Calculated Energy Monitoring

Application Note

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1. Calculated Energy Monitoring

The Calculated Energy Monitoring feature allows to observe the energy consumption of luminaires within a zone using the gateway. The user can access the Energy Use Report for visualization of the energy use data.

The energy consumption is calculated based on a luminaire energy consumption model. It is created by manually configuring the power measured in Watts for several selected light levels and the actual records of light levels monitored by the gateway.

Example:
I have 20 identical luminaires added to my lighting zone. The devices are all of the same type (model). Using Calculated Energy Monitoring, I can find out how much energy is used in that Zone within a specified period of time. By opening the ENERGY USE tab in the Silvair web app, I can set a period of energy measurement (e.g. one day, a week, a month) and obtain energy consumption information for that time.

NOTE: This feature is currently in a beta phase and is intended to be used by early adopters only. We are constantly working to improve this feature, and as a result, the Calculated Energy Monitoring interface in the Silvair web app may change.

If you wish to start using the Calculated Energy Monitoring feature in your project, please contact your Silvair business representative for the early adoption program.

1.1 Calculation Methodology

The Gateway monitors light output of every luminaire in the target zone using the value of Light Lightness Actual (LLA) state. Devices send the LLA state periodically in a one minute interval and after any light output change. The Gateway then aggregates the data per device every 15 minutes.

The monitored Light Lightness Actual is converted to Light Lightness Linear (LLL) according to the formula defined in the mesh specification: $LLA = 65535\sqrt{(LLL/65535}$. The Light Lightness Linear state is proportional to power consumption -P.

Knowing the linear dependency between the power consumption on the light output (described in section 1.3 Creating a New Energy Model) the energy usage En is calculated for every minute as an integral of the average power consumption over a minute, according to the following formulas:

$$En = P * t \quad - \quad where\ t = 1\ min,\ and$$
$$P = A * avg(LLL) + B,\ for\ LLL > 0\ where\ A,\ B\ are\ coefficient\ of\ the\ P(LLL)\ curve$$
$$P = P_0,\ for\ LLL = 0$$

Completeness rate is the ratio of LLA state data sent to the LLA data received in percent. As the gateway cannot detect if a light output change message was lost, completeness rate is calculated based on the periodical LLA state per device that should be provided every minute. This means that in a target zone with 5 devices, the gateway needs to receive at least 5 LLA state messages (one per each device) every minute to achieve 100% completeness rate.

Additional assumptions:

- Energy usage of a device is calculated as the sum of the average power consumption in individual minutes (within the 15 minute aggregation period).
- The gateway requires data from at least one 15 minute period to calculate the energy consumption and completeness rate.
- Gaps in data (minutes for which the LLA data is not received) are filled using the local linear interpolation method.
- Energy consumption per zone is calculated as a sum of energy consumption of all devices in the target zone in that time.
- Energy consumption per area is calculated as a sum of energy consumption of all zones in that time.

1.2 Calculated Energy Monitoring Requirements

For the the feature to work properly, the following criteria must be met:

- **Silvair account is created and configured.**
  To create a new account, visit the Silvair platform.
- **Silvair Gateway is configured in the project.**
- **Silvair mobile app is available.**
- **A project with the target zone is set up and operational.**
  For information on creating projects and commissioning devices, see the Silvair Commissioning User Manual.
- **All devices deployed in the target zone are homogenous.**
  Devices in the zone where you will be using the Calculated Energy Monitoring feature must be exactly the same type (the same model of luminaires used with the same LED drivers).

> **RECOMMENDATION:** To ensure homogeneity of the luminaires in the target zone check if the power consumption for maximum Light Level is the same for all luminaires.

- **All devices deployed in the target zone have a non-variable dependence of power consumed on the light level.**
  All luminaires in the zone must have a constant linear dependence of light output on the power consumed. Therefore, energy monitoring of luminaires with variable color temperature is not supported.
- **Energy meter is available.**
  A device used to measure the power consumption in Watts for a given light level.

1.3 Creating a New Energy Model

Before you begin, see 1.2 Calculated Energy Monitoring requirements.

1. From the Silvair web app open an existing project.
2. Select the area with the target zone.
3. From the **Commissioning** tab, right-click the target zone icon and select **EDIT** → **ENERGY USE** tab.

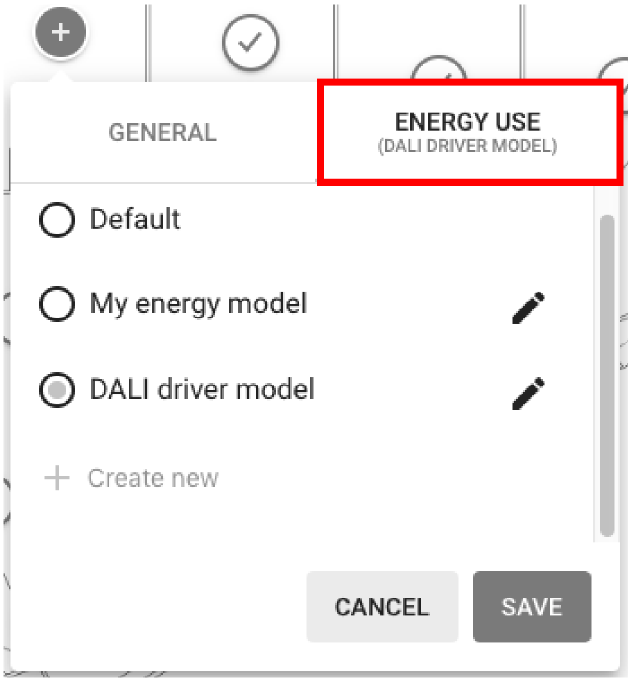

Fig.1 ENERGY USE tab

4. Click + **Create new**.

NOTE: Only one energy model can be used for one zone at a time.

