

Energy monitoring – calculation

Application note

2 June 2022	SN-206 rev. 5.0
-------------	-----------------

SILVAIR

LEGAL NOTICE DISCLAIMER

This document and the contents of all materials available from this document (the “Content”) are subject to copyright (including patent protection) by SILVAIR, unless otherwise indicated. Copyright is not claimed as to any part of the intellectual property owned by Bluetooth SIG, Inc. Product names and markings noted herein may be trademarks of their respective owners. Accordingly, the Content may not be republished in any way without the prior written consent of SILVAIR. In doing so, you may not remove or alter, or cause to be removed or altered, any copyright, trademark, trade name, service mark, or any other proprietary notice or legend appearing on any of the Content. Modification or use of the Content except as expressly provided herein violates SILVAIR’s intellectual property rights. Neither title nor intellectual property rights are transferred to you by access to this document.

The information provided in this document is provided “AS-IS” and SILVAIR specifically disclaims any and all express, implied or statutory warranties, including the implied warranties of fitness for a particular purpose, and of merchantability and against infringement. No person is authorized to make any warranty or representation on behalf of SILVAIR concerning the performance of the described services or information. The user of the document assumes all responsibility and liability for proper and safe handling of the goods and services. Further, the user indemnifies SILVAIR from all claims arising from the handling or use of the goods and services. It is the user’s responsibility to take any and all appropriate precautions with regard to electrostatic discharge and any other technical or legal concerns. Users handling electrostatic discharge installation must have appropriate electronics training and observe good standards of engineering practice. Except as expressly indicated in writing, SILVAIR services are not designed for use in medical, life-saving, or life-sustaining applications or for any other application in which the failure of the SILVAIR service could result in personal injury or death. The information contained in this document may not be used contrary to applicable law or any purpose other than specified in the document i.e. for a lighting control solution.

Unless otherwise specified in the writing, to the maximum extent permitted by applicable law. SILVAIR SHALL NOT BE RESPONSIBLE OR LIABLE TO ANYBODY FOR ANY DIRECT or INDIRECT, SPECIAL, INCIDENTAL, PUNITIVE, OR CONSEQUENTIAL DAMAGES, INCLUDING, BUT NOT LIMITED TO, LOSS OF REVENUES, LOSS OF PROFITS OR LOSS OR INACCURACY OF DATA, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, OR INCURRED IN USING THIS DOCUMENT OR SILVAIR’S SERVICES AND/OR PRODUCTS. SILVAIR’S CUMULATIVE LIABILITY FOR ANY AND ALL DAMAGES IS LIMITED TO THE AMOUNTS PAID TO SILVAIR BY THE USER IN THE LAST 12 (TWELVE) MONTHS FOR THE PARTICULAR PRODUCTS AND/OR SERVICES WITH RESPECT TO WHICH A CLAIM IS MADE. SILVAIR HAS AGREED WITH THE USER THAT THESE LIMITATIONS WILL SURVIVE AND APPLY EVEN IF ANY LIMITED REMEDY SPECIFIED IN THIS AGREEMENT IS FOUND TO HAVE FAILED OF ITS ESSENTIAL PURPOSE.

The parameters provided in this document may vary over time. All operating parameters, including typical parameters, must be validated by each customer’s technical experts.

Except as expressly indicated in writing, no license, express or implied, to any intellectual property rights is granted by this document or by any conduct of SILVAIR.

The document and information provided in this document is proprietary to SILVAIR, and unless otherwise indicated in writing, SILVAIR reserves the right to make any changes to the information in this document or to any products and services at any time without notice.

The document as well as the rights and obligations of SILVAIR and of the user of the documentation and/or SILVAIR’S services hereunder shall be governed by Polish regulations. The user of the document and SILVAIR

agree to submit to the exclusive jurisdiction of, and venue in, the courts of Krakow, in any dispute arising out of or relating to this agreement. The application of the “United Nations Convention on Contracts for the International Sale of Goods” is hereby excluded. All required or permitted notices to Silvair under this document will be made in writing, make reference to this document, and be delivered by hand, or dispatched by prepaid air courier or by registered or certified airmail, postage prepaid, addressed as follows:

