Development and description of the SATO KPI Tool

Andersen, Kamilla Heimar; Melgaard, Simon Pommerencke; Marszal-Pomianowska, Anna; Jensen, Rasmus Lund; Fehr, Thomas; Heiselberg, Per

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

DEPARTMENT OF THE BUILT ENVIRONMENT
AALBORG UNIVERSITY

Development and description of the SATO KPI Tool

Kamilla Heimar Andersen
Simon Pommerencke Melgaard
Anna Marszal-Pomianowska
Rasmus Lund Jensen
Thomas Fehr
Per Kvols Heiselberg

ISSN 1901-726X
DCE Technical Report No. 302

Aalborg University
Department of the Built Environment
Division of Sustainability, Energy & Indoor Environment

DCE Technical Report No. 302

Development and description of the SATO KPI Tool

by

Kamilla Heimar Andersen
Simon Pommerencke Melgaard
Anna Marszal-Pomianowska
Rasmus Lund Jensen
Thomas Fehr
Per Kvols Heiselberg

January 2022

Scientific Publications at the Department of Civil Engineering

Technical Reports are published for timely dissemination of research results and scientific work carried out at the Department of the Built Environment (DCE) at Aalborg University. This medium allows publication of more detailed explanations and results than typically allowed in scientific journals.

Technical Memoranda are produced to enable the preliminary dissemination of scientific work by the personnel of the DCE where such release is deemed to be appropriate. Documents of this kind may be incomplete or temporary versions of papers—or part of continuing work. This should be kept in mind when references are given to publications of this kind.

Contract Reports are produced to report scientific work carried out under contract. Publications of this kind contain confidential matter and are reserved for the sponsors and the DCE. Therefore, Contract Reports are generally not available for public circulation.

Lecture Notes contain material produced by the lecturers at the DCE for educational purposes. This may be scientific notes, lecture books, example problems or manuals for laboratory work, or computer programs developed at the DCE.

Theses are monograms or collections of papers published to report the scientific work carried out at the DCE to obtain a degree as either PhD or Doctor of Technology. The thesis is publicly available after the defence of the degree. Since 2015, Aalborg University Press has published all Ph.D. dissertations in faculty series under the respective faculty. The AAU Ph.D.-portal will host the E-books, where you also find references to all PhDs dissertations published from Aalborg University.

Latest News is published to enable rapid communication of information about scientific work carried out at the DCE. This includes the status of research projects, developments in the laboratories, information about collaborative work and recent research results.

Published 2022 by
Aalborg University
Department of the Built Environment
Thomas Manns Vej 23
DK-9220 Aalborg E, Denmark

Printed in Aalborg at Aalborg University

ISSN 1901-726X
DCE Technical Report No. 302

Contents

Foreword

This document describes the development of the SATO KPI Tool in relation to the H2020 SATO Project.

The authors of this technical report is Kamilla Heimar Andersen, Simon Pommerencke Melgaard, Anna Marszal-Pomianowska, Rasmus Lund Jensen and Per K. Heiselberg (Department of the Built Environment, Aalborg University, Aalborg, Denmark)
Thomas Fehr (EK Energiekonzepte AG, Zürich, Switzerland, Thomas.fehr@fe-partner.com)

Several partners in the SATO consortium were involved in the discussions and contributions of developing the SATO KPI Tool.

The Sato Project

The Horizon2020 "SATO" (Self-Assessment Towards Optimization of Building Energy) project will implement a cloud-based platform that can perform self-assessment and optimize energy-consuming devices in a building. This platform will use an artificial intelligence approach combined with 3D BIM-based visualization to provide an accurate vision of the real-life energy performance of buildings and appliances. In this project, definitions of key performance indicators have gotten substantial attention as they play a prominent role towards the self-assessment and self-optimization platform. See more information about the project here: https://www.sato-project.eu/.

The authors gratefully acknowledge the support from the European Commission through the research project "Self-Assessment Towards Optimization of Building Energy" (SATO) Grant agreement number: 957128.

Third Parties

Description of the SATO KPI Tool

The SATO KPI tool aims to support the selection of relevant and available KPIs for all parts of a building (whole building, system, subsystem, and component-level) to be used for building assessment.

