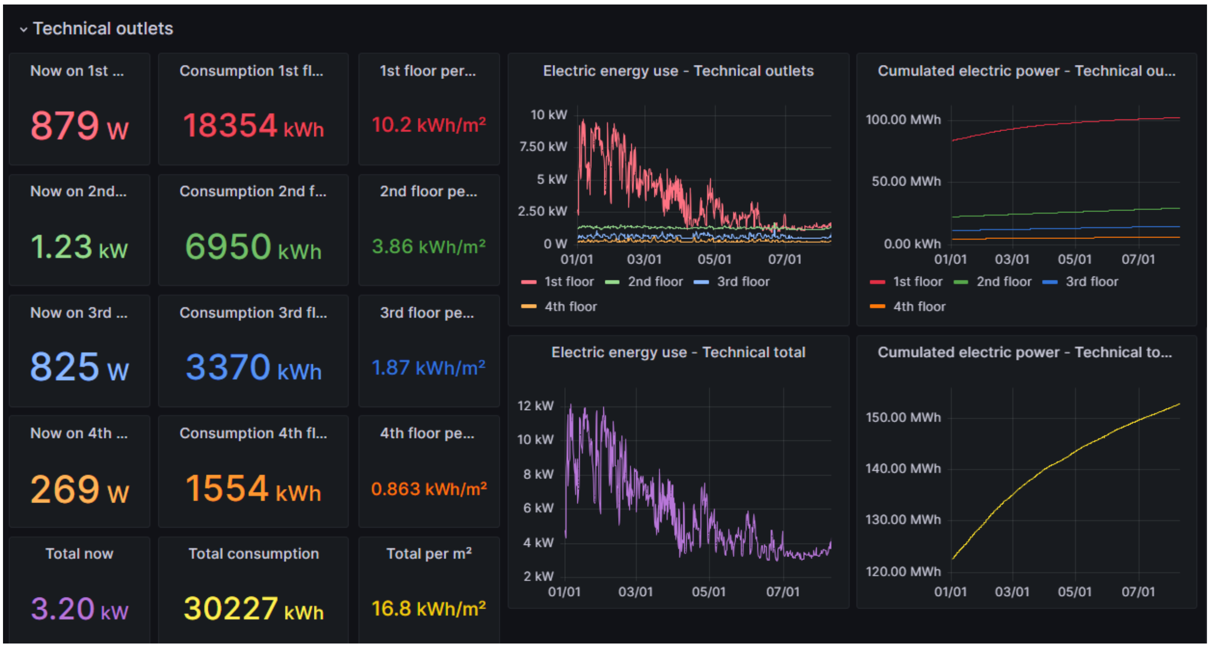

Figure 20 Consumption from technical outlets

Interesting context information on the technical outlets, is that it seems there is a lot used on technical outlets on the first floor of the ZEB building. This is in a sense right, but this includes the power to run the heat-pumps (energy which is regained on the thermal overview).

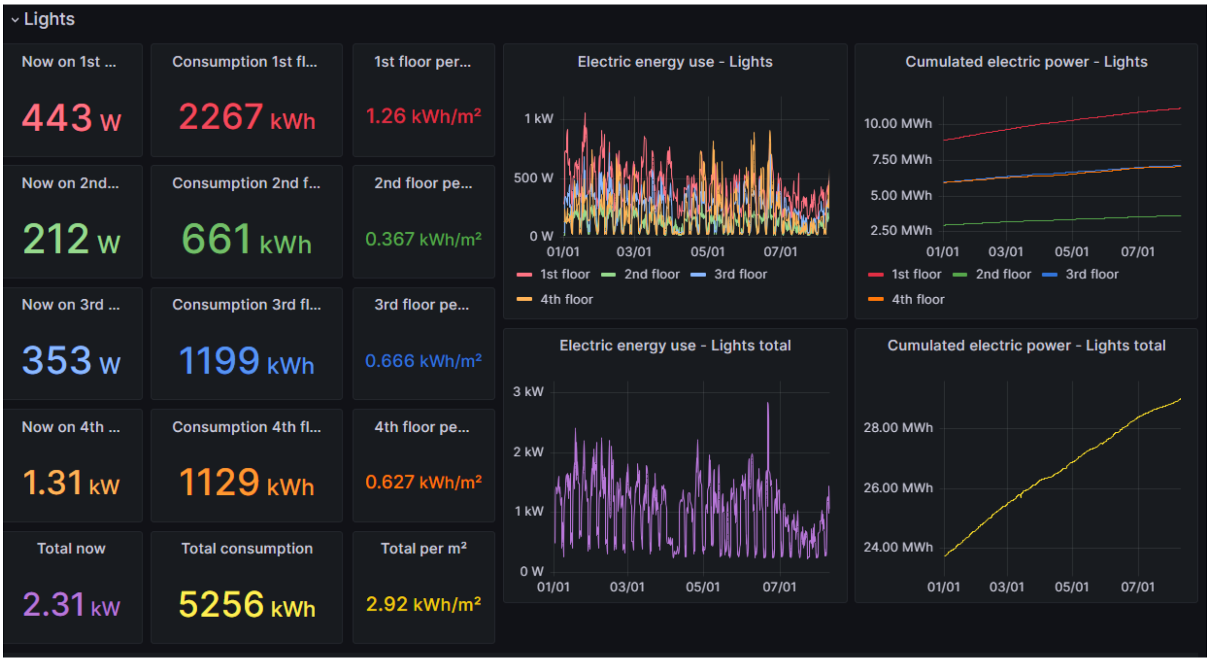

Figure 21 Consumption on lighting

Figure 22 Energy usage compared to expected yearly usage.

The threshold between green and red bars above shows the calculated yearly electric energy use for each component. If the filled-out area is green, then the current electric energy use is below what was calculated. If the filled-out area starts to become red, then the current electric energy use is above what was calculated in the simulation as expected use.

On the other KPIs, we only present the screenshots of the main dashboard below; see Fig. 23.

3.2.2 Basis for ENE 2.2 – Delivered Energy

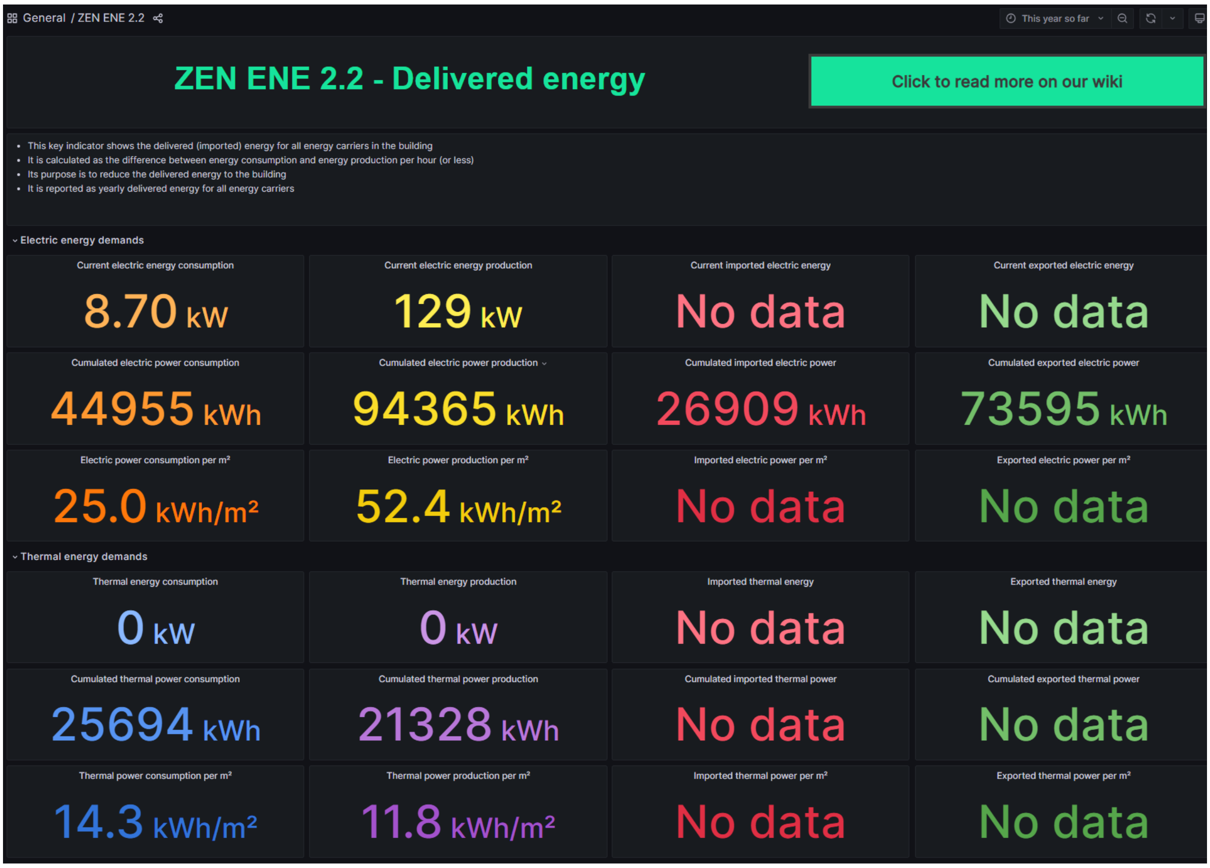

Figure 23 Dashboard for ENE 2.2.