SILVAIR Sp. z o.o.
ul. Jasnogórska 44
31-358 Kraków
Poland

Table of contents

1. Energy calculation	4
1.1 Calculation methodology	4
1.2 Requirements	5
1.3 Creating an energy profile	5
1.4 Elements of energy use report	8
1.5 Retention of energy use data	8
2. Energy calculation accuracy	9
2.1 Gross errors	9
2.2 Estimation errors	9
2.3 Missing data	11
2.4 Conclusions	12
4. Frequently asked questions	13
5. Document revisions	14
Contact information	15

1. Energy calculation

The energy monitoring service allows the energy use of luminaires in a zone to be visualized in the Silvair web app or downloaded via API.

Energy use is calculated based on the light level of a luminaire and its energy profile. The energy profile is created manually for each type of luminaire by measuring the power in watts (W) for several light levels and entering it into the Silvair web app. The calculation assumes that all luminaires in a zone are of the same type.

Example:

I have 20 luminaires of the same type in a zone. They have the same energy profile. Using the Energy Monitoring service, I can see how much energy is used in that zone in a specific period.

By opening the Energy use tab in the [Silvair web app](#), I can select a given month and see how much energy was used over that period.

1.1 Calculation methodology

The gateway monitors the light output of each luminaire in a zone using the Light Lightness Actual (*LLA*) state value. Devices send the *LLA* state every 60 seconds and after any change in light output, and the data is stored in the cloud. The data is then collected every 15 minutes for each device.

The monitored Light Lightness Actual is converted to Light Lightness Linear (*LLL*) according to the formula

defined in the mesh specification: $LLL = \frac{LLA^2}{65535}$. The Light Lightness Linear state is proportional to power (*P*).

Calculating the energy use *En* requires knowing the linear relationship between the power and the light output (described in [Creating an energy profile](#) section). The energy use is calculated for every minute using the power from the user-defined energy profile and according to the formula that follows. If the power for a light output is not defined, the two nearest points on the energy profile (above and below) are taken. Then, the average energy use over one minute is calculated.

$$En = P \cdot t$$

$$\text{where: } t = 1 \text{ [min] and } P = \frac{(LLL - LLL_B)}{(LLL_A - LLL_B)} \cdot (P_A - P_B) + P_B \text{ [W]}$$

where: LLL_A – closest defined *LLL* value above on the energy profile

LLL_B – closest defined *LLL* value below on the energy profile

P_A – power defined for LLL_A

P_B – power defined for LLL_B

The completeness rate is the ratio of data sent to data received, expressed as a percentage. Because the gateway cannot detect if messages about a change in light output were lost, the completeness rate is calculated based only on the periodic *LLA* state per device that is sent every minute. This means that in a zone with five devices, the gateway needs to receive at least five *LLA* state messages (one per device) every minute to achieve a 100% completeness rate.

Additional assumptions:

- Energy use of a device is calculated as the sum of the average energy use during each minute over a 15-minute collection period.
- The gateway must receive data for at least one 15-minute period to calculate the energy use and completeness rate.
- Gaps in data (minutes for which the *LLA* data is not received) are filled using an interpolation method.
- Energy use for a zone is calculated as the sum of energy use of all devices in the zone at that time.
- Energy use for an area is calculated as the sum of energy use of all zones in the area at that time.


1.2 Requirements


For the service to work correctly for a project, the following are necessary:

- **The project contains at least one zone into which at least one device has been added.**
- **A Silvair gateway has been added to the project.**
- **All devices in the zone are of the same type, that is, they have the same energy profile.**
Energy monitoring is not able to distinguish between devices with different energy profiles in a zone.
- **All devices in the zone have a constant power for each light output.**
We do not support energy monitoring of tunable white luminaires.
- **The energy profile has been set up in the Silvair web app.**
Use a power meter to measure the power in watts (W) for a given light level.

1.3 Creating an energy profile


Before you start, see [Energy monitoring requirements](#).

 Only one energy profile can be used for a zone at a time.

 If you have devices of two types in one space, for example different fixtures, we recommend that you create two separate zones (each for one device type). Then, add two energy profiles and link the two zones (for lighting control).

For more information about how to create and link zones, see *SN-200 Silvair Commissioning user manual*.