The SATO KPI Tool is an Excel (.xlsm) based tool with a frontend and a backend. The backend of the KPI Tool consists of two main tabs (Tab 1 and Tab 2) shown in Figure 1 and is not intended to be changed by the general user but to support the selection of KPIs in the frontend. Tab 1 describes the energy system terminology and the SATO KPI Tool user-manual, which describes the content and scope. Tab 2 concerns the Key Performance Indicators, Input for KPIs, Necessary measured variables, Data acquisition methods, Required time resolution.
The frontend consists of a "Parameter selection" tab (Tab 3) which supports the user in selecting desired KPIs for the chosen building system.
The purple color indicates the introduction, the energy system terminology which is used throughout the KPI Tool, and the user manual. The green color is the backend content, and the blue color is the frontend, which is the only tab the user needs to change.

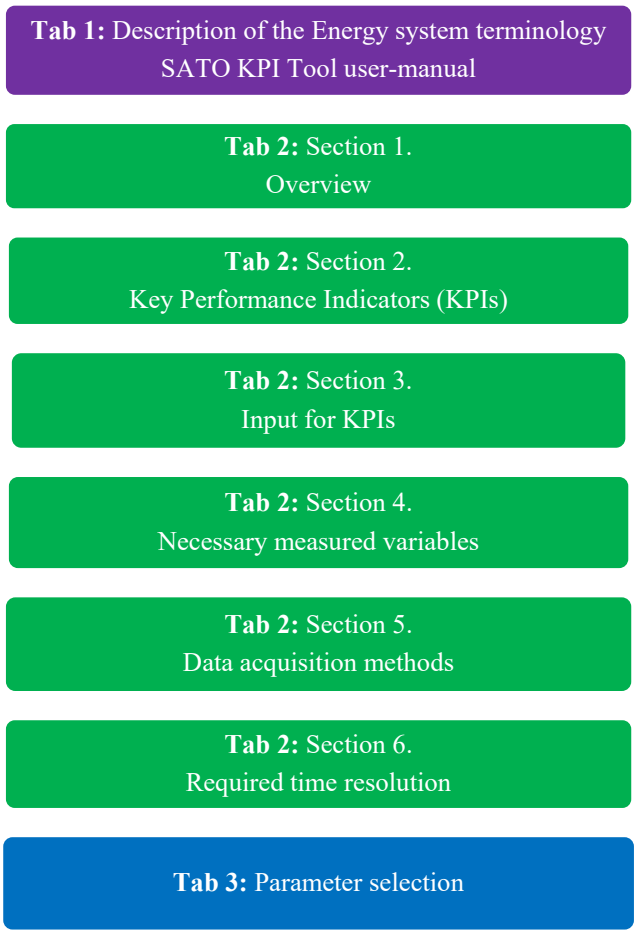

Figure 1: The SATO KPI Tool and the content of the different sections.

Energy system terminology

The overall background structure of the SATO KPI Tool is based on energy systems terminologies shown in Figure 2, energy grid, environmental energy (sources and sinks), energy conversion, energy distribution, energy storage, energy use, appliances, and building envelope. A short description of the energy system terminology is provided below.

