BlueMesh EnergyMonitoring

Application note

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1. Introduction

This document describes the BlueMesh Energy Monitoring service delivered through the BlueMesh web app. The service provides the following functions:

- Visualizing energy use data per zone and area.
- Downloading energy use data as 15-minute blocks per luminaire for a calendar month.
- Calculating annual energy cost savings on the project level for a post-upgrade (new) installation compared to a pre-upgrade (old) installation.

2. Requirements

- A lighting project has been commissioned with the BlueMesh Commissioning tools.
- At least one luminaire has been added to a zone in the project.
- All luminaires in the zone are of the same type, that is, they have the same energy profile.
  Energy monitoring service is not able to distinguish between luminaires of a different type in a zone.
- Each luminaire has a constant power for each light level.
  Energy monitoring of tunable white luminaires is not supported.
- Access to the luminaire so that its power can be measured.
- The BlueMesh mobile app to manually set the light level of the luminaire.
- A power meter to measure the power of the luminaire.
- An energy profile has been set up in the BlueMesh web app.
- A BlueMesh gateway has been added to the project.

The BlueMesh Gateway is supplied by BlueMesh.
See *user guide* for details about gateway hardware and set up.

Because gateway performance is limited, one gateway can monitor energy of up to approximately 200 devices in all areas. If the gateway monitors more than 200 devices, the reporting may not be correct.

Access of data via APIs is a separate service.

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3. Calculation of energy use

Energy use is calculated from the energy profile and the actual light level recorded for each luminaire. Every 60 seconds and after each change in the light level, the energy use for each luminaire is calculated, and the values are aggregated into 15-minute blocks before being stored in the database.

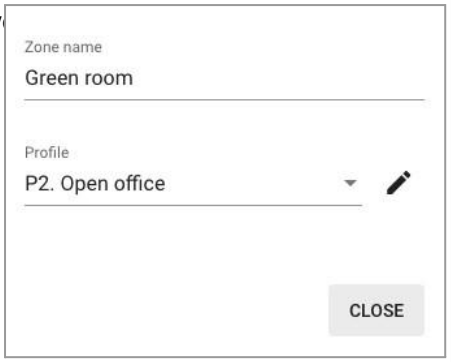
The 15-minute blocks of data are updated at regular intervals – there may be a delay of up to 45 minutes before the value is published. These 15-minute blocks are stored for 24 months. If you need real-time data, use the real-time monitoring API and calculate the energy use by yourself.

To allow calculation of energy use, you must measure the power of luminaires, create energy profiles, and add a BlueMesh Gateway to the project.

3.1 Measuring the power of luminaires

BlueMesh web app

1. In the BlueMesh web app, go to an area with the luminaires whose pow you want to measure.
2. On the **Commissioning** tab, click a zone with the luminaires, and then click ✎.
3. Set **Min.** of the **Low/high-end trim** to 0% and **Max.** to 100%.



4. Click **Save** to save the profile.
5. Repeat steps 1–4 for each zone with the luminaires whose power you want to measure.

BlueMesh **mobile app**

6. In the BlueMesh **mobile app**, go to a zone with the luminaires whose power you want to measure.
7. Go to the **Test** tab.
8. Use the slider to set a light level of a luminaire, or enter it manually.

> ⓘ Start by setting a level of 0%, 1%, or 100%.

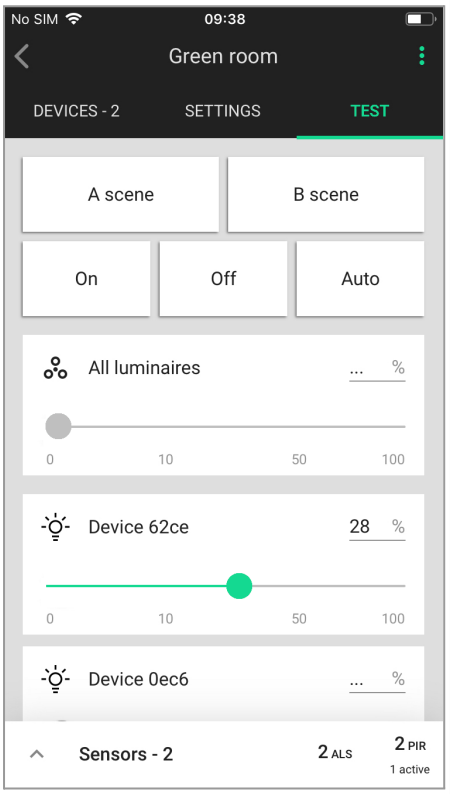
9. Wait until the luminaire reaches the new light level.
10. Use a power meter to measure the power for that light level.

> ⓘ Make sure that the resolution of the power meter is appropriate for the rated power of the luminaire.

> ⓘ To obtain an accurate measurement, the luminaire must have enough time to warm up. If you measure the power too soon after you connect to the power or change the light level, the measurement will not be accurate.

11. Write down the measured power.

> ⓘ Make sure that the value is stable before you write it down.



12. Repeat steps 8–11 for light levels of at least 0%, 1%, and 100%.

> ⓘ Measure more levels near 0% and 100% to increase the accuracy of the energy profile.