Silvair web app

1. In the [Silvair web app](#), open a project and then an area.
2. On the **Commissioning** tab, right-click the zone where you want to measure energy use. Then, select **Edit** and go to the **Energy use** tab (fig. 1a).
3. Expand the **New fixtures** list, and select **Create a new fixture type** (fig. 1a), or select a new type of the fixture that is being installed in the zone and click .
4. A side pane will appear to set up the energy profile for the fixture (fig. 1b).

(a)

(b)

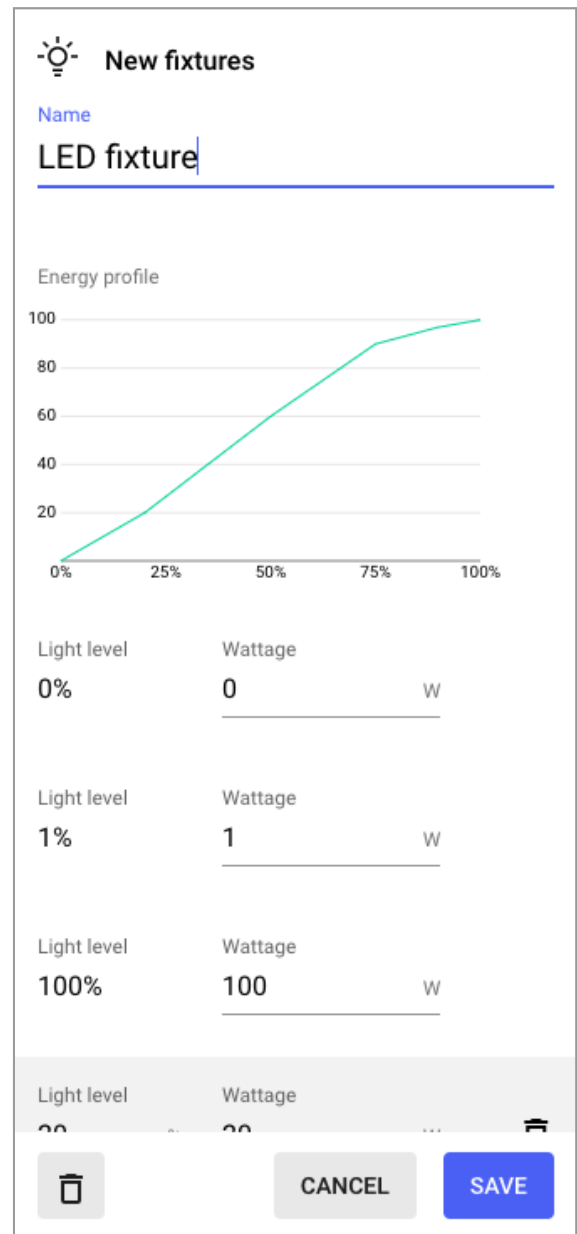
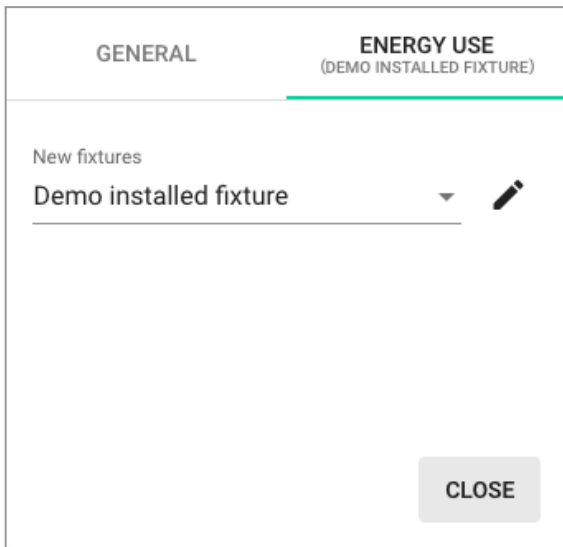





Fig. 1. Energy use tab (a); new energy profile set up (b)

5. In the **Name** field, enter the name for the energy profile. The profile will be available for all zones in the project.
6. For each **Light level**, measure the power in watts (W) of the fixture.
7. Enter the measured power in the **Wattage** fields for the light levels of 0%, 1%, and 100%.