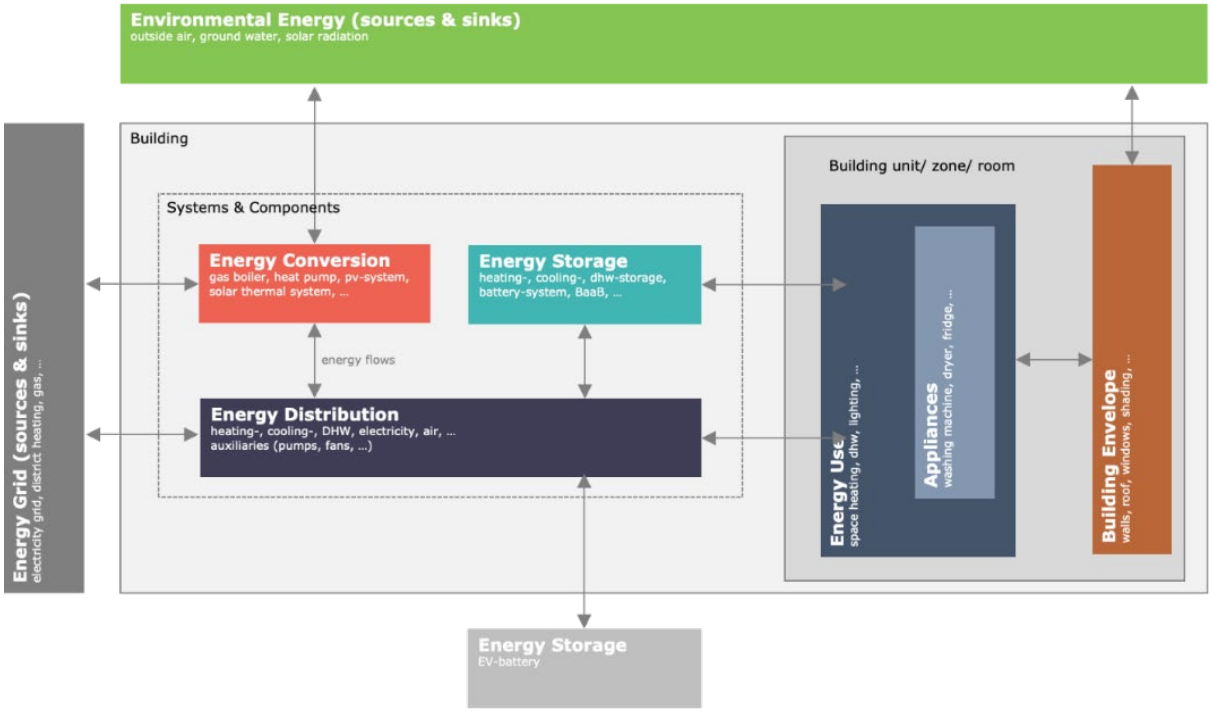

Figure 2: The SATO KPI Tool background – Energy system terminology.

Energy Grid (sources and sinks).
Defined as the exchange of energy between the building and different grids that need to be controlled to ensure that building demands are met while minimizing the stress on the grids and ensuring optimal use of renewable energy sources.

Energy Conversion.
Includes building systems converting energy from grids and environmental sources to meet building thermal and electric energy demands. Systems need to be controlled to ensure optimum efficiency while reducing losses and fulfilling building energy needs.

Environmental Energy (sources and sinks).
Defined as the exchange of energy between the building and the environment through the building envelope. Heat gains and heat losses need to be controlled to minimize the building energy demand. There will also be an exchange of energy between different building systems and the environment exploiting environmental sources and sinks to reduce the need for delivered energy.

Energy Distribution.
Includes building systems distributing heat, water, and fresh air within the building to different spaces according to their specific needs as well as exchanging energy with integrated energy storage as required for system optimization.

Energy Storage.
Includes thermal and electric storage integrated into a building as well as in electric vehicles. It needs to be controlled to ensure that building demands are met while minimizing the stress on the grids and ensuring optimal use of renewable energy sources. It can also be used to provide flexibility services to the electrical as well as the district heating and cooling grids.

Energy Use.
Includes building systems delivering heat, water, light, and fresh air to users in different spaces to ensure optimum indoor environmental quality.

Appliances.
Include different types of energy using service equipment to provide comfort and convenience.

Building Envelope.
Includes building systems that control the exchange of heat gain and losses with the environment.

Development of the Key Performance Indicators (KPIs)

One of the key points of the development of the SATO KPI Tool is the selection of the most valuable variables and performance indicators to be used for building, systems, and component assessment. The KPI development involved several experts with scientific and/or technical backgrounds. The aim was to avoid the selection of useless or too complex indicators and focus on those that are considered to be the most valuable and meaningful. The different KPIs are grouped according to their focus in the following categories: Building performance, Energy performance, Systems and Components, Building to Grid, Environmental impact, Smart readiness indicator, Cost performance, Indoor environment.

Backend content

The backend is developed based on the structure previously mentioned above (energy system terminology) and has its own description in Tab 1 and the user manual. Then, in Tab 2, section 1, the suitable and appropriate selection of KPIs based on system, subsystem, and components, necessary inputs for the KPIs are presented. In Tab 2, sections 2 to 5 concern the necessary measured variables, different data acquisition methods, and required time resolution for sensors.