HINT: If you have e.g. two device types in one space, we recommend creating **two** separate zones operating in one physical space (each for one device type), adding **two** energy models, and then linking the two zones together (for lighting control purposes).
For more information on creating zones and linking them, see the Silvair Commissioning User Manual.

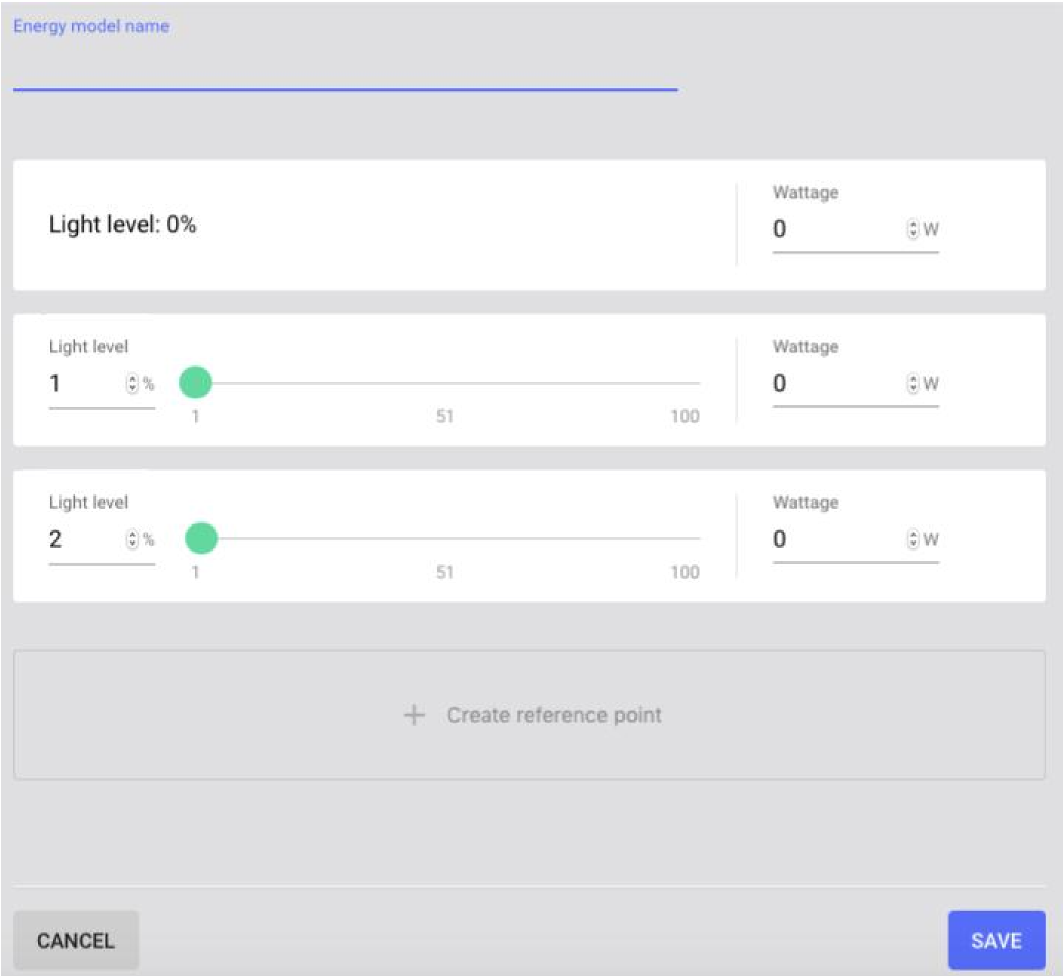

Fig. 2 ENERGY USE model creation page

5. In the **Energy model name** field, enter your energy model name.
6. For the **Light level: 0%** reference point, measure the power consumption for the 0% light level of a device in the target zone and enter the value in the **Wattage** field.

NOTE: For more information on setting the light level and measuring power consumption of luminaires, see the SN-207: Application note - measuring power consumption.

IMPORTANT: When entering the values in the **Wattage** field, ensure that units are provided correctly (e.g. if the meter of the consumed power measures in [100 * mW], the values must be converted to [W]).

7. Perform the following actions for reference points:
   a. Enter the light level percentage value (e.g. 20, 50, 100).
   b. Measure the power consumption for the corresponding light level of a device in the target zone.
   c. Enter the power consumption value in the **Wattage** field.

NOTE: At least 3 reference points are necessary to create the energy model, however the more reference points you add to the energy model, the more accurate energy calculation will be.

8. To add additional reference points, click **+ Create reference point** and repeat step 7.
9. Click **SAVE**.

The energy model is automatically added to the target zone.
The energy model can be edited or removed.
The energy consumption feature is not retroactive, which means that energy is always calculated based on the currently assigned model. If the user edits an existing energy model (adds reference points or changes the Wattage values), the new parameters will only change the energy calculations reported after saving the changes.

1.4 Energy Use Report Elements

To access the Energy use report, open the Silvair web app, navigate to My projects, select the target Area and click the **Energy use** tab.