13. Repeat steps 6–12 for each type of luminaire used in other zones.

3.2 Creating an energy profile

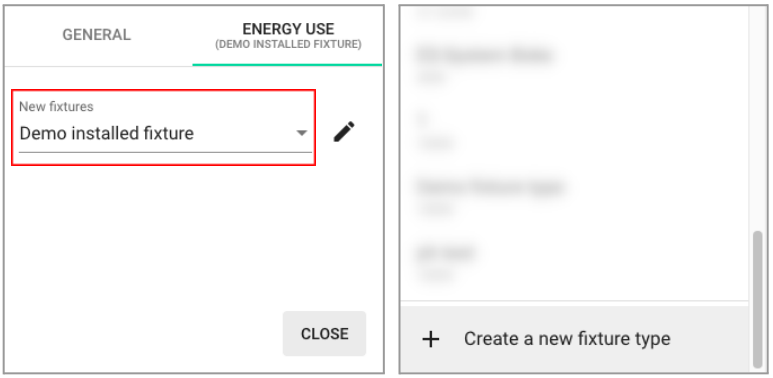
BlueMesh web app

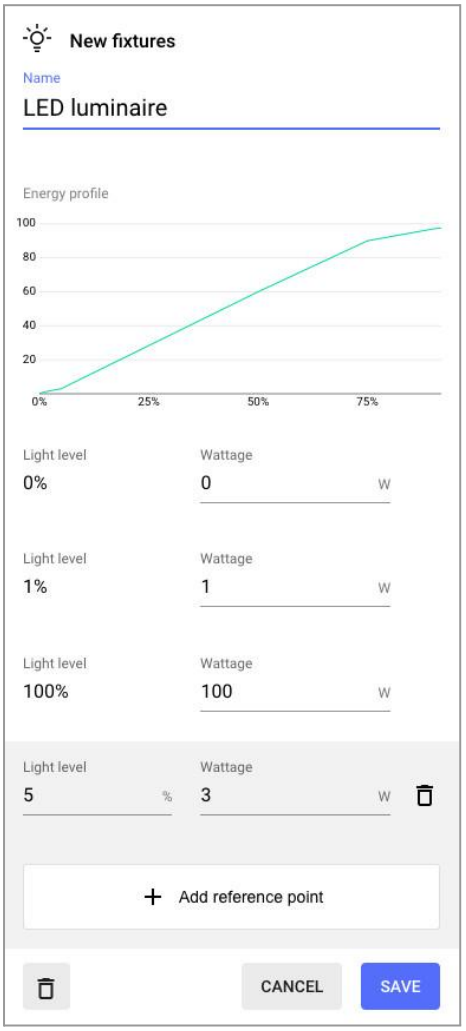
1. In the BlueMesh web app, go to an area where you want to measure energy use, and set up an energy profile for zones.

   The energy profile defines the power of a type of luminaire at a range of light levels. Only one energy profile can be used for a zone at a time.

   If you have luminaires of two types in one space, we recommend that you create two separate zones, each for one luminaire type. Then, set up a different energy profile for each zone, and link the two zones for lighting control. For more information about how to create and link zones, see BlueMesh Commissioning user manual.

2. On the **Commissioning** tab, click the zone and then **Energy use**.
3. Expand the **New fixtures** list, and select which type of luminaire is installed in this zone, or select **Create a new fixture type**.





4. If you have selected **Create a new fixture type**:
   a. In the **Name** field, enter the name for the energy profile.
   b. In the **Wattage** fields, enter the power measured for the luminaire at light levels of 0%, 1%, and 100%. Add more light levels for a more accurate calculation.

      Make sure that the values entered in the **Wattage** fields are in watts (W).

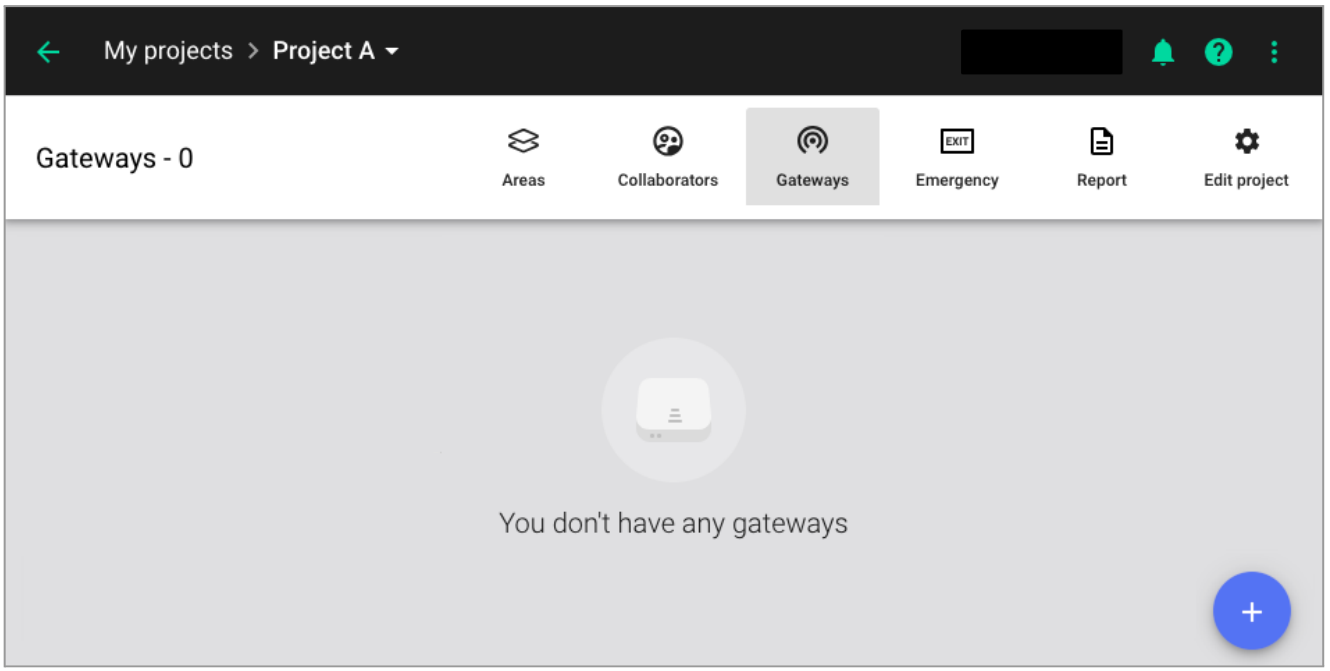
   c. To add more light levels, click **Add reference point**. Enter the required light level as a percentage. Then, enter the power for that light level in the **Wattage** field.
   d. Click **Save**.
5. To set up energy profiles for other zones, repeat steps 1–4.
6. Go to the project, click **Report**, and download the *commissioning report*. Then, view the report to make sure that the energy profiles are set up correctly.