3.2.3 Basis for ENE 2.3 - Self-consumption

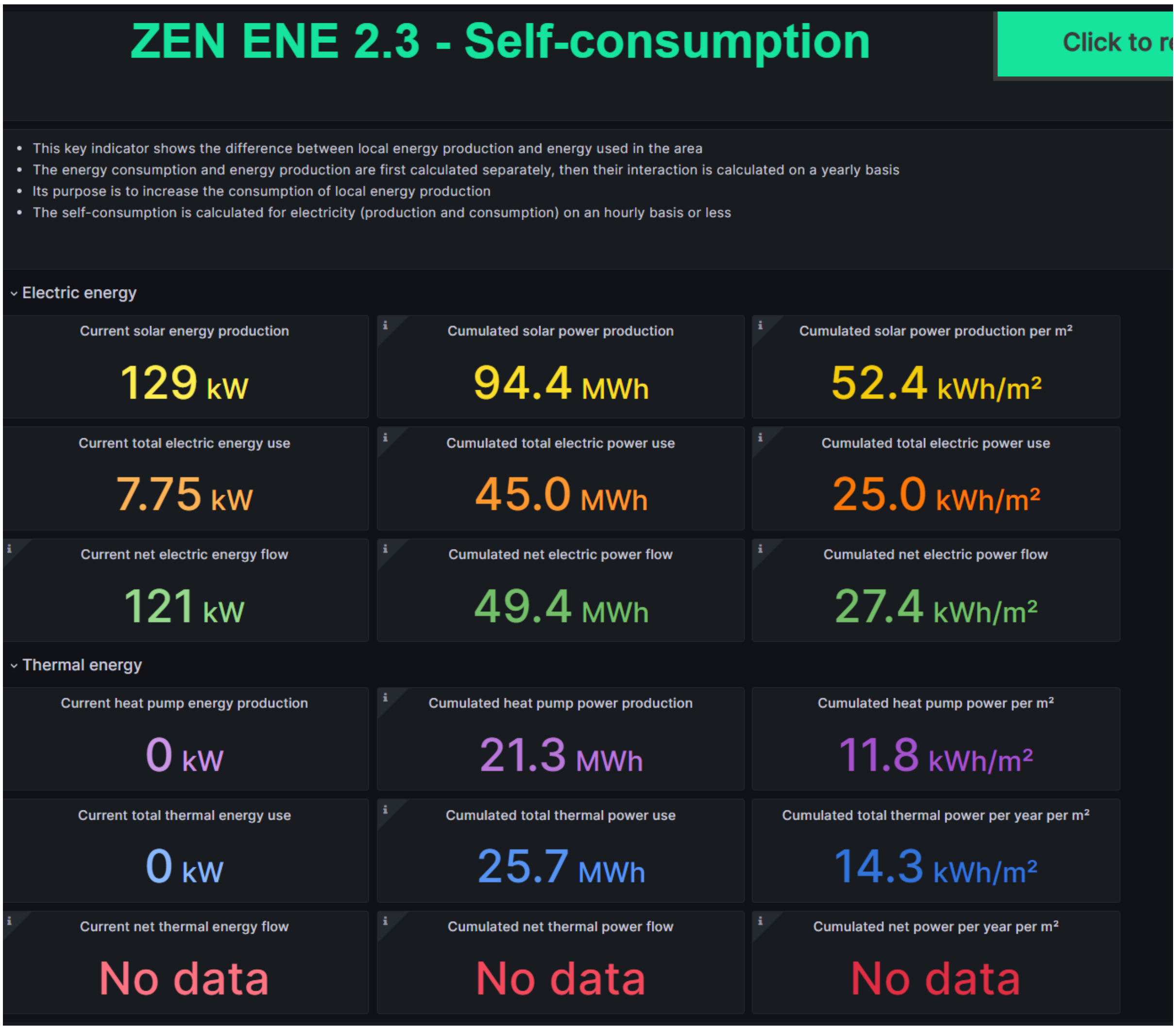

Figure 24 Dashboard for ENE 2.3

Another relevant existing Dashboard can be found at:
Energy use vs calc - ZEB-Public - Dashboards - Grafana (sintef.no)
which shows data related to the operation of the building compared to the expected usage. From an operational point of view, one can also foresee the need to mix actual usage so far with simulations, to see if the actual target is met e.g., at the end of the year.

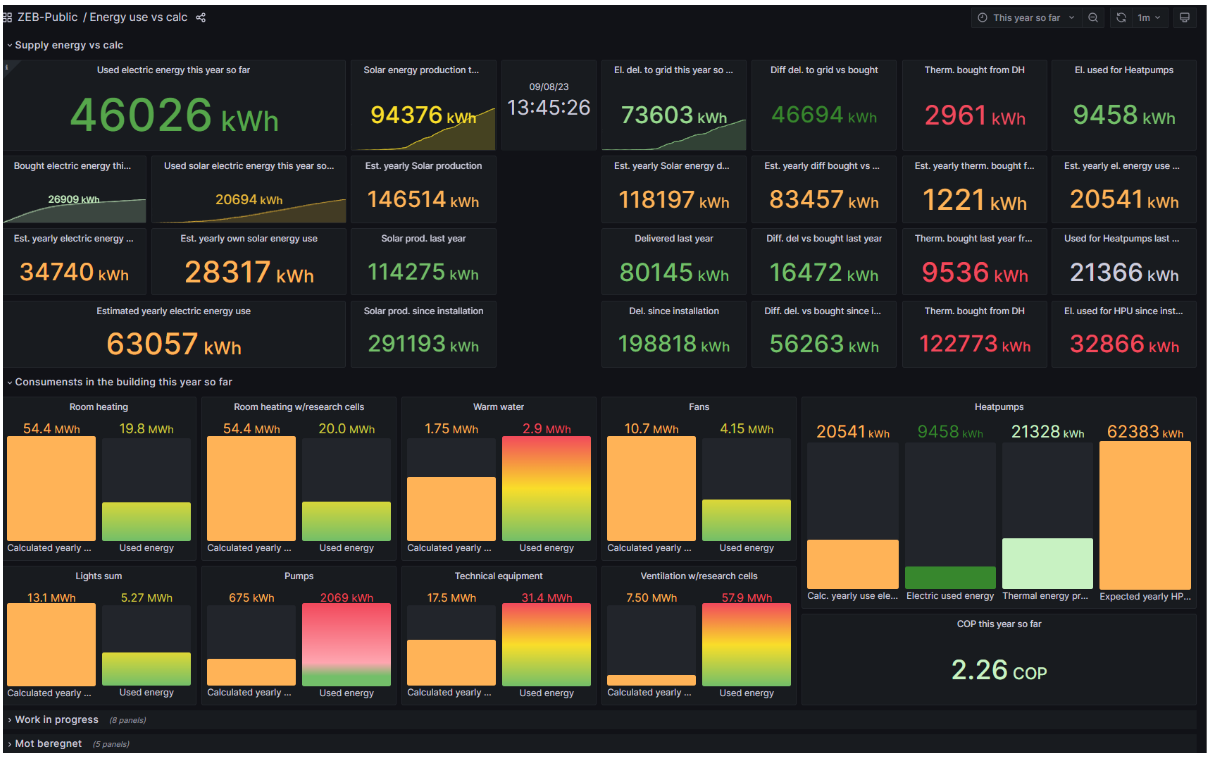

Figure 25 Current vs. expected values

We see here for instance that the energy gathered from heat-pumps is much less than half of the expected yearly production. 2.26 COP is the efficiency of the heat pumps, meaning that these do not function that well, (COP: Coefficient of performance). Most heat pumps have a COP of 2.3 to 3.5.