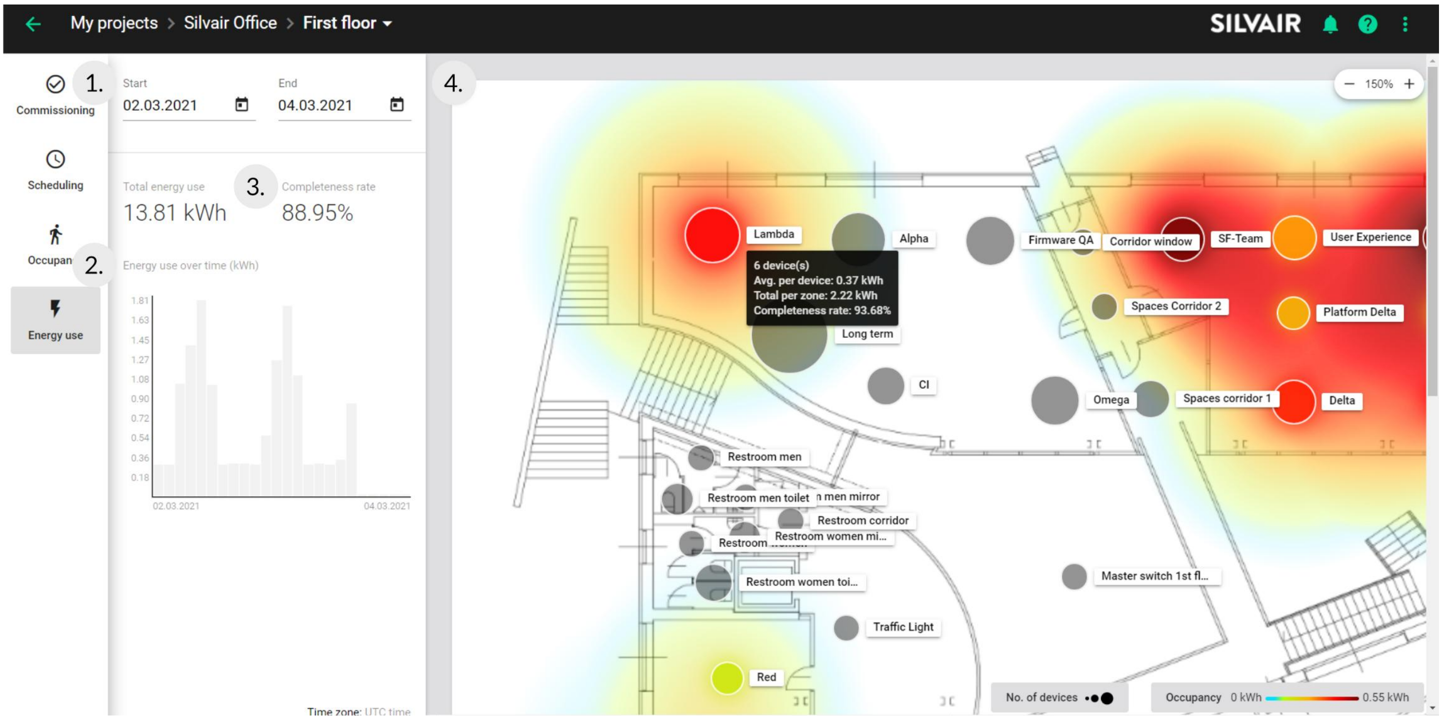

Fig.3 Energy use report panel (Silvair web app)

1. Datepicker - date range of your energy use report.
2. Bar chart - chart representation of energy use (kWh) for the selected time period in the target area.
3. Completeness rate - shows the percentage of data received by the gateway (for more information see 1.1 Calculation Methodology).
4. Heatmap - graphical representation of energy use for the selected time period in the target area.

NOTE: To see details about the number of devices, average energy consumption per device, and total energy consumption per zone, hover the cursor over the target zone icon.

1.5 Energy Use Data Retention

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 consumption data is aggregated and stored per luminaire, per zone, and per area for a maximum of 5 years, with varied data resolution depending on the aggregation period. Please see the following table:

Aggregation period	Data resolution
Last 30 days	15 minutes
Over 30 days, but less than a year	1 day
Over a year, but less than 5 years	1 month
Over 5 years	No data

2. Energy Calculation Accuracy

The analysis of calculating energy using the Light Lightness methodology shows that the main contribution to the calculated energy uncertainty comes from two sources. Accuracy of the energy model determination and the accuracy of the gaps filling method (complementing missing data using local interpolation). The impact of both contributions is discussed in the following subchapters.

2.1 Energy Model Determination Precision

Contribution of the energy model determination precision to energy results can be calculated using the error propagation method, as follows:

$$dEn_i = dA * L_i + dB, \text{ since } dL/L \text{ is negligibly small } (1/65535)$$

Where *A*, *B* are the linear power versus light output coefficients calculated during energy model determination, while *dA* and *dB* are the respective uncertainty of these coefficients.

The error propagation method formula indicates that the dA uncertainty is significant for all except the very small lightness values (see Fig. 4), while the dB uncertainty is significant only for very small lightness values (see Fig. 5).

