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Semi-Automated Generation of Metering Concepts and Energy Flow Diagrams for Technical Monitoring of Building Performance using Knowledge Graphs

Summary

A metering concept is an important preparatory step for implementing Technical Monitoring (TMon) of building performance, and is particularly relevant for energy management, as it defines which meters are required and where they are placed. It is often supported by energy flow diagrams drawn as single-line schematics, which provide an overview of the main components in the energy supply of a building and their connections. Based on these structural representations and the associated meter data, Sankey diagrams visualise the energy balance within defined system boundaries. This work proposes a knowledge graph-based workflow that uses a semantic representation of the systems to support the semi-automated generation of metering concepts and the generation of consistent energy flow diagrams and Sankey diagrams. The complete system topology is modelled as a semantic knowledge graph using an ontology built on ASHRAE Standard 223P and Brick Schema. Based on this semantic model, a rule-based graph interpretation approach identifies relevant system structures and allows semi-automated meter placement. The application case is a building energy system based on a water-source heat pump system with storage, distribution, and consumer groups. The resulting metering concepts are visualised as energy flow diagrams, while linked time-series data enable consistent energy aggregation and the generation of Sankey diagrams from the same underlying representation.

Keywords: Knowledge graphs, Semantic modelling, Metering concept, Energy flow diagram, Sankey diagram, Technical Monitoring

Field of application: Technical Monitoring, Building energy management, Digitalization, Energy-efficient non-residential buildings

1. Introduction

Technical Monitoring (TMon)of building performance is gaining importance in both public and private sectors, as it enables the systematic identification of faults and energy-saving potentials in building operation and can thereby improve energy efficiency, cost-effectiveness, functionality, and indoor comfort.

A prerequisite for implementing TMon is a metering concept that defines which meters and sensors are required and where they need to be placed in order to measure and balance energy flows across relevant system boundaries. In engineering practice, metering concepts are typically derived from technical system schematics and can be documented as energy flow diagrams that show the energy-related system structure together with meter locations.

However, deriving such metering concepts from system schematics is still largely a manual engineering task. It requires a detailed analysis of the system topology and substantial domain expertise to identify relevant energy flows, balancing boundaries, and suitable meter locations. As a result, creating and updating metering concepts requires considerable engineering effort, especially when systems are modified, extended, or when monitoring requirements change.

In addition, Sankey diagrams are widely used in monitoring and analysis to visualise energy flows and to identify losses and optimisation potentials within the system (Schmidt, 2008). Generating such diagrams therefore requires consistent aggregation of measured energy data. Maintaining this consistency manually across schematics, metering concepts, and monitoring data can become challenging in practice.

We propose a novel approach, that leverages knowledge graphs for the semantic representation of HVAC systems. Semantic models and ontologies such as Brick Schema (Balaji et al., 2016) and ASHRAE Standard 223P

(ASHRAE 223P, 2026) provide structured, machine-interpretable descriptions of building assets, topology, and data points. Knowledge graphs built on such models can act as a consistent system representation that links structure and measurement data and thereby support the digital representations of Technical Monitoring processes (Lygerakis et al., 2022).

Based on this semantic representation, this paper proposes a graph-based workflow to derive metering concepts directly from the system topology and to generate consistent energy flow diagrams and Sankey diagrams from the same underlying knowledge graph. The objective is to reduce manual engineering effort and to provide a consistent basis and semi-automated work flow for analysing energy flows and identifying optimisation potentials in real building energy systems.

2. Methodology

This section presents the proposed workflow of this paper for deriving metering concepts and generating Sankey diagrams from a semantic knowledge graph representation of the building energy system.