The location of the different sections in Tab 2, can be seen in Figure 3.

Section 1. Overview: Section 1 consists of an overview of the different systems in the following categories: Energy distribution, Energy storage, Energy conversion, Energy use (+Appliances), Building envelope, EV charging station, Building control and monitoring system, Miscellaneous and Building(s).

Section 2. Key Performance Indicator (KPIs): Section 2 consists of the predefined key variables and indicators represented in the following categories: Building Performance (PB), Energy Performance (EP), Systems & Components (SC), Building2Grid (B2G), Environmental Impact (EI), Smart Readiness Indicator (SRI), Cost Performance (CP), and Indoor Environment (IE). Within each KPI category, specific KPIs are defined, such as total specific annual energy use, primarily delivered energy use, CO2 equivalent emissions, and so on. These specific KPIs are defined in the third row of Excel. Within Section 2, a cell marked with "x" indicates that the specific KPI can be calculated for the given system.

Section 3. Calculation of KPIs: Section 3 shows which measured variables are needed to calculate the KPI in section 2 for each system's overview in section 1. If an "x" is marked in a cell in section 2, the cell will appear white for the same combination of system and KPI in section 3. This indicates that the KPI will be calculated based on the following four identification model types shown in Table 1.

Table 1: Types of KPI calculations.

Type	Description
1	Based on measured time-series
2	Based on filtered measured time-series
3	Based on dynamic in-situ testing where building controls are modified to find the desired parameter
4	Based on data-driven methods (grey box, ML, etc.)

An example of a measured variable and how the KPI will be calculated/measured/analyzed can be seen in Figure 4.

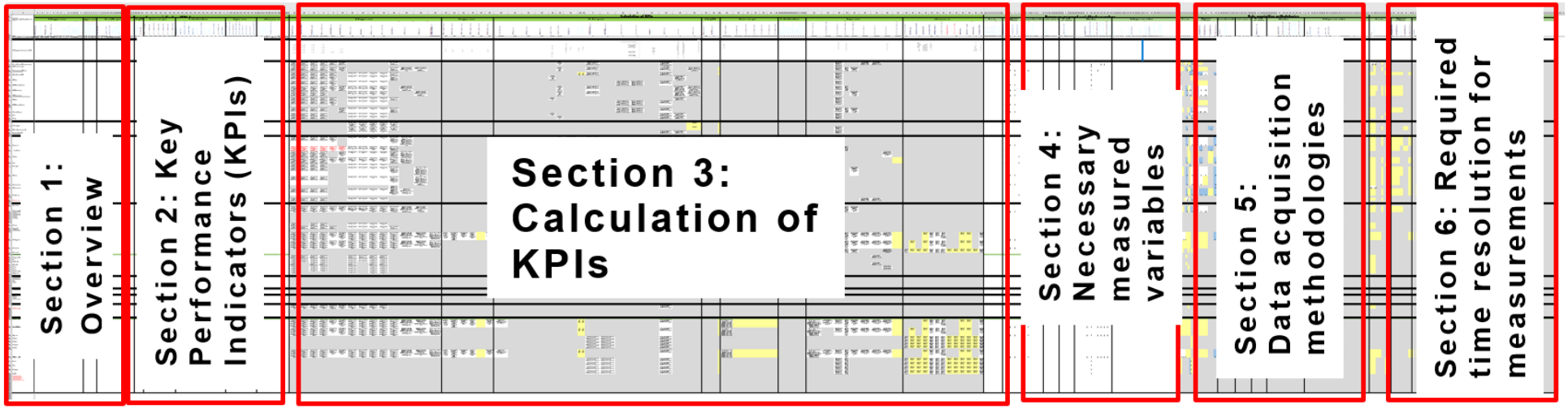

Figure 3: KPI Tool content, and where the various sections are located in the KPI Tool (snip from the .xlsm file), Tab 2.

As one can see in the figure below, the unit "Fan coil/local heating and/or cooling unit in the terminal box" can be calculated with type 1: (energy use (el) OR energy use (DH) AND (DC)) AND surface and/or floor area. This means that the "Fan coil/local heating and/or cooling unit in the terminal box" can either be driven by electrical energy OR district heating/cooling. In addition, the surface and/or floor area is also needed to normalize the result.