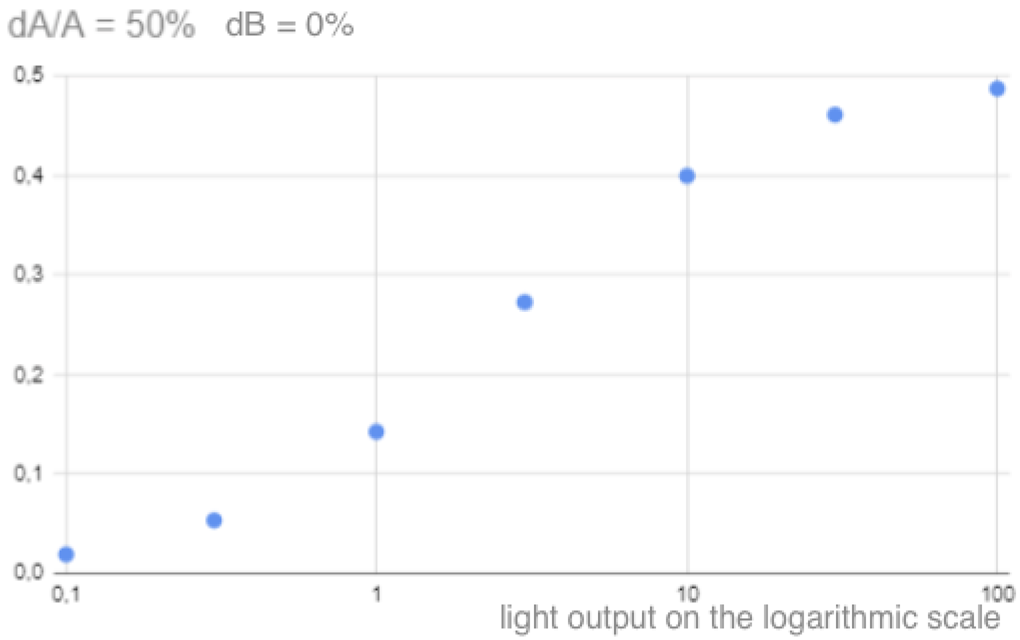

Fig.4 Relation between the relative uncertainty (dA/A) and light output value

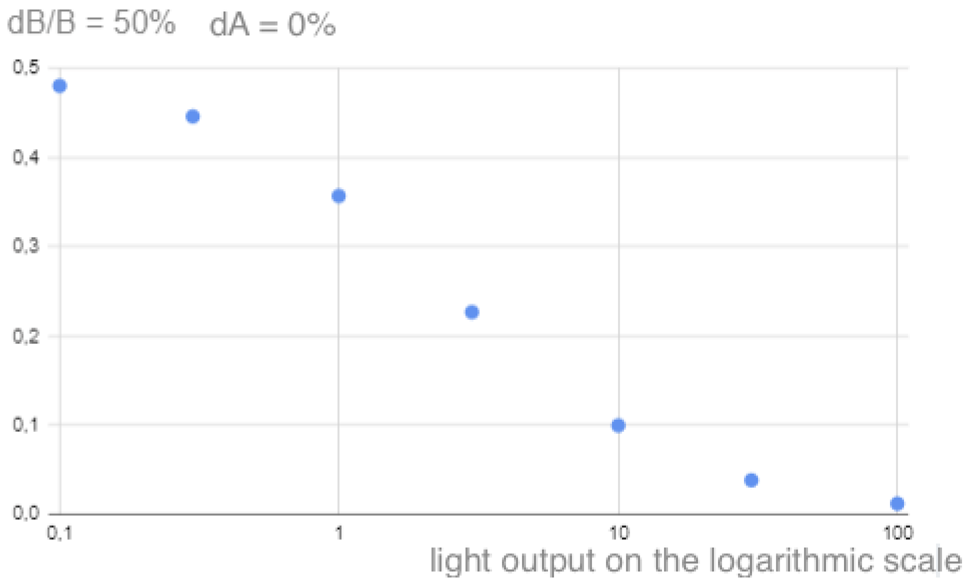

Fig.5 Relation between the relative uncertainty (dB/B) and light output value

2.1.1 Nonlinearity in Power Consumption

To minimize the uncertainty related to the driver's nonlinearity, the first reference point describes the energy usage calculated for LLL = 0 and is treated independently. This is done, because the driver may consume power even if the light is turned off.

When the light is off, the energy consumption precision is equal to the precision of measuring the driver power consumption at rest. Typically, such measurement is much more accurate than calculation of the energy usage based on the energy model, so it is omitted in further considerations.

The following figure shows an example of determining an energy model:

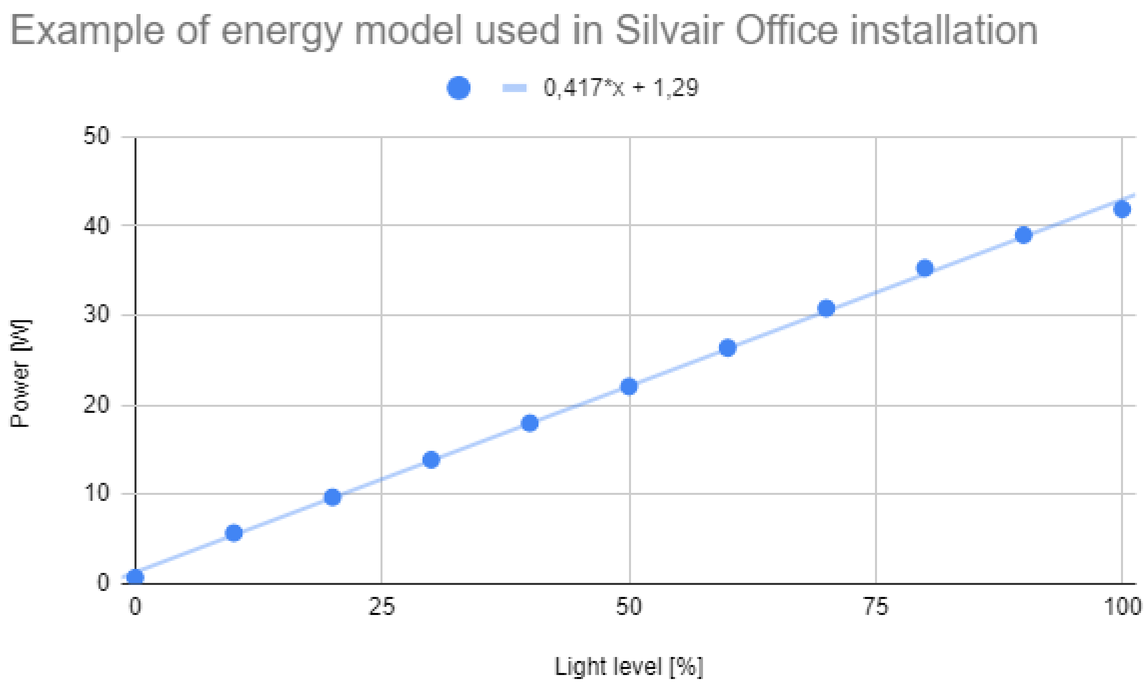

Fig.6 Energy model used in Silvair office installation

The example shows that the relationship between the LLL and the power consumption is linear. The linear coefficients obtained from the regression are:

- A = 0.4165 ± 0.0045
- B = 1,29 ± 0.27

For these values, the relative uncertainty of energy calculation is well below few percent, except for very low LLL values when it can reach up to 20%.
The lowest and highest points (in LLL) deviate the most from the linear dependence. As it was anticipated, the measurement for LLL = 0 deviates, hence it is treated separately. However, the fact that the measurement for LLL = 100 also departs from the diagram may suggest nonlinearity for high power consumption of the driver (saturation).

2.1.2 Control Curve Saturation

Normally the light output increases proportionally to the increase of power. However, some drivers, especially 0-10V Pulse Width Modulation may show the phenomenon of saturation. At a certain point, the linearity stops and raising the control voltage does not increase the light output equivalently. Therefore it is recommended to measure more densely for high values of light level.

HINT: If you observe control curve saturation in your project, it is highly recommended to set the LL Range Max to the last measured linear value, not to impact the energy model precision.

To illustrate the importance of creating a precise energy model (using data presented in Figure 6) we calculated the linear regression excluding the LLL = 100 (in addition to LLL = 0). The coefficients are:

- A = 0.4203 ± 0.0026
- B = 1.29 ± 0.14

Values of the linear coefficients are very similar to the previous case, but with significantly smaller uncertainties : A changed from 0.0045 to 0.0026 and B changed from 0.27 to 0.14.
This simple example cannot unequivocally prove that for higher LLL values there are saturations, but they should definitely encourage more measurements for LLL close to 0 and 100%, where nonlinearity may occur.

2.1.3 Nonhomogeneous Devices in the Target Zone

At this stage, for the energy calculation to be reliable, all luminaires in the target zone must be the same type. Not meeting this requirement may result in high inaccuracy of estimating the energy consumption. The following example illustrates how the uncertainty of energy measurement is influenced by the use of nonhomogeneous devices in one zone.

A zone with 2 devices was created. The power consumption for LLL = 100 differed by around 10%. Three energy models were created and the accuracy of energy calculation was compared for each of them. Figure 7 shows the data points for Luminaires A and B together with 3 energy models, calculated using the measurements for the first, second, and both devices together.