3.2.4 Current data architecture for providing the data to Grafana

The main result from this work is the underlying data architecture necessary to provide the data for such dashboards. We present the main approach, structuring both according to levels in the technical architecture described in Section 2.2, and the different parts of an Enterprise Architecture described in section 2.3.

Fig. 26 provides a high-level overview of main data-sources and data flows.

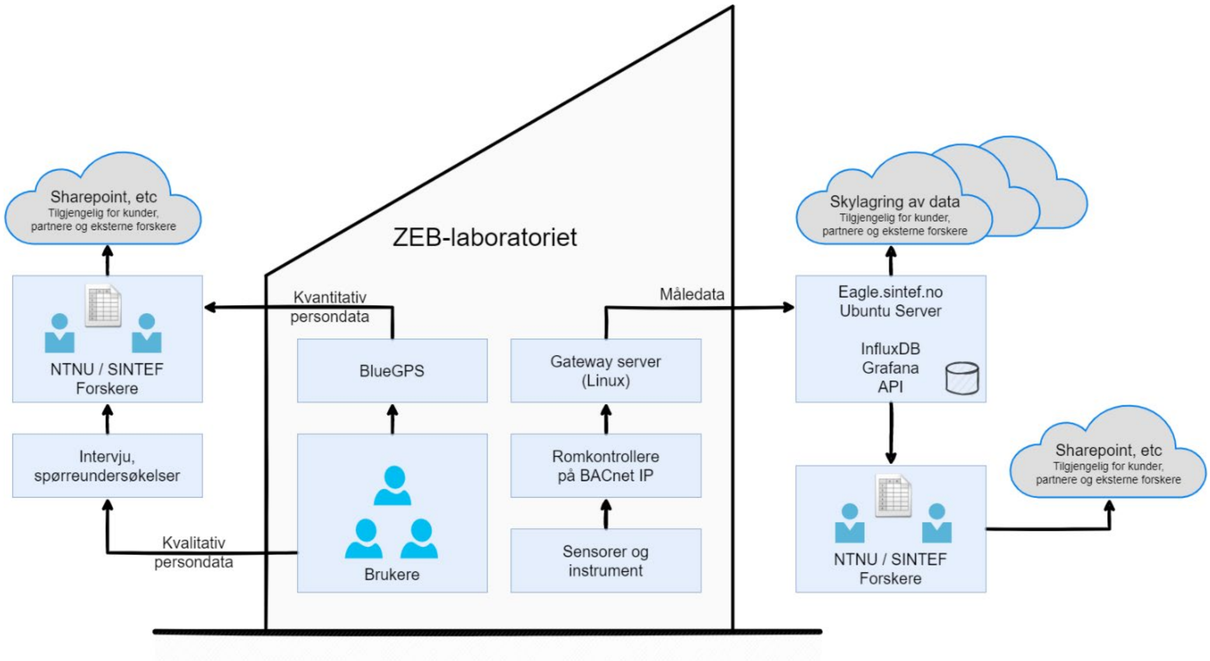

Figure 26 ZEB Laboratory data architecture - conceptual level

The terms used in Fig. 26 can be positioned according to the data architecture shown in Figure 4, using the terms edge, fog, cloudlet, private cloud and public cloud. This is shown in Table 2.

Table 2 ZEB Laboratory data architecture - conceptual level

	Edge	Fog	Cloudlet	Private cloud	Public cloud
Goals				KPI – follow up design target	KPI – definitions, Baselines
Services	Dashboard	Dashboard	Dashboard	KPI information	KPI information
Business Actors	Users of ZEB laboratory	NTNU/ SINTEF researchers		Customers, partners (technology providers Siemens, and entrepreneur Vegdekke), external researchers (internal in ZEN)	Other researchers Grafana Lab
Application and data processing		BlueGPS, gateway server		Flux-script Both public and private server	Grafana
Data Space				Influx DB, Sharepoint (documents)	Influx DB
Technologies	Standard telecom	Standard telecom, BACnet,		Standard telecom	

	Edge	Fog	Cloudlet	Private cloud	Public cloud
		Gateway server VPN			
Physical infrastructure	ZEB laboratory, sensors and instruments https://oceanlabobservatory.no/sensors/ in room and in badge	Received from sensors, every minute		Data sent to this level every 5 minutes	

Additional technical details of the ZEB Laboratory data architecture and the data flow are shown in Fig. 27. The data from sensors and actuators located in the field flow through an automation layer, through the BACnet/IP to a gateway, where the data is transferred to Influx. The left side of the figure shows the stationary installations and instrumentation in the ZEB laboratory, while the right side shows the gateway for mobile or third-party access to the data.

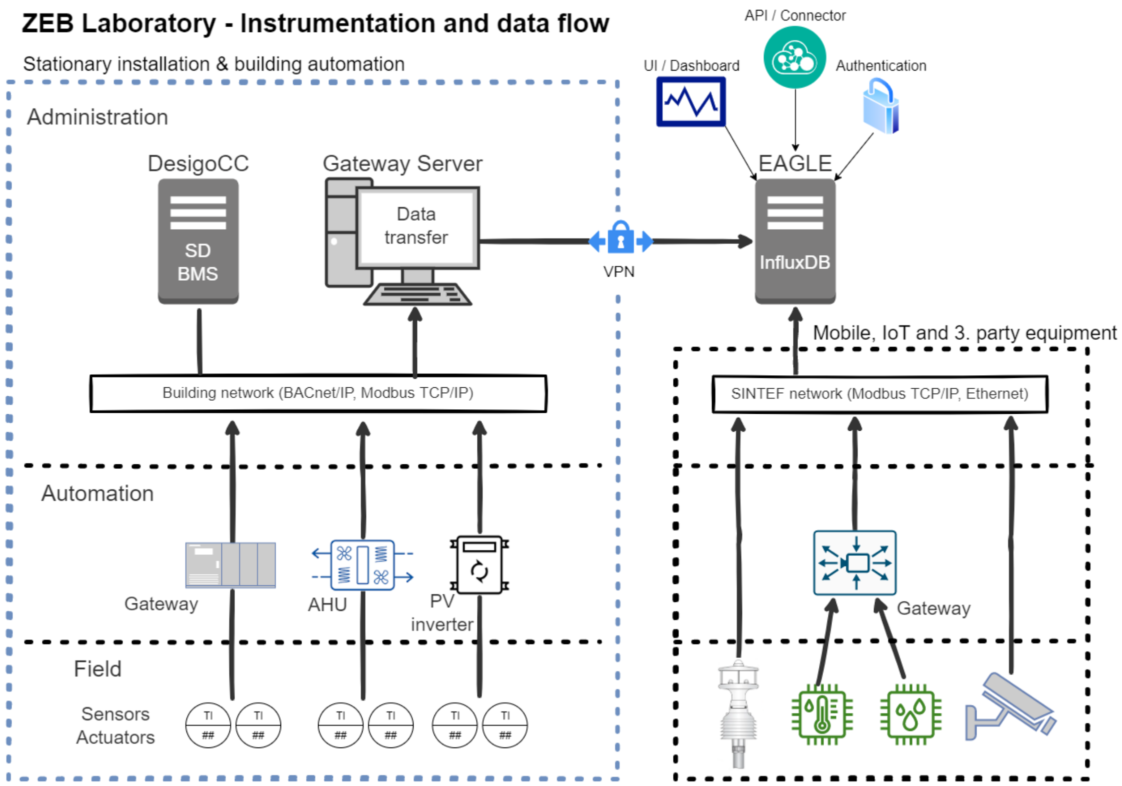

Figure 27 Instrumentation and data flow

The instrumentation and data flow model shown in Fig. 27 is mapped to the data architecture and the edge, fog, cloudlet, private cloud and public cloud. This is shown in Table 3.