	Total annual spesific energy use	Seasonal avg spesific energy use? (4 seasons, averaged over 3 months)
Unit	kWh/m2 per year	kWh/m2
Energy use		
Terminal unit		
Fan coil/local heating and/or cooling unit in terminal box	Type 1: (Energy use (el) OR (Energy use (dh) AND Energy use (dc))) AND Surface and/or floor area	Type 2: (Energy use (el) OR (Energy use (dh) AND Energy use (dc))) AND Surface and/or floor area

Figure 4: Snip from KPI Tool. Example on how to calculate the KPIs, in this example Fan coil for total annual specific energy use.

Section 4. Necessary measured variables: Section 4 contains the necessary variables for each area/system. It consists of the following categories: Smart meter, Appliance temperatures, Outdoor weather condition, Room/zone measurements, System and component performance, Grid and utilities, and Building information/metadata. The number in each cell below the variables, which is automatically generated, indicates how many times it is used in KPIs. This is to give an overview of how many KPIs are affected by each variable. An example of this can be seen in Figure 5 below for selecting variables.

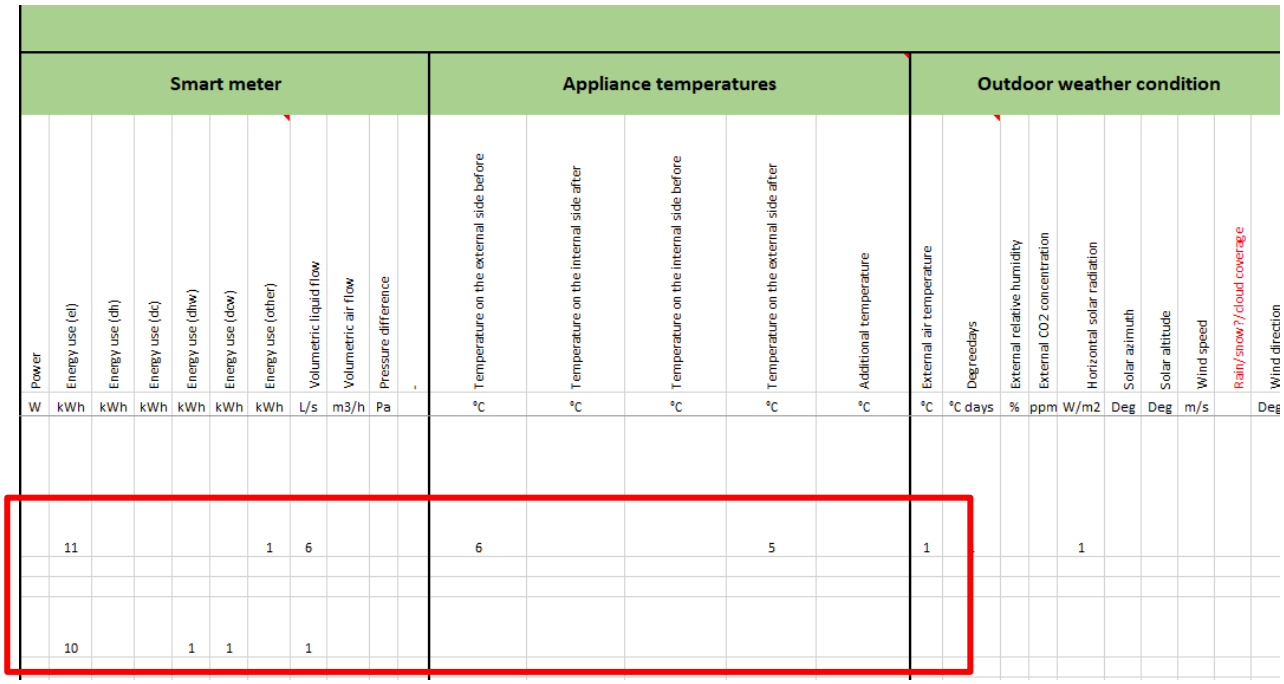

Figure 5: Snip from Section 4. The numbers in the cells indicated how many KPI/system combinations it is sampled in total.