2.1 Semantic Modeling of the Building Energy System

The application case is a non-residential building energy system based on a water-source heat pump system with thermal storage, distribution, consumer groups. Starting from the available system schematic (Figure 1), the relevant system components, hydraulic and electrical connections, and balancing boundaries are implemented as RDF-based semantic graph instances by mapping them to ontology classes and relations, with the support of an AI-based application enabling the digitization and edition of plant schematics as well as a KG representation. The application supports the automatic detection of symbols in the schematic and their identification based on the corresponding legend entries of the same diagram by means of a self-supervised learning approach (Hain et al., 2026). The semantic model is built using the TBSys (Technical Building System) ontology which extends ASHRAE Standard 223P and Brick Schema with additional concepts (Gölzhäuser et al., 2025). The resulting knowledge graph represents the system structure together with the available monitoring information and forms the basis for the subsequent derivation of the metering concept.

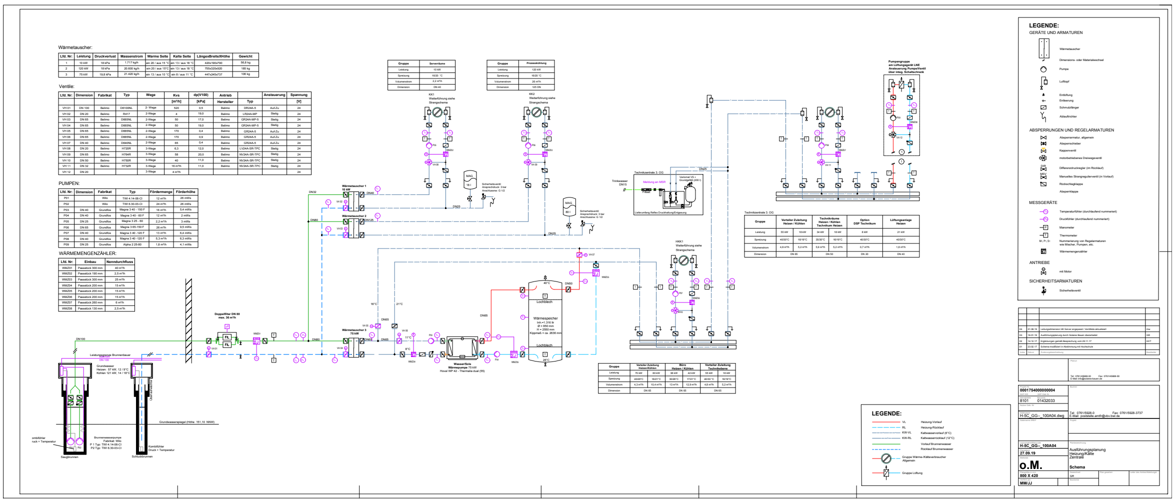


Fig. 1: Schematic of the investigated building energy system with a groundwater heat source, heat pump, and a thermal storage unit.

2.2 Derivation of an Energy Flow Diagram

From the semantic system model, an energy flow diagram is derived in the form of a single-line schematic that provides an overview of the main assets in the energy supply chain of a building, including energy generation, transformation, storage, distribution, and transfer to the zones.

For the energy flow diagram, a subgraph is extracted from the full knowledge graph. This subgraph contains only the entities and relations required for the energy flow diagram, namely components, connections, and balancing boundaries. A graph interpretation approach is proposed to semi-automate this extraction by querying the knowledge graph topology, selecting the relevant relations, and deriving the corresponding energy flow diagram. The minimum required entities for this representation are summarised in Table 1.

Tab. 1: Minimum entities required for deriving the energy flow diagram from the knowledge graph.

Entity	**Description**
Components	Physical equipment of the energy system (e.g., heat pump, storage).
Connections	Hydraulic or electrical connections defining the system topology.
System boundaries	Energy balancing boundaries between generation, storage, distribution, and consumption.

This energy flow diagram then serves as the basis for the subsequent derivation of the metering concept.

2.3 Derivation of the Metering Concept

A metering concept defines which meters are required and where they should be installed within an energy system. In the proposed workflow, meter placements are derived on top of the energy flow diagram representation stored in the knowledge graph.