Table 3 ZEB laboratory instrumentation and data flow related to the data architecture.

	Edge	Fog	Cloudlet	Private cloud	Public cloud
Goals				KPI – follow up design target	KPI – definitions, Baselines
Services				Authentication	Dashboard
Business Actors	Users of ZEB laboratory	NTNU/SINTEF researchers		Customers, partners, external researchers	
Application and data processing				API/Connector	
Data Space				Influx DB,	Met.no
Technologies	Gateway, AHU, PV Inverter	Building network		Gateway server, VPN	
Physical infrastructure	ZEB laboratory, sensors, actuators DesigoCC SD BMS				Mobile, IoT, 3rd party equipment

In the ZEB laboratory, the data acquisition system is centred around a time-series DB, as illustrated in Fig. 24.

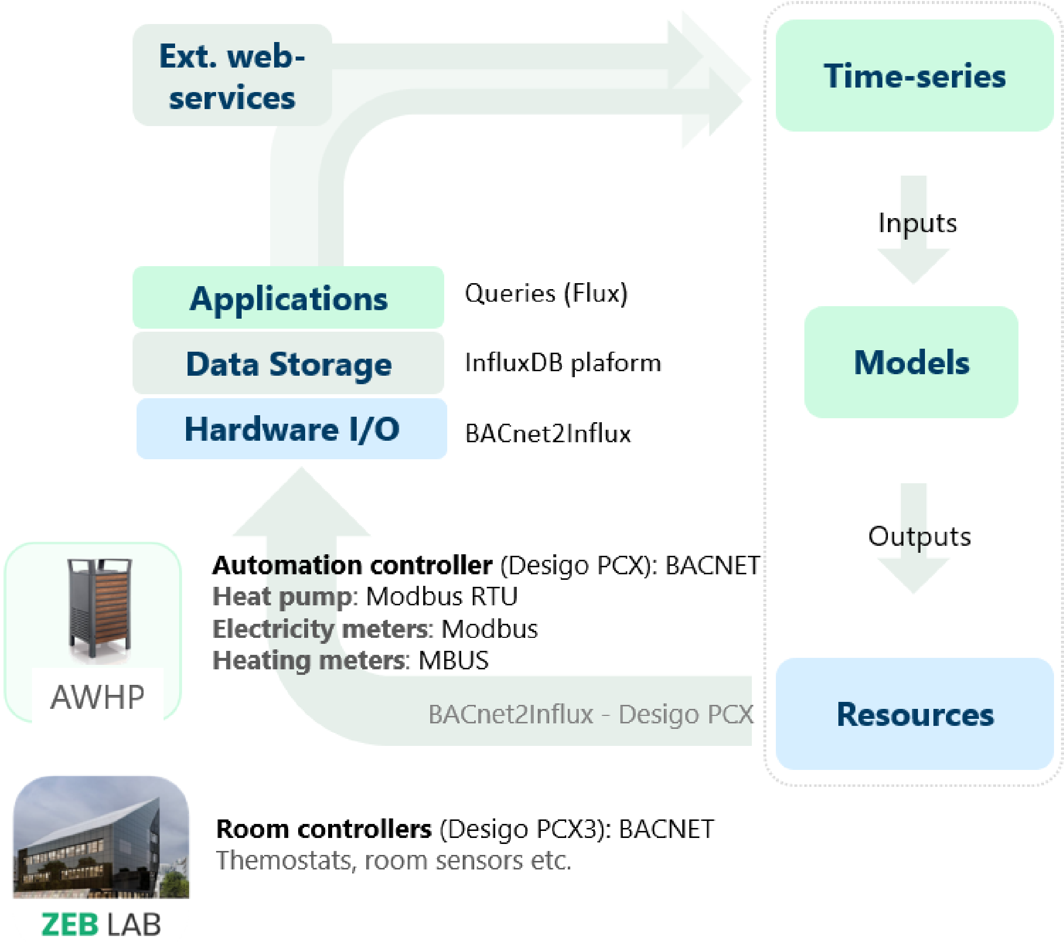

Figure 28 from IEA-HPT Annex 56 project – BAC in Action: Connected heat pumps in the ZEB Laboratory building (Skeie, Clauß, Birgen, 2022)

The hardware abstraction follows a 3-layer architecture:

- InfluxDB is utilized to combine data from multiple sources and to query minute resolution data for various applications.
- Data ingestion by "BACnet2Influx" Python script (on-site) writing streams of data to Influx DB time-series platform
- Building automation controllers (Desigo PCX) makes data available over BACnet/IP messaging protocol.

In the Grafana tool, one can present data from all sensors through its representation in the influxDB or provide aggregated values. As part of the flow, also manual updates on historical data might be performed, given that there have been errors in the data captured automatically. - A data processing pipeline has been made in Python (Pandas) using the InfluxDB client library.

- Outliers were removed to produce data for the physical modelling procedure, and hours with missing data were interpolated with the time-of-day mean values from the past seven days.
- The same averaging approach was used to provide forecasts of, e.g., internal gains and operating setpoints into the future (in combination with weather forecasts).
- Metrics are written back to the InfluxDB for visualization in the observability platform Grafana.

The concrete technologies here are just examples of possible solutions, on all levels other concrete technologies exist, and can be interchanged freely as long as one agrees on the data formats and interfaces. In addition to the data, meta-data is central to be able to interpret the data. This is shown in Fig. 29, as indicated below:

- Meta-data are written into Influx from an Excel spreadsheet,
- stored as key-value pairs which can be used to build InfluxDB queries.
- naming according to a universal labelling scheme used in Norway (Statsbyggs TFM)

The data handling described above is also a kind of meta-data that it is important to store to be able to use the time-series data.

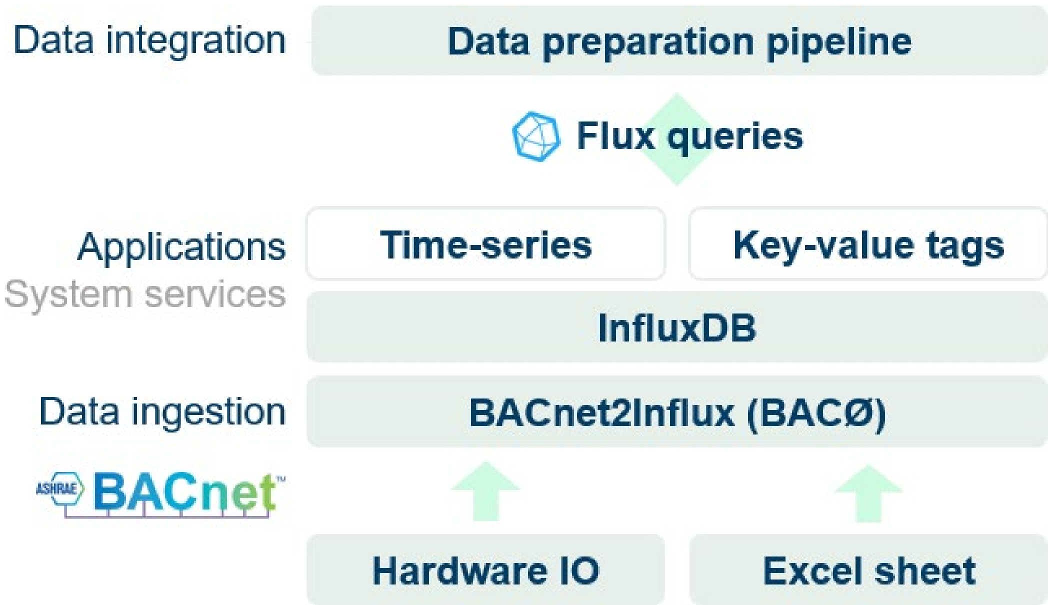

Figure 29 Current meta-data handling

3.2.5 Ideas for a more generic architecture for ZEB laboratory data-provision

The current solution is based on several proprietary solutions, and it is useful both for ZEB laboratory in itself and for the use of different pilots to standardize e.g., storage and data-calculations. In particular, the handling of meta-data is very ad-hoc, thus should be improved in a more general architecture.