 For more information about how to set the light level and measure power of luminaires, see *SN-207 Energy monitoring – energy profiles*.


 When you enter the values in the **Wattage** fields, make sure that the units are correct. Convert the values to watts (W) if necessary.

8. To add more light levels, click **Add reference point**. Enter the required light level as a percentage (for example 20%, 50%, or 90%). Then, enter the power for that light level in the **Wattage** field.

 The more levels you add, the more accurate the energy calculation will be. We recommend that you add more levels near 0% and 100% to increase the accuracy of the calculation.

9. When all the light levels are added, click **Save**.

The energy profile is automatically added to the zone. You can edit or remove the profile at any time. You can also use the profile in other zones in the project.

 Energy use is always calculated based on the profile currently assigned, not backward. If the energy profile is edited (for example, a light level is added or changed), the new parameters will only be applied in the energy calculations after the changes are saved.

1.4 Elements of energy use report

To view the energy use report, open the [Silvair web app](#). Then, open your project and area, and click the **Energy use** tab (fig. 2).

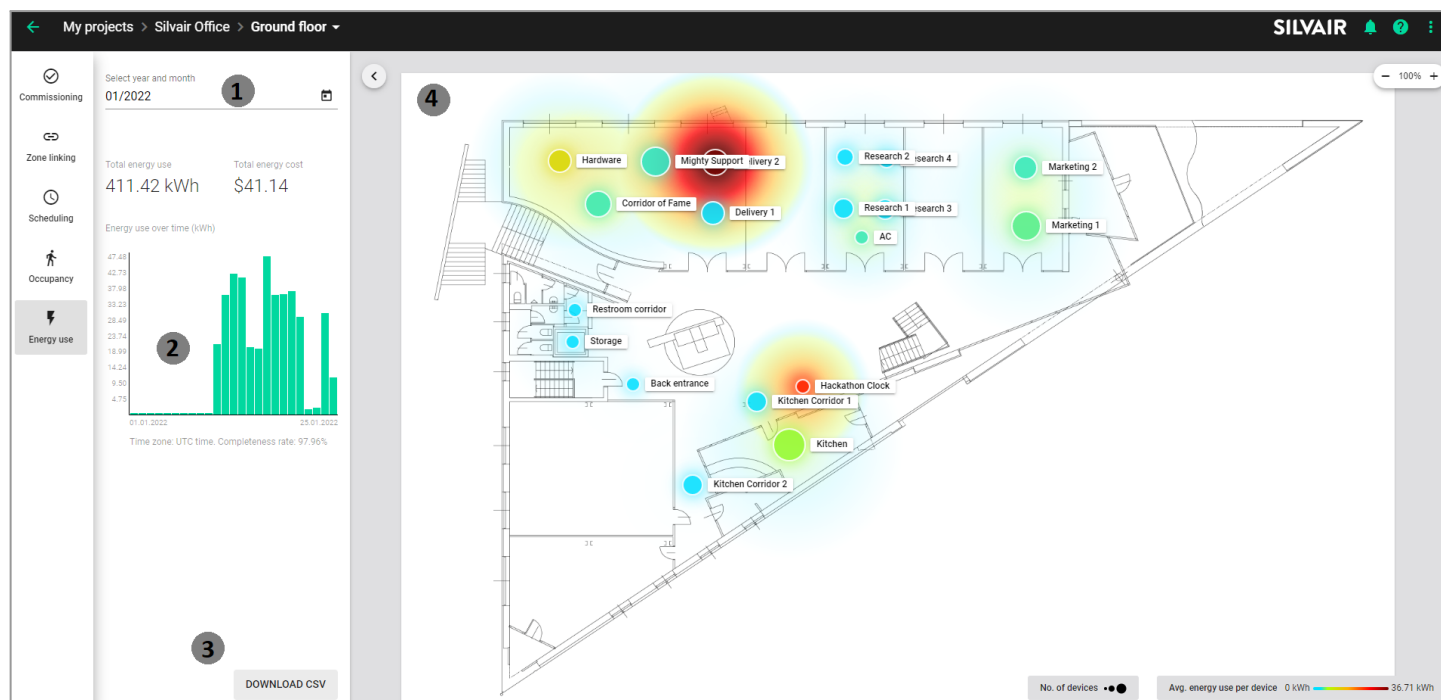


Fig. 2. Energy use report in the Silvair web app

1. Date picker – date range of your energy use report.
2. Bar chart – shows energy use (kWh) for the selected time period in the area.
3. Download button – downloads the data as a CSV file that contains 15-minute parts for each node in the project over the selected month. For large installations, downloading can take some time.
4. Heatmap – shows energy use for the selected time period in the area.