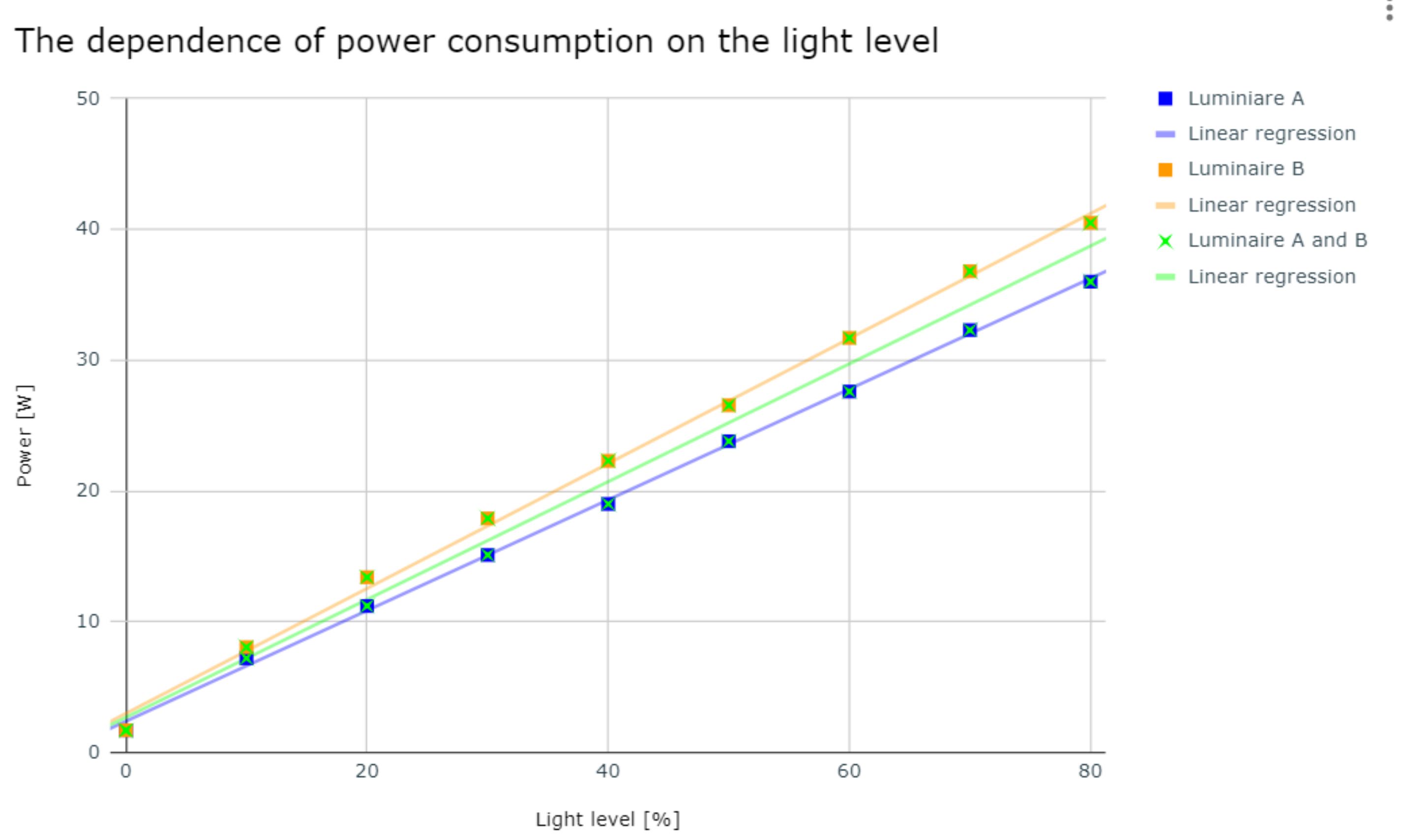

Fig.7 Relation between power consumption and light level

Uncertainties of the linear coefficients calculated from data of one device are much smaller than uncertainties calculated from data of both drivers. However, to minimise the inaccuracy of determining the energy usage in a zone, we should use the energy model for both devices. For emphasis, we will compare the energy calculated for model 1, 2 and 3 with the measured data for the entire zone when both devices are constantly working at half-power. The results are summarized in the following table:

	Measured value	Model 1 (based on Device A)	Model 2 (based on Device B)	Model 3 (based on Device average)
Device A	23.8 W	23.61 W	26.97 W	25.29 W
Device B	26.55 W	23.61 W	26.97 W	25.29 W
Sum	50.35 W	47.22 W	53.94 W	50.58 W
Measured value discrepancy	0	- 3.13 W	3.59 W	0.23 W

The discrepancy between the measured value and the model outcome is smallest for model 3, where we used the average measurement of both devices.

2.2 Accuracy of Gaps Filling Method

Due to the nature of radio transmission, the most common reason for not delivering information in a mesh network is packet collision. In such a case, the data does not reach the destination.

2.2.1 Random Data Removal

Data collected from the Silvair office was used to verify the precision of the gap filling method. Collision data loss was simulated by removing random data.

To establish the precision of the gap filling method, a direct comparison of the original data with the data filled using the gap-supplementing algorithm.

During collection of data, the change in the light output over time was slow, as in most lighting profiles used by the Silvair platform, the duration of the light on the state is at the level of several dozen minutes. Monitoring of the light output was sampled at least once a minute (quite frequently).

Figure 8 presents the test results as a dependence of the relative uncertainties on the percentage of deleted data.