One suggestion is illustrated in Fig. 30.

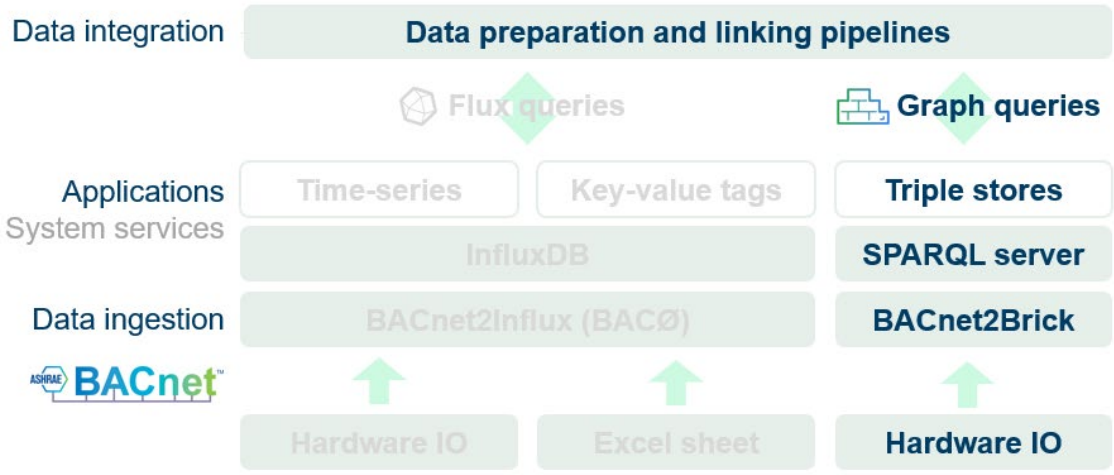

Figure 30 Standardized meta-data handling.

- BACnet to Brick model from a BACnet network, and then augment the basic model with metadata.
- Soon to be possible with NREL's building Metadata OnTology Interoperability Framework:
  - BuildingMOTIF (https://nrel.github.io/BuildingMOTIF/README.html)
  - BACnet2Brick (https://github.com/BrickSchema/brick-bacnet)

IFC (BIM) and BRICK models may also be linked in the future. Additionally, one might want to have a parallel infrastructure capturing data directly from sensor for use by researchers, both internally and externally, not going via an influx-DB. Relevant work is done in connection to this in the Smart Building Hub project.

3.3 ZEB Laboratory data architecture as an ICT ecosystem

The ZEB laboratory data architecture can also be described as an Enterprise Architecture model, using the +CityxChange Enterprise Architecture framework, described in Section 2.3.2 and Fig. 10. This architectural framework describes the ICT ecosystem in seven layers, where one layer serves another layer, which is described above it. An overview of the seven layers and their contents are also provided in Table 2 and Table 3. The Enterprise Architecture model is shown in Fig. 31.

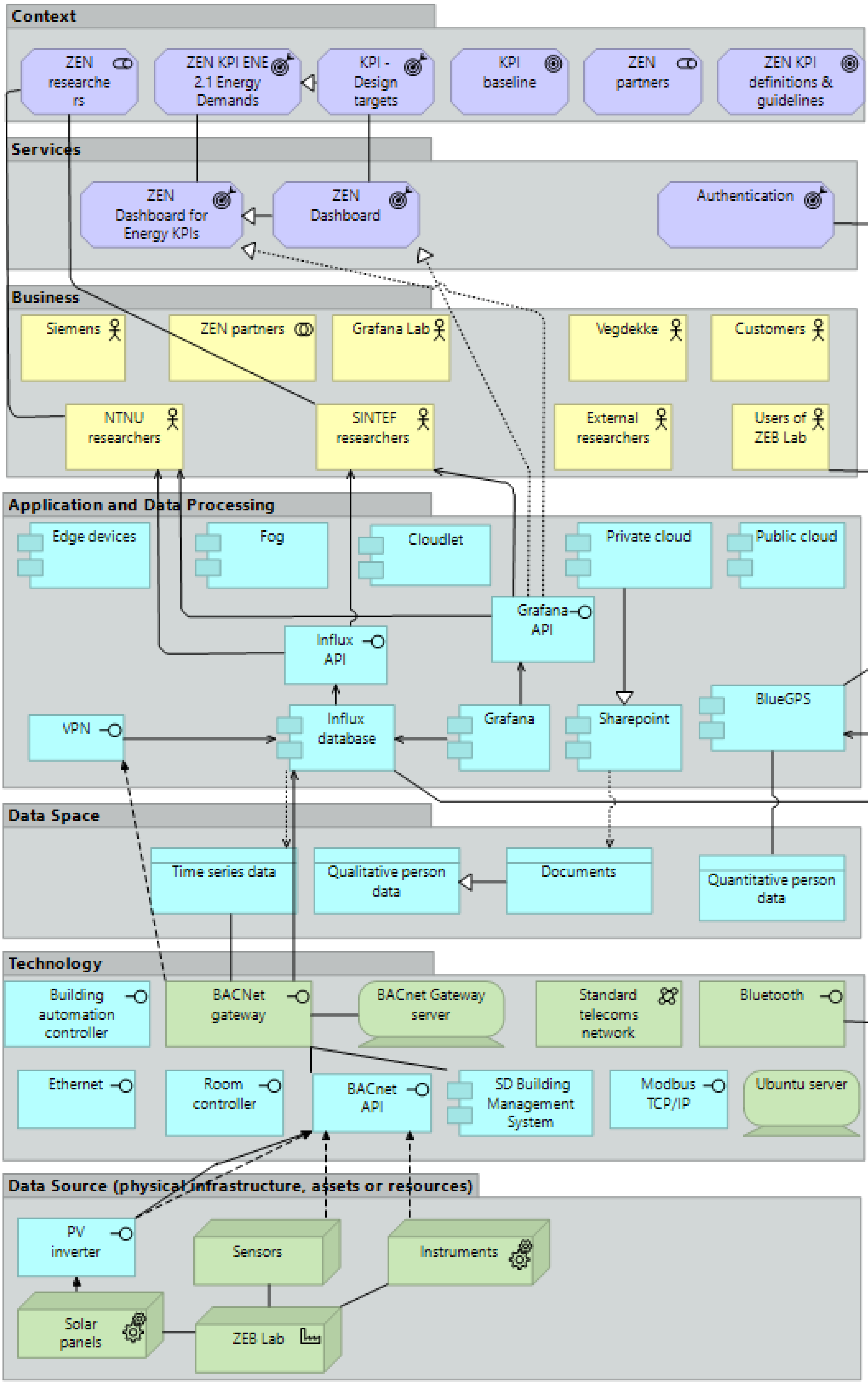

Figure 31 ZEB laboratory ICT ecosystem - Enterprise Architecture model

A description of the seven layers is provided below:

- The context layer describes the needs or the interests of the stakeholders. For the ZEB laboratory, one of the contexts is the ZEN KPI and guidelines, e.g., a specific context could be the energy KPI.
- The service layer describes the services to meet the needs described in the context layer; in this case, the energy KPI need could be met by a dashboard that displays information and data related to the energy KPI.
- The business layer describes the actors involves in providing the service; in this case they could be NTNU and/or SINTEF researchers, but also industrial partners is included.
- These actors serve the need by using some applications described in the application layer of the architectural framework; in this case, the researcher asks Grafana through the web interface. Grafana then accesses Influx and fetches the relevant data. Influx provides persistent data storage (i.e., long term data storage). Note that in this depiction, we have included the original architecture layers at this layer. This is just for experimentation, probably it is better to have these layers (edge, fog, cloudlet, private and public cloud) orthogonal to the EA Layers with more relationships depicted based on connection in Tables 2 and 3.
- The relevant data is described in the data space layer; in this case, it could be time series data related to energy consumption and production in the ZEB laboratory (an example dashboard is shown in Figure 15). The influx DB may be available on both a public and private cloud.
- The data is collected through the BACnet gateway described in the technology layer, which uses the BACnet API and the SD building management system to access the data from the assets and resources in the ZEB laboratory.
- The assets and the resources that provide the data include the PV panels and sensors in the ZEB laboratory.