To see the number of devices, average energy use per device, and total energy use per zone, move the cursor over the zone icon.

1.5 Retention of energy use data

Energy monitoring data is stored by Silvair and available via:

- Energy use report in the [Silvair web app](#).
- Energy monitoring API at <https://api.platform-prod.silvair.com/docs/public/>.

The energy data is collected and stored per luminaire, per zone, and per area for a maximum of two years, as 15-minute parts.

2. Energy calculation accuracy

Potential sources of error in the calculation are as follows.

- Energy profile is incorrectly defined (gross errors).
- Too few light levels added to the energy profile (estimation errors).
- Random data loss and longer-period data loss (missing data).

They are discussed in the following sections.

2.1 Gross errors

Incorrect units are entered

Light levels were defined incorrectly for the energy profile. It is easy to notice when only one level is incorrectly defined, because you can see it in the profile chart. But it is much more difficult to notice an error when all the light levels are given in different units. For example, the power meter shows milliwatts (mW), but the values are entered as if they were watts (W). Such an error made in one energy profile can distort the calculation of total energy use in the whole project.

Devices in a zone are not of the same type

We assume one energy profile per zone, so if there are different types of devices installed in a zone, the energy profile will not reflect the actual energy use for some of them. As a result, the energy calculated for the zone will not be accurate. We recommend that you divide such a zone into smaller zones of one type of device and use zone linking.

2.2 Estimation errors

The energy use is calculated based on an interpolation between the two nearest points (above and below) on the energy profile entered in the web app.

Errors in estimated energy in the light level range where the relationship between power and light level is linear can result only from the accuracy of the driver output (example 1). For typical drivers this can be a few percent.

At light levels near 0% and 100% where the relationship between power and light level is not linear, errors in calculated energy can increase. These increased errors result from errors in power estimated for light levels that were not added to the energy profile (example 2).

Example 1:

We have an energy profile with some light levels and their related power. For a light level of 42% that is not added to the energy profile (fig. 1b), the energy use will be calculated based on power for light levels of 20% and 50%.

Light level	Power	Power estimated for a light level of 42% (LLL_{42})
0%	0 W	$P_{42} = \frac{(LLL_{42} - LLL_{20})}{(LLL_{50} - LLL_{20})} \cdot (P_{50} - P_{20}) + P_{20} =$ $= \frac{(42 - 20)}{(50 - 20)} \cdot (40 - 10) + 10 = \frac{22}{30} \cdot 30 + 10 = 32 \text{ [W]}$
1%	2 W	
20%	10 W	
50%	40 W	
80%	70 W	
90%	80 W	
100%	85 W	

If the power changes between the two nearest points are linear, the maximum error of estimated energy use is equal to the accuracy of the driver output.

Example 2:

We have an energy profile with too few light levels defined near 0% and 100%. There will be additional errors in calculated energy for these light levels. These errors result from errors in estimated power (fig. 3).