Relevant system structures (e.g., hydraulic loops, motor-drive chains) are identified through graph queries (e.g., SPARQL) applied to the knowledge graph. Typical query patterns include the detection of hydraulic circuits, balancing boundary crossings, or connections between components. These structures represent potential locations where measurements may be required.

For each identified structure, predefined placement criteria are evaluated to determine whether a meter should be assigned. The placement criteria are defined based on expert knowledge and practical experience from industry and are formalised as explicit rules or constraints operating on the knowledge graph. Such criteria can include functional features, balancing boundaries, or technical parameters. For example, a heating circuit may be equipped with a heat meter if its nominal thermal power exceeds a defined threshold.

The resulting meter assignments are represented explicitly in the knowledge graph, thereby establishing a consistent linkage between system topology, meter placement, and the subsequent aggregation of measured values.

2.4 Data Binding of Measured Time-Series

Measured time-series data from physical meters are linked to the corresponding meter entities in the knowledge graph. A meter can be associated with one or more time series in the monitoring database, depending on the available measured variables. These links allow the workflow to retrieve the relevant energy values (E_i) for a defined period $[t_0, t_1]$. By associating these values with the corresponding graph entities, the semantic model provides the quantitative basis for energy balancing and Sankey diagram generation.

2.5 Generation of Sankey Diagrams

Based on the linked meter time-series, Sankey diagrams are generated by using the knowledge graph to map measured values to the corresponding energy flow relations in the system. The knowledge graph provides the structural information needed to identify which meters belong to which part of the system and how the measured values are assigned to the relevant energy flow paths and balancing boundaries.

For this purpose, the measured energy data linked to the meter entities are aggregated according to the corresponding system relations represented in the knowledge graph. In this way, the knowledge graph is used to connect meter values with the structural energy flow representation of the system and to derive the quantitative flows shown in the Sankey diagram.

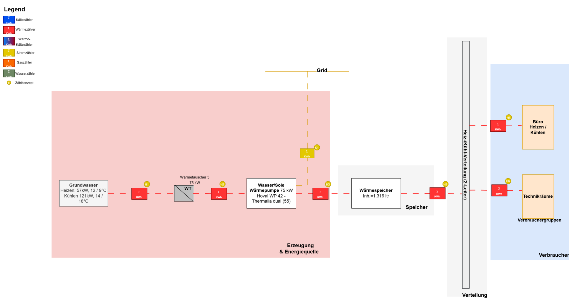
3. Results

Note: The results shown in this abstract illustrate the intended outputs of the proposed workflow and are based on manually created prototypes. A complete evaluation will be provided in the full paper and presentation, including the semantic building model, the semi-automated derivation of metering concepts, and the generation of energy flow diagrams and Sankey diagrams from the knowledge graph linked to measured meter time-series.

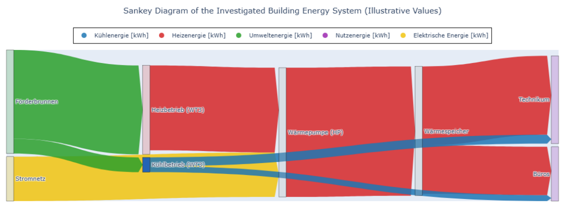
3.1 Metering Concept and Sankey Diagram (Illustrative)

Figure 2 shows the two target outputs addressed in this work. The metering concept provides a simplified structural representation of the building energy system and includes the main energy system components, hydraulic and electrical connections, meter locations, and the defined balancing boundaries. It illustrates the intended output of the proposed workflow for deriving a metering concept from the semantic system model.

The Sankey diagram is generated using illustrative values and represents two operating modes of the system (heating and cooling). It visualises the quantitative energy flows between the relevant system elements and illustrates the energy balance across the system. With measured data, this representation can support monitoring-oriented analysis, such as tracing energy paths and identifying losses or deviations.



(a) Metering concept (manually created illustration).



(b) Sankey diagram with illustrative values for heating and cooling modes (manual prototype).

Fig. 2: Prototype outputs corresponding to the proposed workflow.

4. References

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