The main aim of the Enterprise Architecture model, shown in Fig. 31, is to illustrate how the data architecture described earlier is relevant for meeting the needs of the stakeholders. Hence, it may be incomplete and lack some details such as specific APIs, etc. It illustrates how the components in the data architecture are related to high level or strategic needs. It can further be used to understand the data flow, depending on the needs of the stakeholders.

The main components in the data architecture described in Fig. 26 and Fig. 27 are described in the lower layers of the Enterprise Architecture model: data sources (assets and resources), technology, data space and application layers. In particular, the lower layers often describe stationary components, such as the ones shown in Fig. 27, and may remain unchanged, independent of the varying needs of the stakeholders, i.e., a diversity of contexts and services in the upper layers could be supported by the same data architecture. It should be noted that the components described in this Enterprise Architecture model describe one specific solution for the data architecture. Several of these components could be replaced by other similar technologies that provide the same functionality.

3.4 Scenarios for accessing data

The data gathered from the ZEB laboratory may be accessed in several ways and serve several purposes to meet the diverse needs of the stakeholders. The model shown in Fig. 31 shows a general scenario, where data is accessed to create dashboards, such as the dashboard in the ZEB laboratory building. In the following sub-sections, additional scenarios are described, where different data pipelines may be used, although the data architecture remain the same.

3.4.1 Direct from the building

Users are able to access data directly from the assets and resources in the ZEB laboratory through the SD Building Management System. In this scenario, the user may be the building manager or the building maintenance manager, who in interested in the general status of the building, or specific information, e.g., related to energy efficiency, solar production or indoor climate in the building. An Enterprise Architecture model for this scenario is shown in Fig. 32. The specific components of the model that are relevant for this scenario are shown with a red rectangle and the relevant relationships are shown as bold lines connecting the different components. In this case, the building manager can access the SD Building Management System directly to retrieve data. There may also be applications that support services such as provide notifications to the building manager, e.g., activates an alarm when maintenance is due, or under specified conditions.

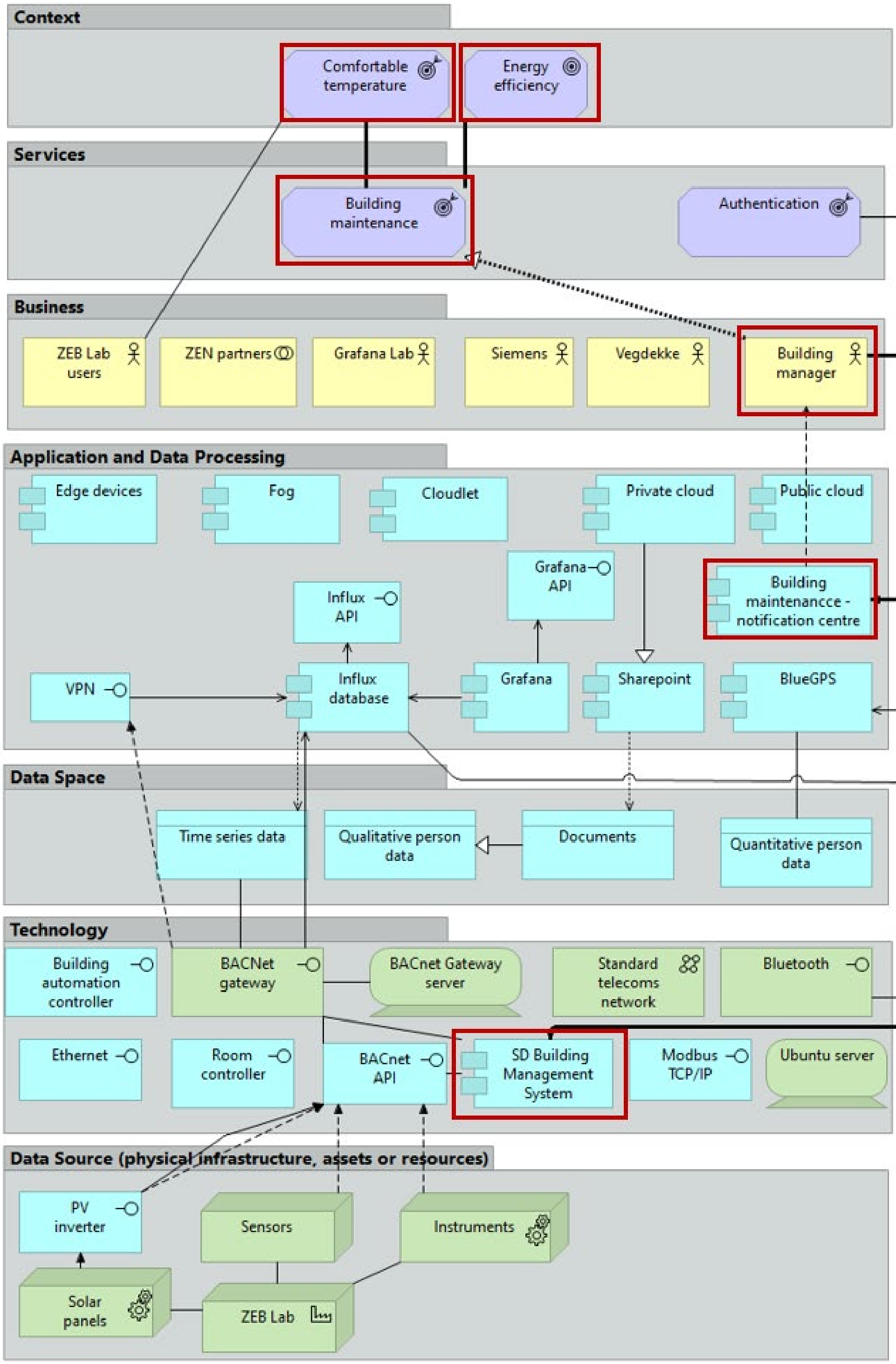

Figure 32 ZEB laboratory ICT ecosystem - Enterprise Architecture model, scenario: direct access to data from the building. Relevant components are shown with a red rectangle and relevant relationships are shown as bold lines.

3.4.2 Web-based front end and scripts

Data from Influx and Grafana could be accessed in several ways. The most common way is through the Grafana API as shown in the model in Fig. 31. In addition, data could also be accessed using a web-based front end to Grafana and through scripts and this is shown in Fig. 33. Examples of the Grafana web-based front end are shown in Fig. 13 and Fig. 14, where Fig. 14 illustrates the interface to select the desired time period that is of interest to the user. Users may also access Grafana and retrieve data through scripts. The web-based front end and scripts enhances the possibilities to retrieve data from Grafana and to customize the data that is retrieved. Similarly, users could also access data directly from Influx, through an API, e.g., developed using Python. This is relevant for researchers, who may require specific data sets for specific research activities, such as to run simulations or to create dashboards for a specific target group.