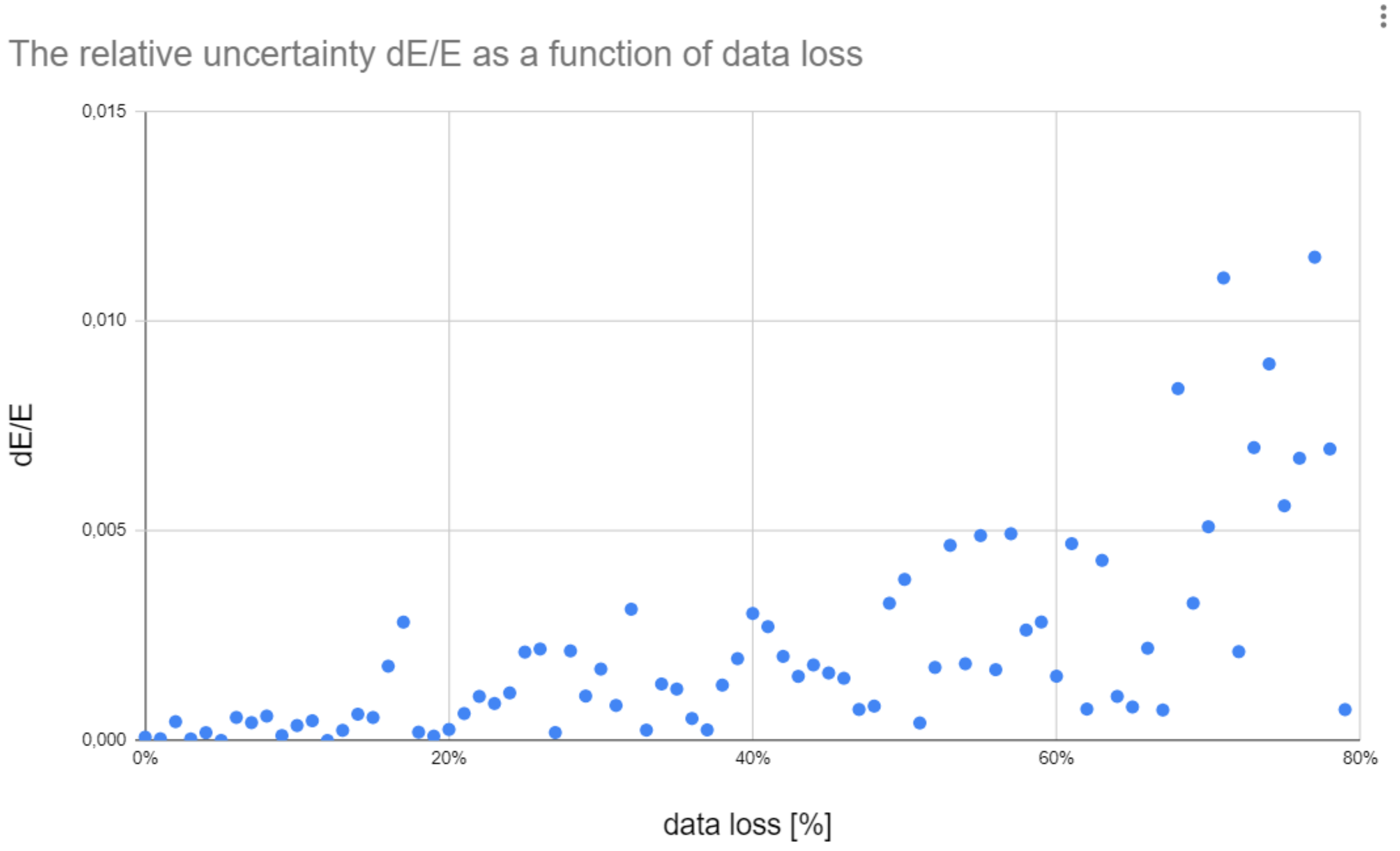

Fig.8 Energy calculation uncertainty depending on the data loss percentage (data supplemented with gap-supplementing algorithm)

General conclusions:

- Higher percentage of data loss is correlated with bigger relative uncertainty (dE/E)
- Because of slow changes in the light output over time and frequent light output measurements, the relative uncertainty is well below 1 %, even for large percentage of data loss (over 60%)

2.2.2 Longer Period Data Removal

As it was presented earlier with random data loss, the contribution to the uncertainty of energy measurement from the gap filling method stays below the level of one percent. This is strictly associated with the high redundancy of the light output measurement.

However, the local linear interpolation method can be significantly wrong in case of data loss over a longer period, especially when the light output value changes over that time. This can occur when the gateway loses power for a longer time.

To estimate the impact of gateway power loss on the final relative energy estimation accuracy , larger chunks of data were removed. Then, the precision was estimated by direct comparison of the original data with the partial data (with certain periods deleted) filled in using linear interpolation.