3.3 Adding a BlueMesh Gateway to the project and selecting areas

1. Make sure that the status LED of the gateway is solid green.

BlueMesh web app

2. In the BlueMesh web app, open the project and click **Gateways**.



3. Click **+** to add the gateway.
4. If asked, enter the latitude and longitude of your project.

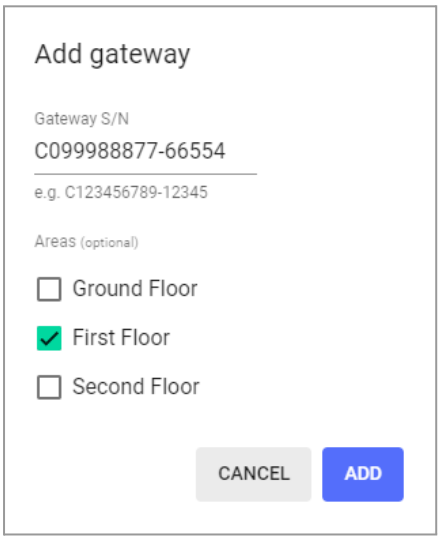
> To find the latitude and longitude, use Google Maps or OpenStreetMap.

> Enter the values with at least two decimal places.
> The more decimal places you use, the more accurate the calculated sunrise and sunset times will be.

5. Enter the serial number (S/N) of the gateway.

> Find the serial number on the back of the gateway.

6. Select one area to be monitored by this gateway.
7. Click **Add**.



4. Visualization of energy use

4.1 Energy use report for areas

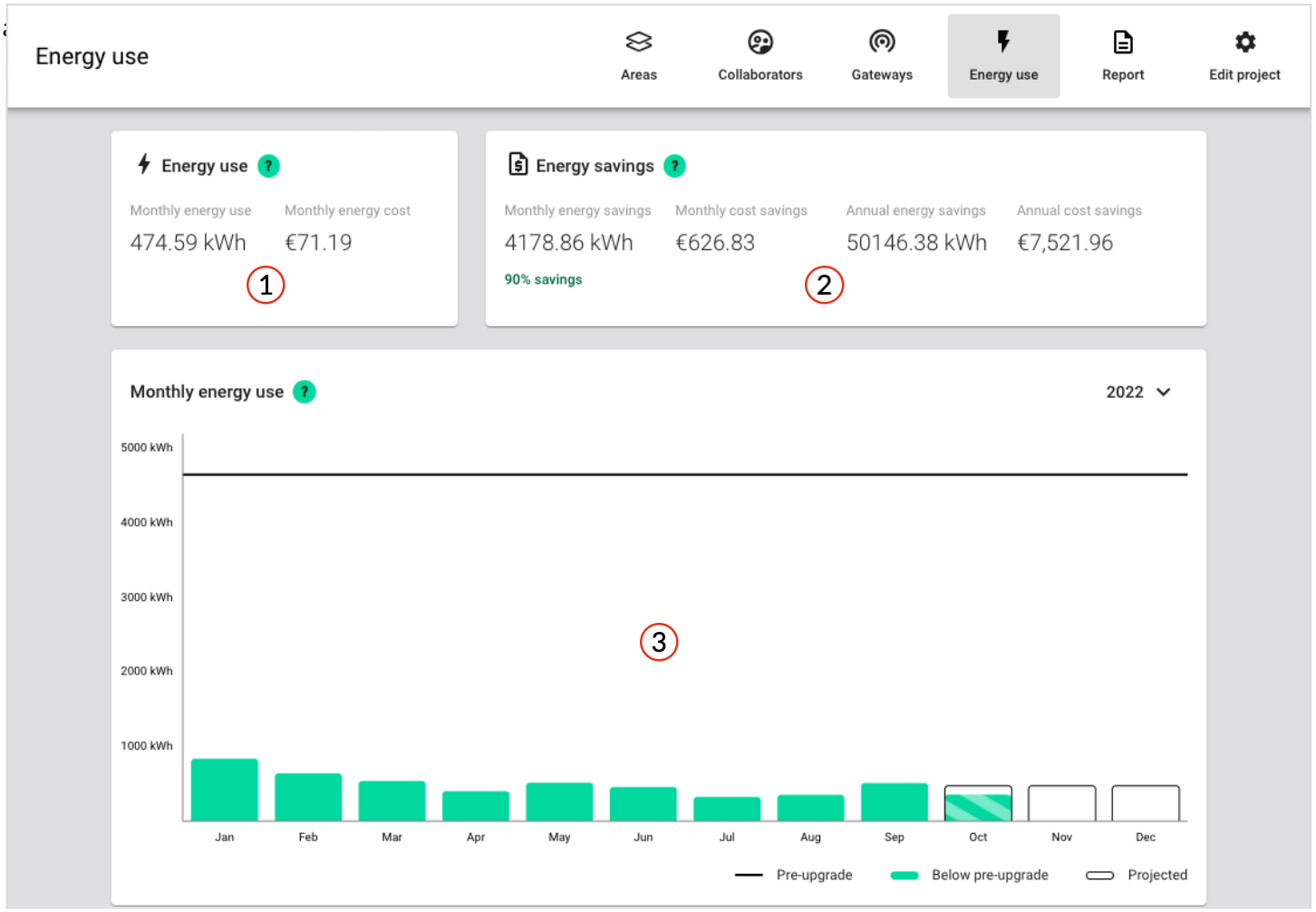
To view the energy use report for an area, open the BlueMesh web app, go to the project and area,

1. Date picker – selected month/day of your energy use report.
2. Total energy use and cost for the selected month/day in the area.
3. Bar chart – energy use in the area per day in the selected month or per 15-minute time period in the selected day.
4. Download report – downloads a CSV file with energy use data (in kWh) aggregated over 15-minute time periods for each device in the project over the calendar month. For large projects, downloading can take some time.
5. Heatmap – energy use for the selected month/day for each zone in the area. The larger the circle, the more devices are in the zone. The color indicates how much energy was used.