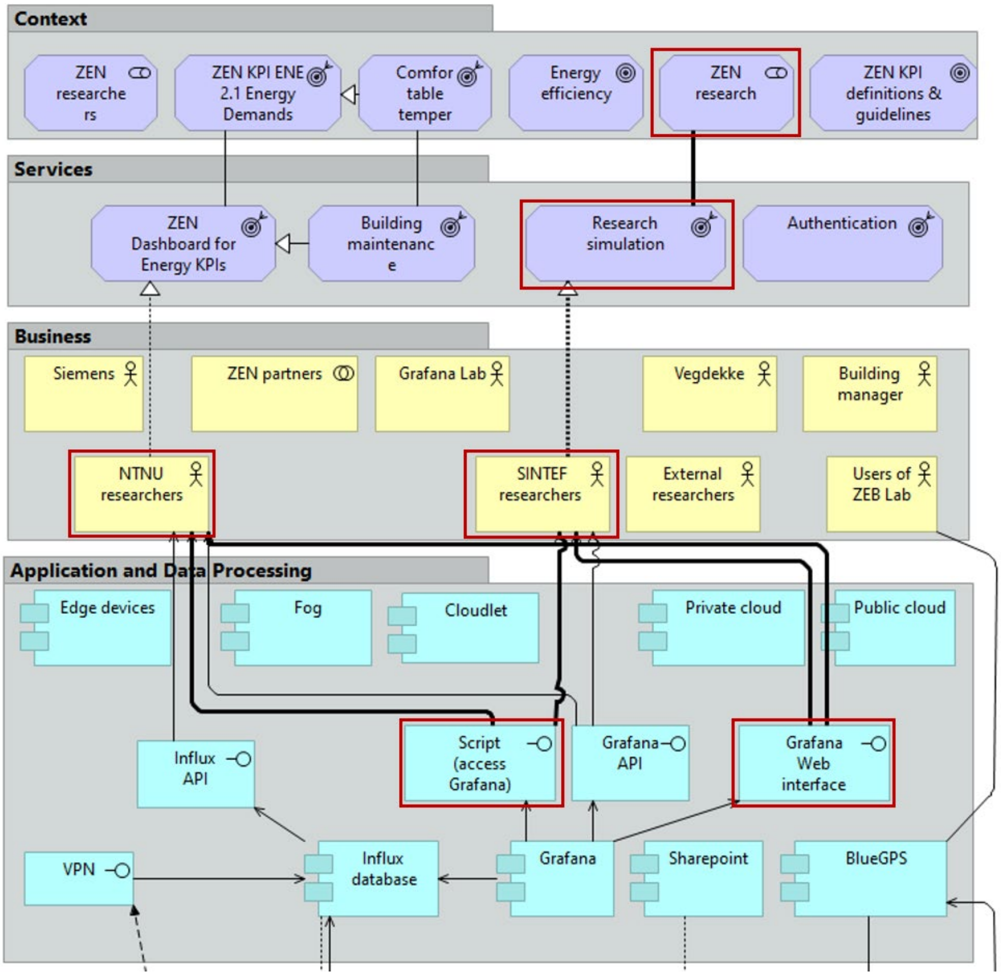

Figure 33 ZEB laboratory ICT ecosystem - Enterprise Architecture model, scenario: different ways to access Grafana. Relevant components are shown with a red rectangle and relevant relationships are shown as bold lines.

The Enterprise Architecture model in Fig. 33 shows the specific components relevant for accessing data through the web-based front end and scripts. The upper four layers are included in the figure as this is where additional components, e.g., "scripts" in the application layer or a new service such as "research simulation" may appear. The components in the lower layers, i.e., the data architecture, remains the same as for the other scenarios.

3.4.3 Back-end service and API

Another way to access data from the ZEB laboratory is by using an API and through the back-end services of Grafana and Influx. This is also useful when the data is available on a private cloud and not on a public cloud. When a user needs asynchronous access to data, or continuous access over time, it is possible to save the data to a buffer, which supports processing of the data in batches and ensures that there are no gaps in the data. The data can then be processed in many ways, depending on the needs of the stakeholders, e.g., to obtain the "power (Watts per hour)" as displayed on the ZEN ENE-ergy KPI related dashboards (e.g., as shown in Fig. 15).

3.4.4 Tailored data access – Campus Service

In some situations, a tailored and direct access is needed, e.g., the Campus Service at NTNU Gløshaugen campus, which gathers data from several buildings and visualizes energy consumption of all or several buildings within the campus. In such situations, the user is interested in accessing raw data from several buildings such as the ZEB laboratory and other buildings on campus. In this case, the Campus Service has its own gateway which access the BACnet gateway of the ZEB laboratory (in the technology layer) as well as the BACnet gateway of several other buildings, as shown in Fig. 34. The Campus Service then processes the data using their own applications.

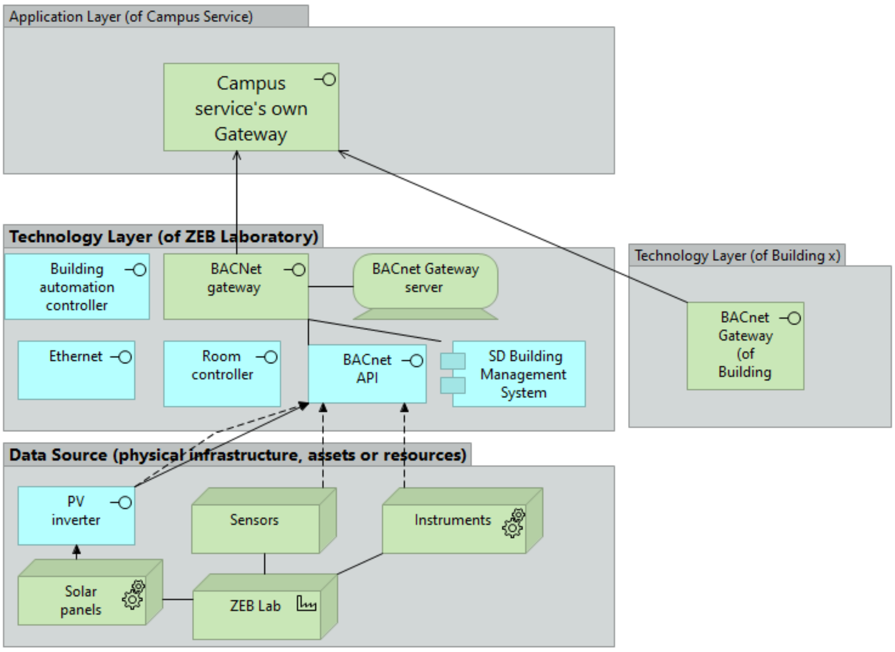

Figure 34 ZEB laboratory ICT ecosystem - Enterprise Architecture model, scenario: tailored and direct data access.

The model shown in Fig. 34 shows a part of the enterprise architecture of the ZEB laboratory, which is relevant for this situation, and since this report is about the data architecture in the ZEB laboratory. It is likely that other buildings on the campus that the Campus Service accesses data from may have similar components in their lower layers of the architecture, such as the BACnet gateway.

The Campus Service itself could also be represented using the seven layers of the architecture. What is perhaps of interest here are the upper layers of the Campus Service. The application layer is likely to include applications to process the raw from the different buildings, such as aggregate data and to visualize the data, and APIs. The business layer may include the different actors that are relevant from the different buildings or the data providers, and technology providers. The services could include dashboards to visualize energy consumption.

This case is particularly interesting from a zero-emission neighbourhood perspective as it looks at the data architecture within a neighbourhood and how data from several buildings is accessed, gathered, shared and processed for creating services.

3.4.5 External systems write data

There are several systems that gather and write data to the Influx database. For example, robots can be used to gather data about the indoor climate, or the availability of sunlight in the different positions in the building, or to check if windows are open or closed. Elhub, for instance might in other cases have relevant energy data (e.g., from other comparable buildings). Such systems use the MQTT or RESTful protocols to transfer data to the BACforsk system, or the BACforsk system picks up the data using MQTT from various devices and systems. The BACforsk system then writes the data to Influx. This is shown in Fig. 35, which shows the lower layers of the ZEB laboratory data architecture. The relevant components are shown with a red rectangle and bold connection lines.