Section 5. Data acquisition methods: Section 5 is the Data acquisition methodologies and is based on/refers to section 4 (Necessary measured variables). However, here each cell is defined with the following letters and their description of the acquisition of the data shown in Table 2:

Table 2: Data acquisition methods, abbreviations, and descriptions.

Abbreviation	Description
S	Sensor
VS	Virtual sensor (same resolution as a sensor, but calculated from other measurements)
ES	External sensor (measured by a sensor not located in the unit/area)
M	Metadata (acquired from producer/design team, etc.)
CAL	Calculated (lower resolution than the sensor, but calculated from other measurements)

Data acquisition methodology and color example can be seen in Table 3 and in Figure 6 below.

Table 3: Data acquisition and color representation.

Colour	Description
Grey	Not required for analysis of KPI
Light yellow	Required for analysis of KPI, but missing a value in the field
White	Required for analysis of KPI and filled in
Light blue	Not required for analysis of the defined KPI, but the value is filled in (indicates sensors, which are expected to be used in the future)

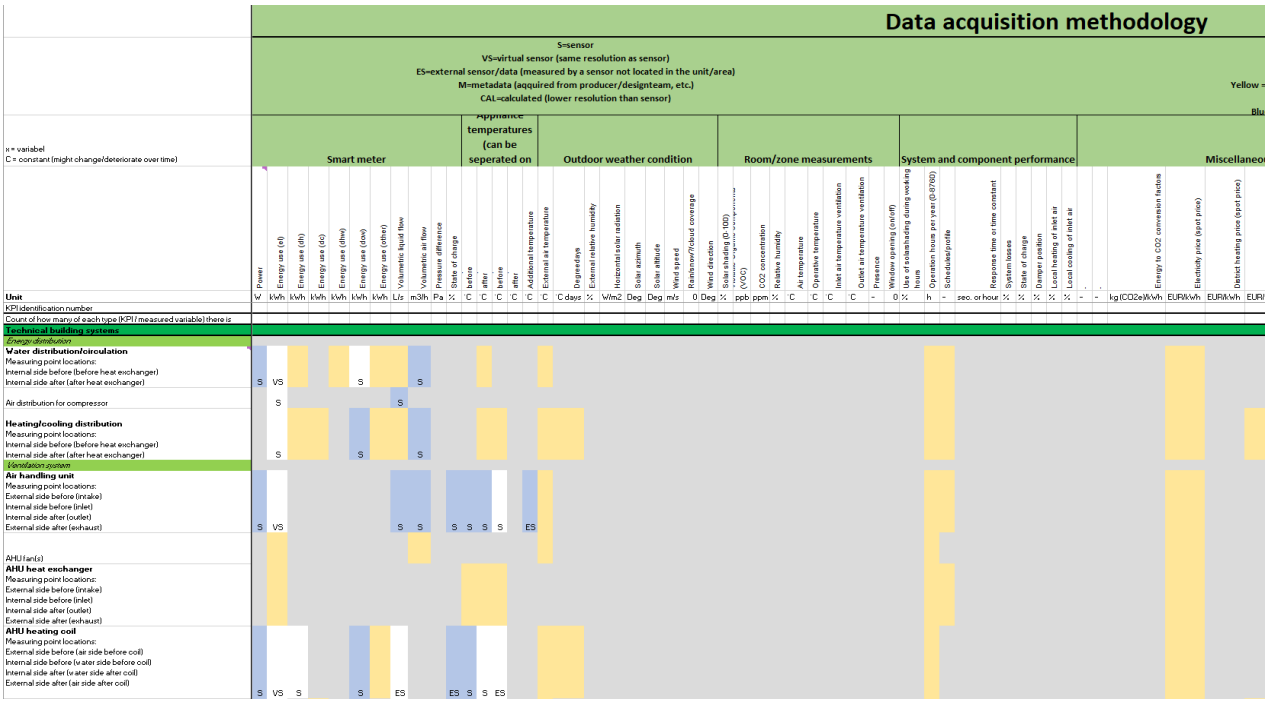

Figure 6: Section 5, snip from KPI Tool. Data acquisition methodology and color.