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

4.2 Energy use and savings for projects

To view the energy use and savings for a project, open the BlueMesh web app, go to the project,



1. Average monthly energy use and cost for the project from the date when monitoring started.
2. Monthly and annual savings for the project over 12 months.
3. Bar chart – actual and projected average monthly energy use for the new installation, and the average monthly energy use for the pre-upgrade (old) installation.

5. Calculation of energy and cost savings

After setting up energy profiles for each zone to be monitored, you can create a 12-month forecast of energy and cost savings for an upgrade project. Energy savings can be calculated using one of two methods.

The first method compares the recorded energy use of the post-upgrade (new) fixtures with the annual pre-upgrade (old) energy use of the old installation. This requires entering the following data in the web app:

- Average energy price (per kWh)
- Total annual energy use of the pre-upgrade installation (in kWh)

The second method compares the recorded energy use of the post-upgrade (new) fixtures with the energy use of the pre-upgrade (old) fixtures. This requires entering the following data in the web app:

- Average energy price (per kWh)
- Number of fixtures of each pre-upgrade (old) type in the whole old installation
- Power of each pre-upgrade fixture type
- Estimated number of operating hours for fixtures of each pre-upgrade type

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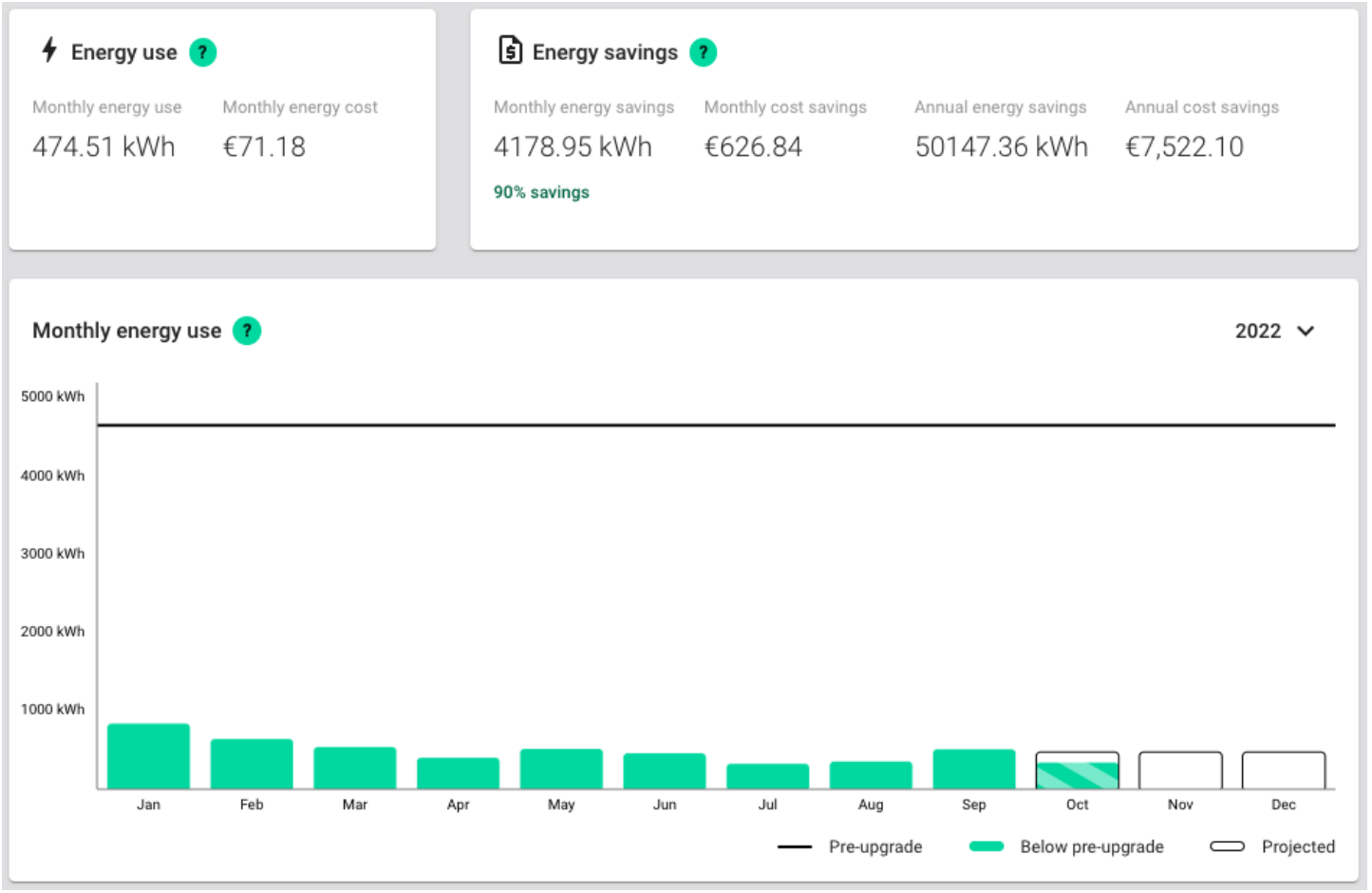
The monitored energy use is used to calculate the annual energy use for the upgraded project as an indicator of the savings that could be achieved.