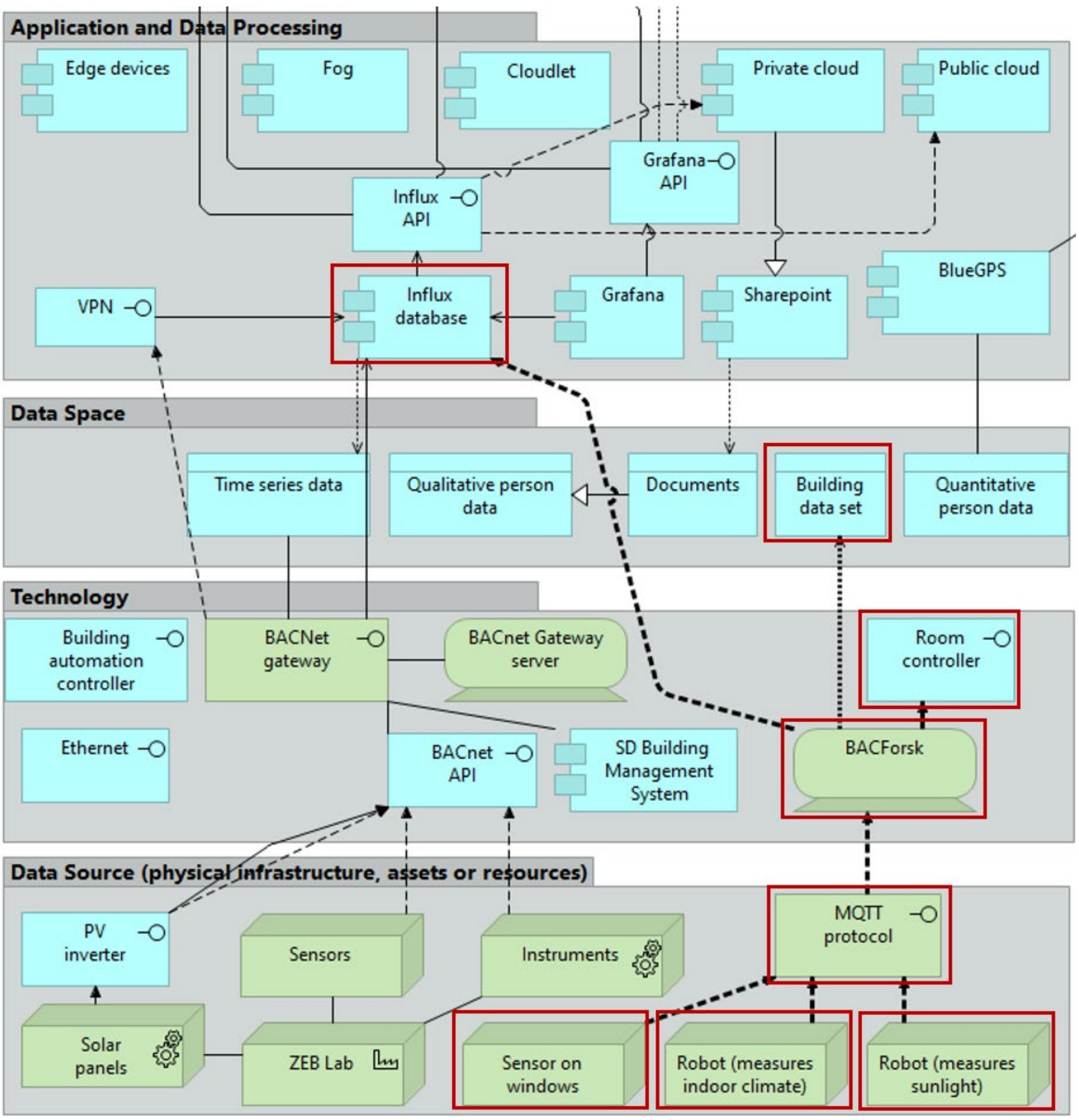

Figure 35 ZEB laboratory ICT ecosystem - Enterprise Architecture model, scenario: write data. Relevant components are shown with a red rectangle and relevant relationships are shown as bold lines.

BACforsk also communicates directly with the room controller, e.g., in situations when some adjustments need to be made, such as adjusting the ventilation in a room or a specific area. BACforsk is also able to access the building data set and make changes in it, such as adjust the “set point”, based on the updates data values gathered through the external systems.

4 Case ZEB Laboratory - Lessons learned.

4.1 Learnings for the further development of the ZEN ICT architecture

As expected, the original architecture was overly general, although the main levels (edge, fog, cloudlet, cloud) makes sense also in the case, even if there is no cloudlet-layer here since we have only data from one building and not a full-fledged neighbourhood. Data is captured, processed and made available at different levels, rather than all collected in a cloud to be made generally available for all, which is the general approach e.g. in EU data spaces and the smart building hub project.[3] The case is driven by the need for access to data on the current state, and to some design targets, but not a combination of current data and simulated data of the future, which could be relevant for a building manager.

On the other hand, aspects of service access and monitoring as illustrated in Fig. 6. and Fig. 7. is less complex in the case. We see in the Archimate models how one can combine the technical levels and business levels with flows (e.g., showing how some data can go straight from edge to cloud, other is going first to the fog). The movement of data (from real-time, to last recent, to historical) must be looked into in more detail. As observed from the Grafana-dashboards. the dividing line between last-recent and historical data is not clear-cut. One can also more clearly define boundaries of who owns / is responsible for the various parts of the infrastructure using Archimate.

One aspect not looked into in the case in detail is aspects related to the security infrastructure. Data as collected presently needed for following up the KPIs do not have privacy issues. Privacy issues can be linked to data for following up e.g., workplace quality (see below). Thus, introduction of a distinction between private and public cloud is warranted.

It was also noted that the current solution with Influx did not support the management of meta-data and there are plans to adopt a standardized meta data schema, such as BRICK. Just note here that there are many alternatives for most of the chosen technologies.

The parallel treatment of data and metadata is not dealt with in the original architecture and should be worked on further. Meta-data is both a traditional data-model and a data movement plan (what is done with the data from it is collected to it is used and visualized, and more subtle aspect on a different granularity level (e.g., that some apparatus is not working appropriately in a certain time-period)).
Given the large activity nationally and internationally on such ICT and data architecture, it is advised to coordinate further work on this with the SBHub-project, where both SINTEF and NTNU collaborate, with the ZEBlab as a case.

[3] https://www.sintef.no/prosjekter/2023/smart-building-hub/

4.2 Learning to take back to the KPI-work in ZEN.

Working with a single building has enabled the identification of several issues with the current description and coverage of the KPIs:

- The KPIs are described from the point of view of how to calculate possible future values (which is important in early phases), but not how to capture data on actual operation of the building or neighbourhood. This part should also be taken into account, as well as how to compare calculated/simulated and actual values, and the time-periods that are most useful to compare on. Also, merging of simulations of the future with history so far is interesting given that goals might be for energy production over a long period. E.g., a combination of Profet using Model predictive control based on actual usage, and simulation of future expected usage is probably of interest.
- One area missing completely is the living and working conditions of those using and living in the buildings. Partly such aspects are covered in standards, and adherence to these can be used to follow this up, but this should probably be complemented with both sensor data on air quality and subjective data from occupants of the building.
- The economic area is underdeveloped, and one could look at, e.g., how space is used to ensure return on investment and affordability of premises provided. This should be balanced with other criteria e.g., those on space-usage (URB-KPIs). KPIs for the ICT and data architecture are missing. This is relevant for ensuring a sustainable use of data and a sustainable ICT infrastructure. See section 2.2.3 for a start on this. From the point of view of sustainable ICT, one can use SUSAF [11] as an approach to find interesting data and KPIS for achieving sustainable ICT solutions. This includes also aspects of usability, privacy and security.
- The relationships between different existing KPIs should be better documented. In ZEN-report 44 it is basically provided by an undirected graph, not indicating the kind of relationship there are between the different criteria.

5 Conclusion and further work

The case is simple compared to the scope of ZEN since the focus has been on an individual building as part of a smart neighbourhood, and not a total neighbourhood. Given that, not all KPIs are relevant, thus the next step is to investigate this on an area level. Through energinet[4] one can access additional buildings at Gløshaugen. Still, starting small has given a good testbed providing relevant results both for the ICT Architecture and for the development of the KPIs themselves.

Next, we need additional feedback from those responsible for the different KPI-areas.

- How is it best to represent the different KPIs in a dashboard? A work on representing emission and other data for a building manager will be done spring 2024.
- How should one investigate the interactions between KPIs?
- How to capture missing areas as pointed to above?
- How to integrate illustrating design targets, historical data, and simulated future data?

For those needing a more holistic view e.g., from the different entrepreneurs and technology providers questions might be overlapping.

[4] https://www.energinet.net/building/id/53035

- How should one investigate and illustrate the interactions between KPIs?
- How to capture missing areas (if any)?
- How to integrate illustrating baselines/reference data, design targets, historical data, and simulated future data?

Similarly, researchers on different areas might want to have tailored views on the overall dataset.

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Appendix A: Glossary

- **Data persistence**: the longevity of data after the application that created it has been closed or the power to that device is off. In such a case, the data must be written to non-volatile storage, which is a type of memory that can retain that information long-term, even if the application is no longer running.
- **Enterprise Architecture**:
- **MQTT protocol** is a lightweight, publish-subscribe, machine to machine network protocol for message queue/message queuing service. It is designed for connections with remote locations that have devices with resource constraints or limited network bandwidth.

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