Section 6. Required time resolution: Lastly, section 6 is the Required time resolution for data, and this section also refers back to section 4 (Necessary measured variables). Here, each cell is filled with two values: An X and a Y, which is the preferred and acceptable time resolution based on what we want to measure. The format is written as X/Y and uses minutes as the unit for both. A snip from the SATO KPI Tool can be seen in Figure 7 below.

Figure 7: Section 6, snip from the SATO KPI Tool.

Frontend content

The frontend consists of a separate tab (Tab 3) with three dropdown menus for a fast and easy overview of:

1. See KPIs and measured variables within the chosen category and system, subsystem or component.
Step 1: Choose energy system terminology (EST) category: *Can choose between the energy system terminologies categories*
Step 2: Choose the building system connected to the EST category: *Can choose between all building systems contained in the EST category*
Output: KPIs for the chosen system and necessary measured variables for the chosen system based on the KPIs

2. See the systems that contain the chosen KPI based on the KPI category and KPI.
Step 1: Choose the KPI category
Step 2: Choose KPI based on the KPI category
Output: *Will view the building systems that contain the chosen KPI regardless of EST*

3. View the systems and methods for the chosen measured variable
Step 1: Choose the measured variable category
Step 2: Choose the measured variable
Output: Will show the systems that contain the chosen measured variable, how many times it appears, the data acquisition method, and time resolution (per minute)

Figure 8 shows a snip of the selection in numbers 1), 2) and 3) above.

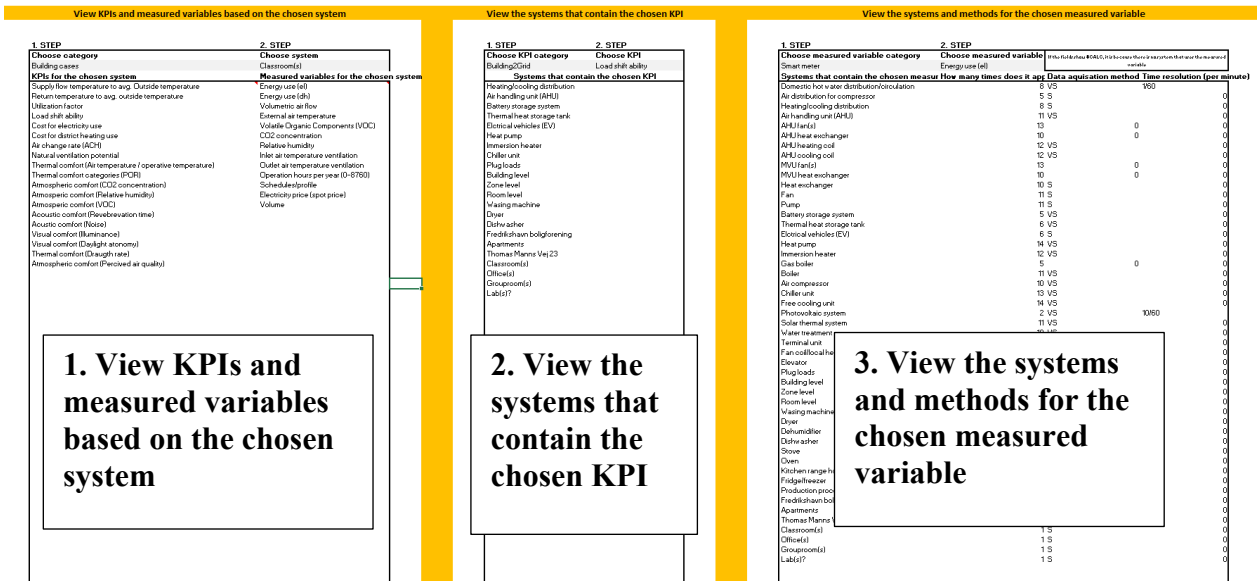

Figure 8: Parameter selection tab. Sort and filter KPIs based on systems, categories, necessary measured variables, and data acquisition method.

KPI algorithms

Once the KPI has been chosen, and all the data found, the algorithm is found in the additional tabs, such as Building Performance (PB), Energy Performance (EP), Systems & Components (SC), Building2Grid (B2G), Environmental Impact (EI), Smart Readiness Indicator (SRI), Cost Performance (CP), and Indoor Environment (IE), as these describe the various KPI categories, equations, units, meaning/definition, and references.