The values shown in the view are calculated as follows:

Monthly energy use = energy use / days of data * (365 / 12)

Monthly energy cost = monthly energy use * energy price

Monthly energy savings = baseline energy use – monthly energy use

Monthly cost savings = monthly energy savings * energy price

Annual energy savings = monthly energy savings * 12

Annual cost savings = annual energy savings * energy price

Pre-upgrade energy use (bar chart) = baseline energy use

Energy use (bar chart) = sum of 15-minute blocks of energy use in the month for all zones in the project

Projected energy use (bar chart) = monthly energy use

where:

Energy use = sum of 15-minute blocks of energy use for all zones in the period (either from the last 12 months, or from the monitoring start date)

Days of data = number of days from the monitoring start date, or 365 days if 12 months of data is available

Energy price = price entered in the project settings

Baseline energy use = pre-upgrade energy use for the project (entered in the project settings) averaged over 12 months

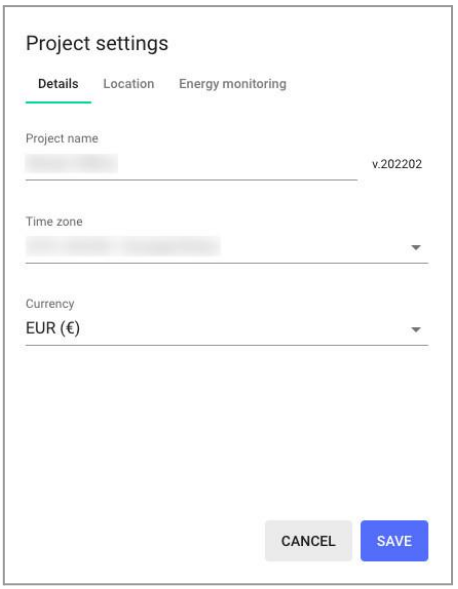
6. Setting up energy and cost savings calculation

BlueMesh web app

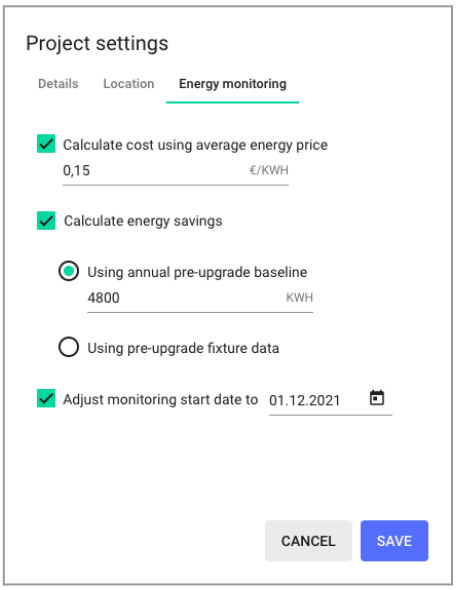
1. In the BlueMesh **web app**,

open the project and click **Edit project**.2. On the **Details** tab,

select the correct currency.

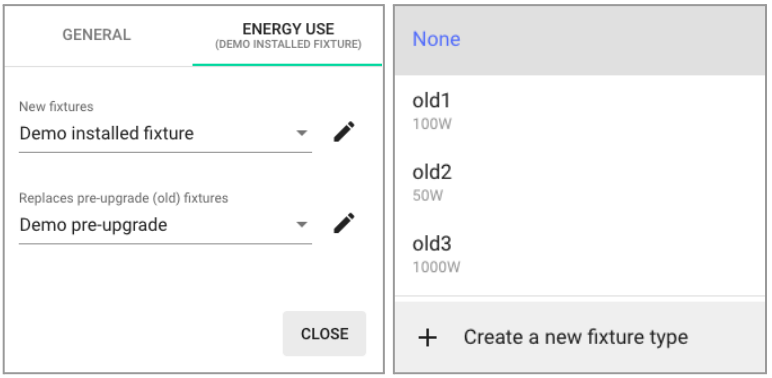


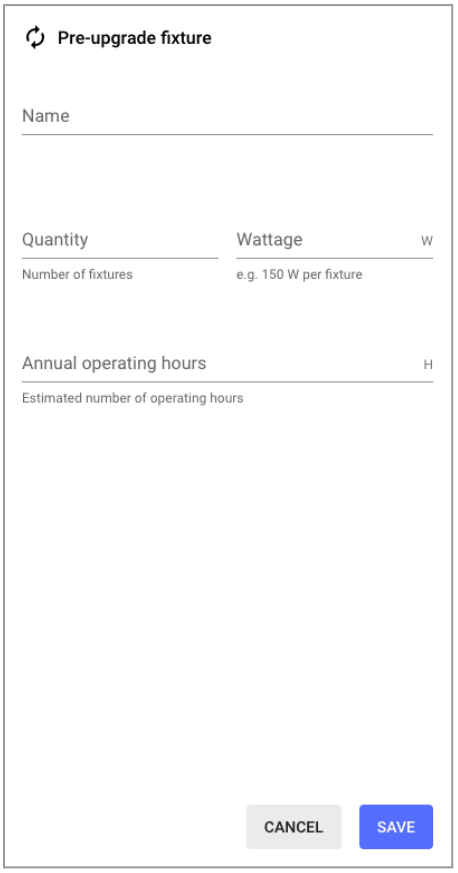
3. Go to the **Energy monitoring** tab.



   a. Select **Calculate cost** and enter the average energy price.
   b. Select a method to calculate energy savings:
      i. Using annual pre-upgrade baseline, and enter the total annual energy use of the pre-upgrade installation.
      ii. Using pre-upgrade fixture data.
   c. Select the date for the monitoring to start.
4. Click **Save**.