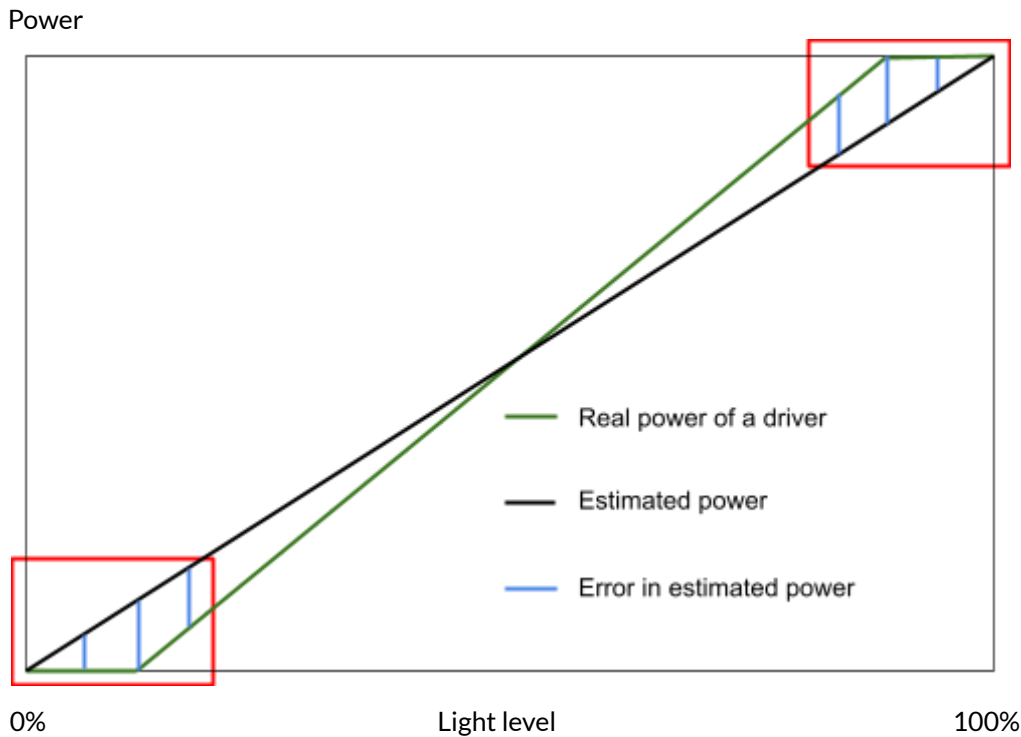


Fig. 3. Error in power estimated for light levels near 0% and 100%

For light levels near 0% and 100% that were not added to the energy profile, the estimated power can be much different from the real power. In such a case, we recommend that you add more light levels to the energy profile near 0% and 100%. This will increase the accuracy of the energy calculation.

2.3 Missing data

Because the transmission of data in a Bluetooth mesh network is radio-based, the most common cause of missing data is interference. Our solution uses an interpolation to fill the gaps in data.

Verification of gap-filling method

To verify the accuracy of the gap-filling method and simulate interference data loss, we used a test installation at our office and removed random data. We then compared the original data with the data added using the interpolation (fig. 4).

During the period of data collection the change in light output over time was slow. This is because in most lighting conditions the light remains at a constant level for 30–60 minutes. But the light output is sampled at least once a minute.