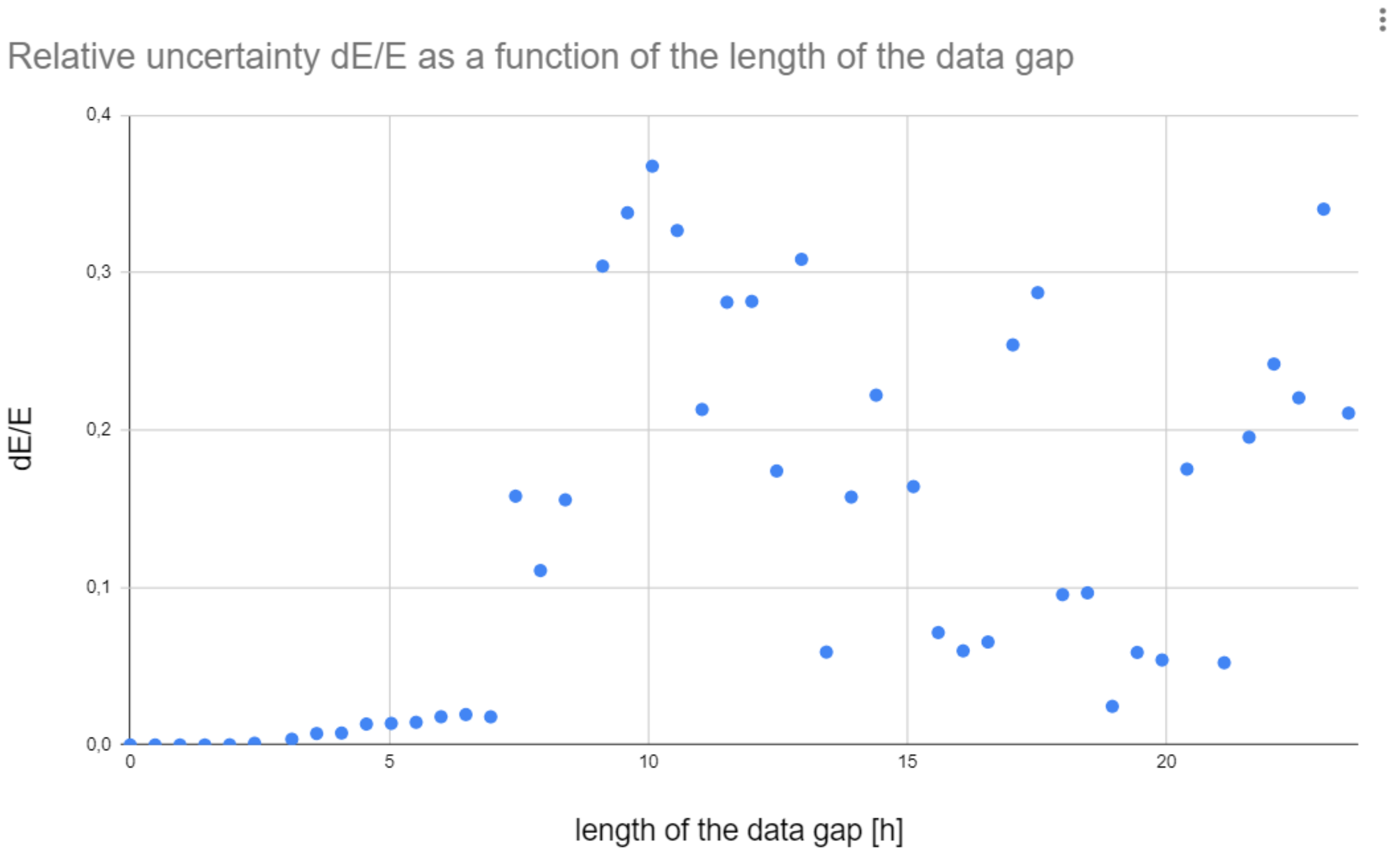

Fig.9 Energy calculation uncertainty depending on the length of the data gap (data supplemented from interpolation)

General conclusions:

- The precision deteriorates as the length of missing data increases
- The relative uncertainty (dE/E) is significantly larger than in case of random data loss
- Even for quite a long data gap (~7 hours) the relative uncertainty is still well below 10%. However, the impact of the length of the gap depends on when the gap occurs and what lighting profiles are used during that time.

2.3 Conclusions

- Since user mistakes may lead to gross errors, it is important to check homogeneity of all devices and to carefully perform the energy model determination process.
- Precision of the energy calculation depends on the precision of the determining the energy model and the precision of the gaps filling algorithm.
- Error analysis showed that the gaps filling algorithm works very well for random data loss. The relative uncertainty of calculated energy is less than a percent even for large data loss.
- For typical installations, where data is randomly lost due to collisions, energy model errors are the dominant source of energy calculation imprecision .

- As precision of the linear interpolation method (used to fill in gaps in data) significantly deteriorates over longer periods of time, it is important to monitor data from those periods.

3. Potential Gross Errors

The process of determining the energy model seems to be the most vulnerable to committing gross errors. For that reason, the following are few examples of the most impactful and yet easy to commit mistakes.

3.1 Use of the Default Energy Model

The first simple mistake is not assigning the newly created energy model to the target zone. This results in using the default model with values A = 1 and B = 0, which obviously causes the calculation of energy consumption to be completely wrong.
At times, this fallacy can be so large that omitting the energy model selection in one zone can significantly affect the total energy consumption in the whole project.

3.2 Input of Incorrect Units

The second source of gross error may come from a mistake done during defining the reference points for the energy model. A situation when only one point is incorrectly defined is relatively easy to notice, because it will have a significant impact on the precision of A and B parameters. However, it is much more difficult to catch an error when all the reference points are given in the same, incorrect way (for example, the meter of the consumed power measures in [100 * mW], but the user entered the values read directly from the meter as there were in [W]).
It is very important, because such an error made in one energy model may strongly affect the calculation of the energy usage for the whole project.

3.3 Use of Nonhomogeneous Devices

Another example of a gross error is not checking whether the devices used in the zone are all of the same type. In this situation, if the user measures the energy model for all the devices, the nonhomogeneity of devices will be reflected in the imprecision of the linear regression parameters. However, if only data from one selected device is used to determine an energy model, it may systematically distort the result of energy calculation in the target zone.

4. Frequently Asked Questions

Q1: If there is a power failure lasting an hour and the lights were on right before the power failure, when the power is restored, will the Cloud indicate that for the hour the power was out or will it assume that the lights were still on during the power failure?
A: In such a case the result comes from linear interpolation from the last data point before the failure to the first one after the failure.

Q2: If the gateway didn't send the energy consumption information to the Cloud prior to a power failure, is that information lost or is it kept in memory, so that the data can be sent to the Cloud when the power is restored?
A: There is no mechanism to store a current buffer to the nonvolatile memory. So at the moment, the data is lost on power loss.

Q3: If it is only the gateway that is broken, disabled or unplugged, but the nodes are functioning, will all the energy consumption information be lost? (i.e. it's not temporarily stored in the nodes until the gateway is powered up and operational). Would it mean that for the time that the gateway is unpowered, the data on the Cloud indicate that the lights were off during this time (once the gateway is powered)?
A: Yes, if the gateway doesn't work at a given moment, power consumption information from that moment is lost.

Q4: If there is an issue with the Internet connection will the gateway store the information locally and send it to the Cloud once the Internet service is restored?
A: The gateway does not retain data locally, so when the internet connection is down, the information will be lost.

5. Document Revisions

Rev	Date	Editor	Changes
4	02.04.2021	LR, ZZ	Updated the following section: - 1. Calculated Energy Monitoring - 4. Frequently Asked Questions Added the following sections: - 2. Energy Calculation Precision - 3. Potential Gross Errors
3	02.09.2019	IK	Added the Frequently Asked Questions chapter.
2	05.08.2019	IK	Added information about Report Retention Policy (obsolete).
1	26.04.2019	IK	Initial release.

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