5. If you have selected **Using pre-upgrade fixture data**, go to one of the zones and create all types of luminaires that were used in the whole pre-upgrade installation.
   a. On the floor plan, click the zone and then **Energy use**.
   b. Expand the **Replaces pre-upgrade (old) fixtures** list and select **Create a new fixture type**.





      i. In the **Name** field, enter the name for the pre-upgrade (old) fixture.
      ii. In the **Quantity** field, enter how many of these fixtures were installed in total in the pre-upgrade installation.
      iii. In the **Wattage** field, enter the rated power (in watts) of this fixture type.
      iv. In the **Annual operating hours** field, enter how many hours these fixtures operated in a year.
      v. Click **Save**.

> Information about pre-upgrade fixture types must apply to the whole pre-upgrade installation.

   c. Create the remaining types of luminaires that were used in the pre-upgrade installation, until all pre-upgrade types are added to the **Replaces pre-upgrade (old) fixtures** list.

> Energy use of the pre-upgrade installation is calculated as the sum of energy use of each type of pre-upgrade fixtures added to the list.

   d. For each zone, go to **Energy use**.
      i. Select which type of pre-upgrade fixtures is replaced by the new fixtures in this zone.
      ii. If the new fixture type does not replace any of the types found in the pre-upgrade installation, select **None**.

> The setup is now complete. Soon, the dashboard will start displaying the projected savings based on the monitored energy use. Over time, the projection will become more accurate.

7. Energy calculation method

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.

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

The energy use En over one minute is then calculated 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.

$$En = P \cdot t$$

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 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 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 must receive at least five LLA state messages (one per device) every minute to achieve a 100% completeness rate.

Additional assumptions:

- 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.

7.1 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.

7.1.1 Gross errors

Incorrect units are entered

Light levels were defined incorrectly for the energy profile. If only one level is incorrectly defined, 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.

Luminaires in a zone are not of the same type

Only one energy profile can be set up per zone, so if there are different types of luminaires 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 luminaire and use zone linking.

7.1.2 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 (see Example 1). For typical drivers this can be a few percent.

But 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 have not been added to the energy profile (see Example 2).

Example 1

We have an energy profile with some light levels and their related power. For a light level of 42% that has not been set up in the energy profile, the energy use will be calculated based on power for light levels of 20% and 50%, the two nearest values that have been entered.

Light level	Power	Power estimated for a light level of 42% (LLL_{42})
0%	0 W	$P_{42} = \frac{(LLL_{42} - LLL_{20})}{(LLL_{50} - LLL_{20})} \cdot (P_{50} - P_{20}) + P_{20} =$ $= \frac{(42 - 20)}{(50 - 20)} \cdot (40 - 10) + 10 = \frac{22}{30} \cdot 30 + 10 = 32\ [\mathrm{W}]$
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 in 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. 1).

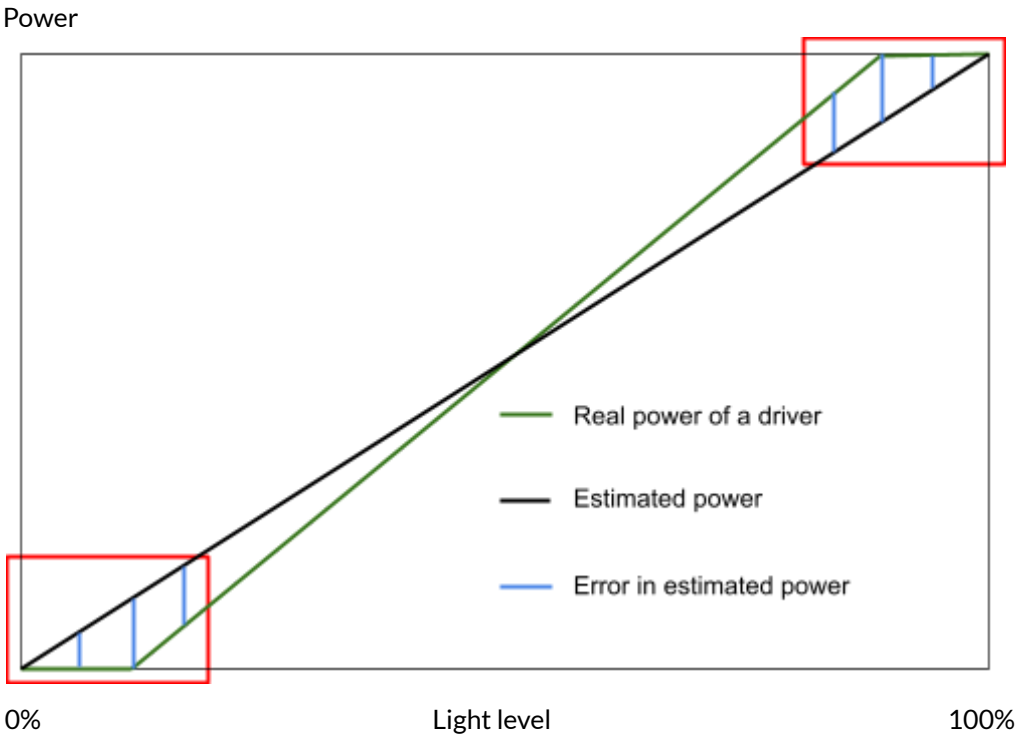


Fig. 1. *Error in power estimated for light levels near 0% and 100%*

For light levels near 0% and 100% that have not been added to the energy profile, the estimated power can be very different from the real power. In such cases, 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.

7.1.3 Missing data

There are two main causes of missing data. Because the transmission of data in a Bluetooth mesh network is radio-based, one cause is interference. The second cause is power loss, when the gateway is not able to receive data. Our solution uses interpolation to fill the gaps in data.

Missing data caused by interference

To verify the accuracy of interpolation and simulate data loss due to interference, we conducted tests using an installation at our office and removed random data. We then compared the original data with the data in which gaps were filled using interpolation (Fig. 2).