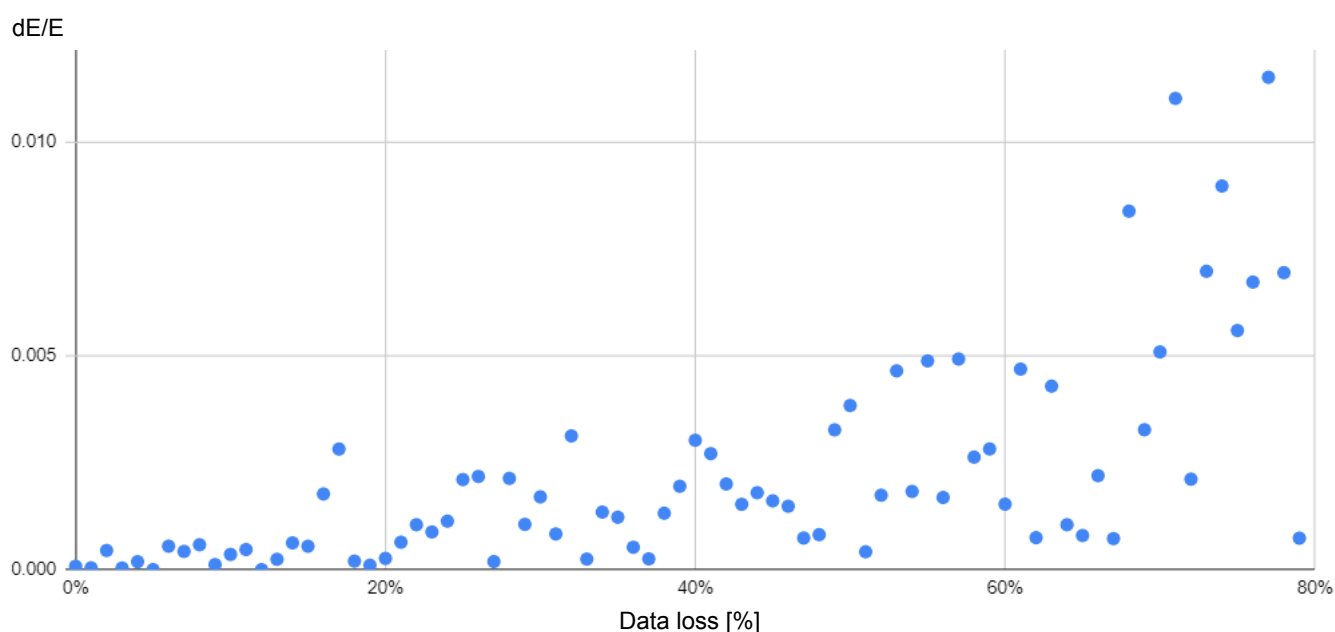


Fig. 4. Energy calculation uncertainty in relation to the data loss percentage (data added with gap-filling method)

General conclusions:

A higher percentage of data loss correlates with larger relative uncertainty (dE/E). Because changes in the light output over time are slow and light output measurements are frequent, the uncertainty is well below 1%, even for high rates (over 60%) of data loss.

Verification of interpolation method

With the use of the gap-filling method, the uncertainty of energy measurement is typically less than 1%. This is because light outputs tend to change over long periods of time and sampling is quite frequent.

But the interpolation can be very inaccurate when data is lost over a long period of time, especially when the light output during that period changes. This can for example occur if the gateway loses power.

To estimate how much the gateway power loss affects the final accuracy of the energy calculation, we removed larger blocks of data. We then directly compared the original data with the partial data. Certain periods were deleted and replaced with data calculated using interpolation (fig. 5).