KPI list

Table 4 below shows the complete list of KPIs.

Table 4: Complete KPI list in the SATO KPI Tool.

KPI category	KPI
Indoor environment	Thermal comfort (Air temperature / operative temperature within each comfort categories)
Indoor environment	Visual comfort (Daylight autonomy)
Indoor environment	Air change rate (ACH)
Indoor environment	Natural ventilation potential
Indoor environment	Thermal comfort categories (POR)
Indoor environment	Atmospheric comfort (CO2 concentration)
Indoor environment	Atmospheric comfort (Relative humidity)
Indoor environment	Atmospheric comfort (VOC)
Indoor environment	Acoustic comfort (Reverberation time)
Indoor environment	Acoustic comfort (Noise)
Indoor environment	Visual comfort (Illuminance)
Indoor environment	Thermal comfort (Draught rate)
Indoor environment	Atmospheric comfort (Perceived air quality)
Cost performance	Total cost of energy use
Cost performance	Income (electricity to grid)
Cost performance	Cost for electricity use
Cost performance	Cost for district heating use
Cost performance	Cost for district cooling use
Cost performance	Cost for DHW use
Cost performance	Cost for DCW use
Cost performance	Cost for gas use
Cost performance	Cost for other energy use
Environmental impact	Total CO2e emissions
Environmental impact	CO2 emissions (el)
Environmental impact	CO2 emissions (dh/dc)
Environmental impact	CO2 emissions (dhw)
Environmental impact	CO2 emissions (dcw)
Environmental impact	CO2 emissions (other)
Building2Grid	Local production to grid
Building2Grid	Self-consumption of renewables
Building2Grid	Load shift ability
Systems and components	Specific yield (solar)

Systems and components	Annual produced energy
Systems and components	Monthly produced energy
Systems and components	Daily produced energy
Systems and components	Specific Fan Power
Systems and components	Specific Pump Power
Systems and components	Coefficient Of Performance
Systems and components	Seasonal Energy Efficient Ratio (cooling)
Systems and components	Seasonal Coefficient of Performance (heating)
Systems and components	Supply flow temperature to avg. Outside temperature
Systems and components	Return temperature to avg. outside temperature
Systems and components	Cooling recovery rate
Systems and components	Heat recovery rate
Systems and components	Ventilation effectiveness
Systems and components	Utilization factor
Systems and components	Load factor
Systems and components	Efficiency factor
Energy performance	Primary delivered energy (el)
Energy performance	Primary delivered energy (dh/dc)
Energy performance	Primary delivered energy (dhw)
Energy performance	Primary delivered energy (dcw)
Energy performance	Primary delivered energy (total)
Energy performance	Non-renewable primary energy delivered (total)
Building performance	Total annual specific energy use
Building performance	Seasonal avg specific energy use? (4 seasons, averaged over 3 months)
Building performance	Monthly avg specific energy use
Building performance	Daily avg specific energy use
Building performance	Deepest winter energy use (electricity)
Building performance	Deepest winter energy use (thermal)
Building performance	Annual max peak power
Building performance	Seasonal avg peak power
Building performance	Monthly max peak power
Building performance	Daily max peak power
Building performance	Energy signature curve (ESC)
Building performance	Heating signature curve (HSC)
Building performance	Cooling signature curve (CSC)
Building performance	Heating coefficient (Yearly energy use for heating/heating degree hours)
Smart readiness indicator	Heating Smart Readiness Score
Smart readiness indicator	Cooling Smart Readiness Score
Smart readiness indicator	Domestic Hot Water Smart Readiness Score
Smart readiness indicator	Controlled Ventilation Smart Readiness Score
Smart readiness indicator	Lighting Smart Readiness Score
Smart readiness indicator	Dynamic Building Envelope Smart Readiness Score
Smart readiness indicator	Electricity Smart Readiness Score
Smart readiness indicator	Electric Vehicle Charging Smart Readiness Score
Smart readiness indicator	Monitoring and Control Smart Readiness Score

Smart readiness indicator	Criteria Smart Readiness Score
Smart readiness indicator	Smart Readiness Score
Smart readiness indicator	Smart Readiness Indicator

Recent publications in the DCE Technical Report Series