While collecting data, the change in light output over time was slow. In most lighting conditions the light remains constant for 30 to 60 minutes and the light output is measured at least once a minute.

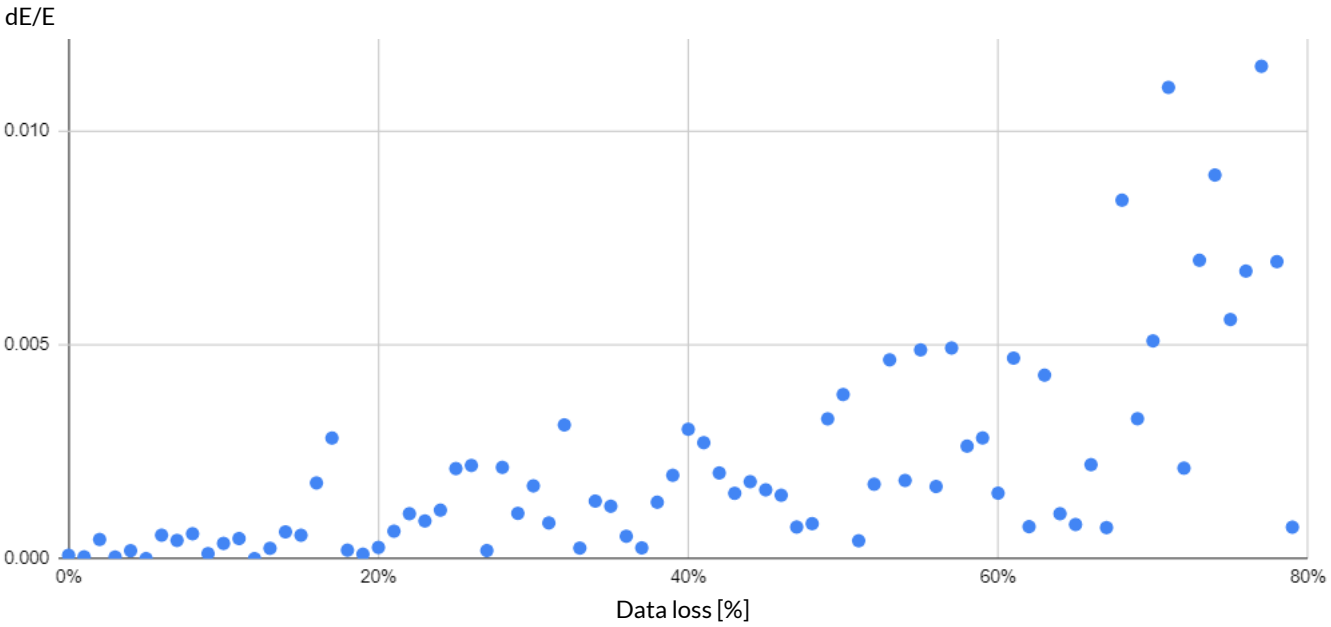


Fig. 2. *Energy calculation uncertainty in relation to the data loss percentage (data added by interpolation)*

General conclusions:

Accuracy decreases with the increase in missing data. But because the light output changes slowly and is measured frequently, the uncertainty is well below 1%, even when more than 60% of data is lost.

Missing data caused by power loss

Interpolation can be very inaccurate when data is lost over a long period of time, especially if the light output during that period changes. This can occur, for example, 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 compared the original data with the data in which gaps were filled using interpolation (Fig. 3).