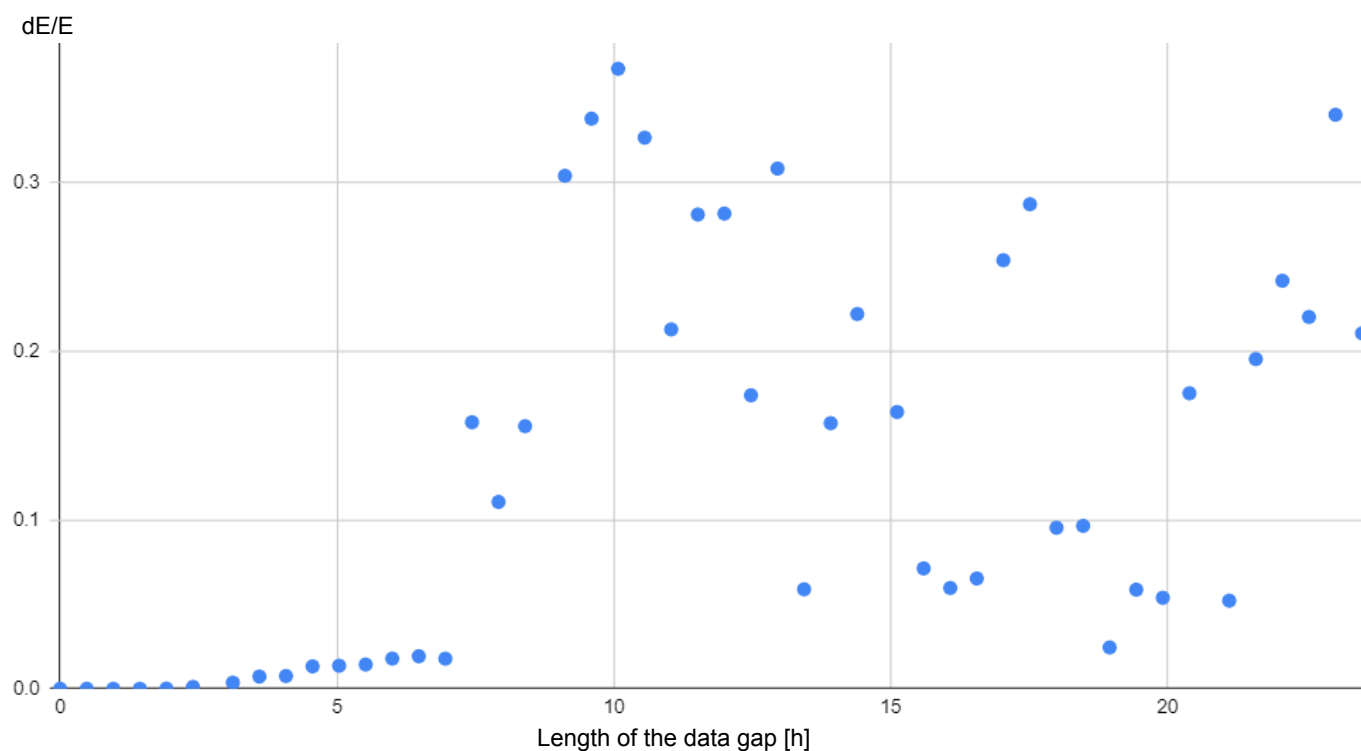


Fig. 5. Energy calculation uncertainty in relation to the length of the data gap (data added by interpolation)

General conclusions:

As expected, the accuracy decreases with the increase in the amount of missing data. The relative uncertainty (dE/E) is much larger than in the case of random data loss. But even for quite a long gap in data (~7 hours) the relative uncertainty is still well below 10%. The effect of data loss depends on when the loss occurs and what lighting profiles are being used during that time.

2.4 Conclusions

- To avoid gross errors, it is important to make sure that all the devices in a zone are of the same type and to carefully define the energy profile.
- The accuracy of the energy calculation depends on the accuracy with which the energy profile is defined and the accuracy of the interpolation.
- Error analysis showed that the interpolation works very well for random data loss. The relative uncertainty of calculated energy is less than 1% even for large data loss.
- For typical installations where data is randomly lost due to interference, errors in energy profile are the main cause of inaccuracy of energy calculation.
- Because accuracy of the interpolation method is much lower over longer periods of time, it is important to minimize data gaps.

4. Frequently asked questions

The lights were on and then a power failure occurred. After the power is restored will the energy monitoring data show that the lights were on or off during the failure?

The data for that period will use an interpolation between the last data point before the power failure and the first data point after the power is restored.

If the gateway did not send the energy data to the cloud before a power failure, is that data lost or is it retained in the gateway memory and sent to the cloud when power is restored?

There is no mechanism to store any data on the gateway, so data is lost on power loss. But gaps in the data will be interpolated between the last data point before the power failure and the first point after the power is restored.

If the gateway stops working (fails or is unplugged) but the devices are working, will all the energy data be lost? That is, isn't data stored in the devices? After the gateway is powered will the data show that the lights were on or off while the gateway was off?

If the gateway stops working, energy data for that period is lost. But gaps in the data will be interpolated before the gateway stopped working and the first point after it started working again.

If there is a problem with the internet connection, will the gateway store the energy use data locally and send it to the cloud when the connection is restored?

The gateway does not store any energy use data locally, so if the internet connection goes down the data will be lost. But gaps in the data will be interpolated and the completeness rate for that period will reflect this.

5. Document revisions

Revision	Date	Editor	Changes
5.0	2 June 2022	GM	Updated Calculation methodology , Creating an energy profile , and Energy calculation accuracy sections. Introduced editorial changes. Implemented template rev. 1.2.
4.1	26 January 2022	ES	Introduced editorial changes.
4	2 April 2021	LR, ZZ	Updated the following section: <ul style="list-style-type: none"> - 1. Calculated Energy Monitoring - 4. Frequently Asked Questions Added the following sections: <ul style="list-style-type: none"> - 2. Energy Calculation Precision - 3. Potential Gross Errors
3	2 September 2019	IK	Added the Frequently Asked Questions.
2	5 August 2019	IK	Added information about Report Retention Policy (obsolete).
1	26 April 2019	IK	Initial release.

Contact information

Support: support@silvair.com
Business development: business@silvair.com

For more information please visit: www.silvair.com

Our offices:

Europe

ul. Jasnogórska 44
31-358, Kraków
POLAND

North America

717 Market Street, Suite 100
San Francisco, CA 94103
USA