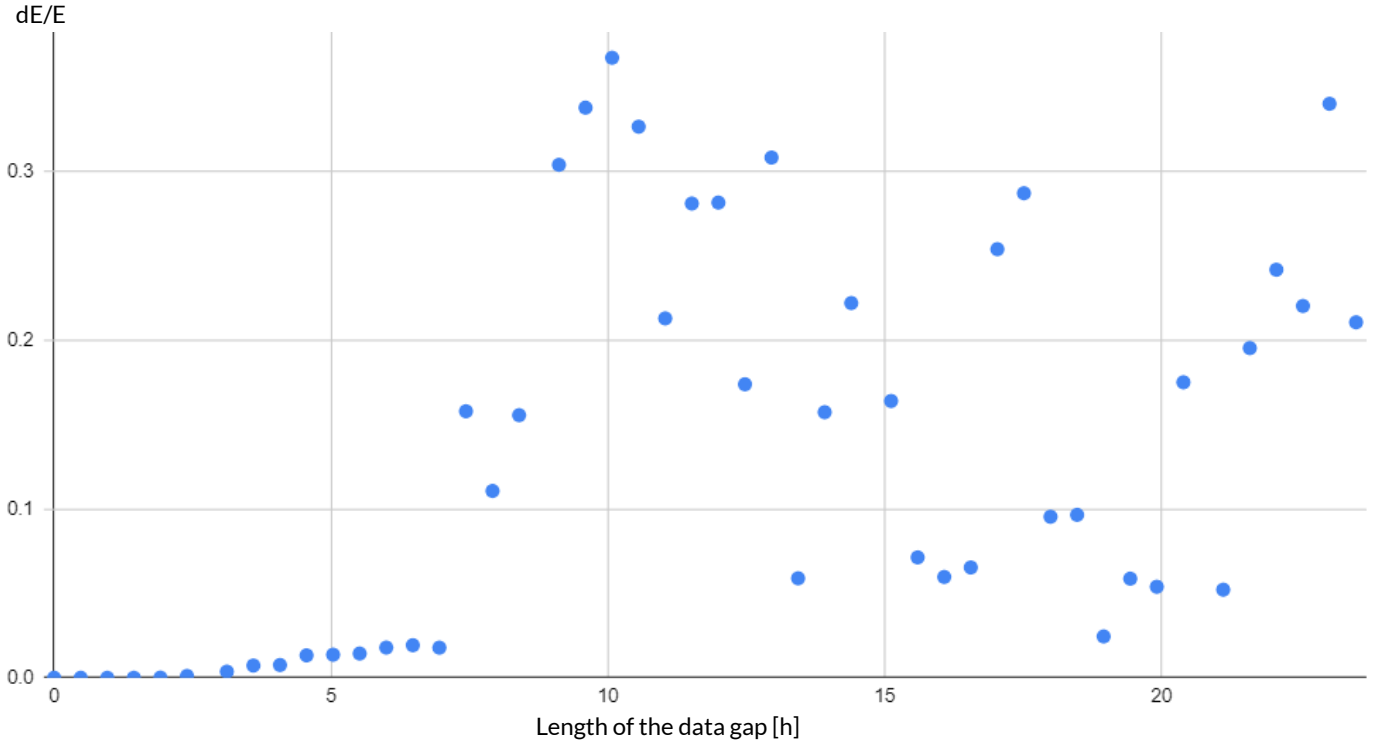


Fig. 3. *Energy calculation uncertainty in relation to the length of the data gap (data added by interpolation)*

General conclusions:
As before, accuracy decreases with the increase in missing data. However, the relative uncertainty (dE/E) is much larger when data loss is caused by power loss than when it is caused by interference. But even for a long gap in data (around 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 in use during that time.

7.1.4 Conclusions

- To avoid gross errors, make sure that all the luminaires in a zone are of the same type and 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.
- Interpolation works very well for missing data caused by interference. The relative uncertainty of calculated energy is less than 1% even for large data loss.
- In typical installations where data loss is caused by interference, errors in the energy profile are the main source of inaccuracy of energy calculation.
- Because accuracy of interpolation is much lower over longer periods of time, it is important to minimize data gaps.
- The energy data is collected and stored per luminaire, per zone, and per area for 24 months, as 15-minute averages.

8. 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 be interpolated between the last data point before the power failure and the first 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 stored by the gateway and sent to the cloud when power is restored?
The gateway does not store any data, so data for that period is lost. 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?
The devices do not store any data, so data for that period will be lost. But gaps in the data will be interpolated between the last data point before the gateway stopped working and the first point after it started working again.

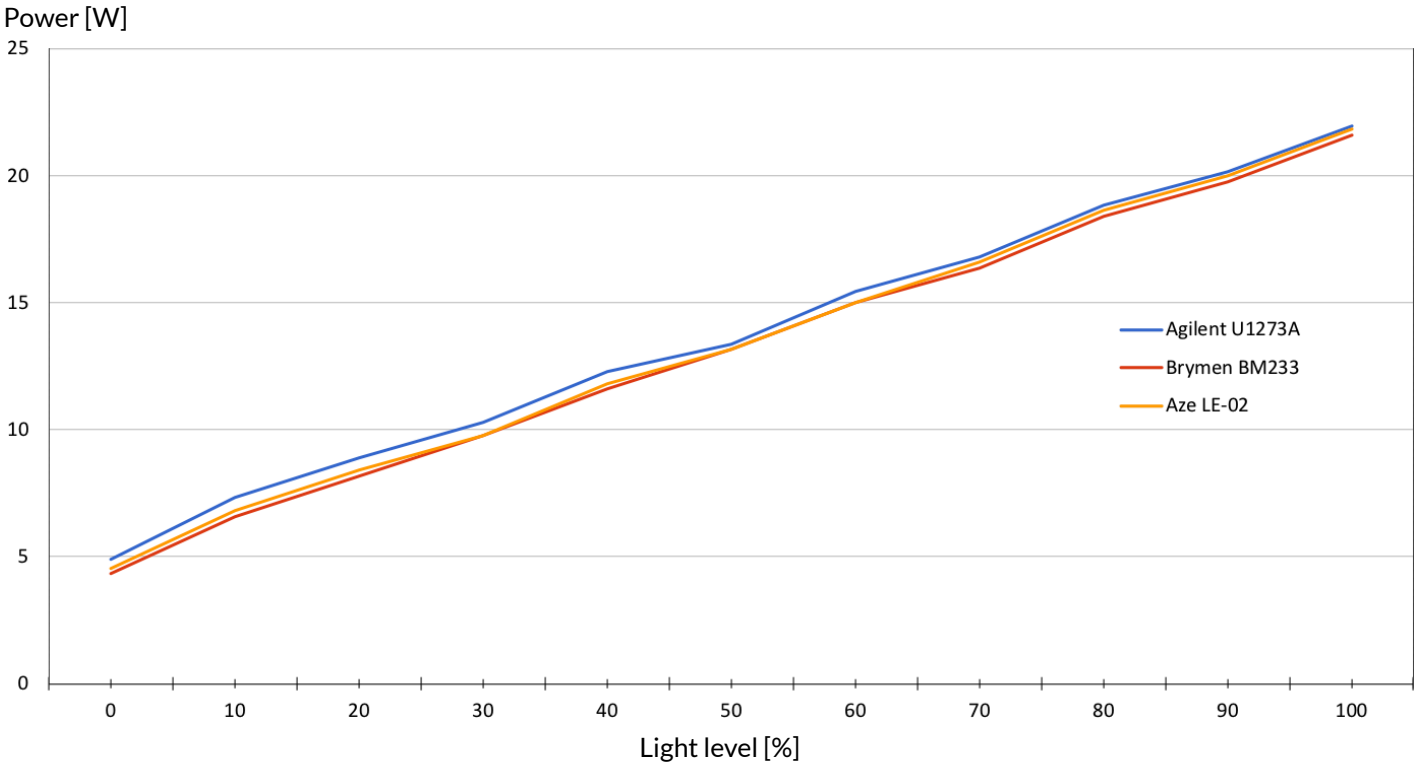
If there is a problem with the internet connection, will the gateway store the energy use data and send it to the cloud when the connection is restored?
The gateway does not store any data, so data for that period will be lost. But gaps in the data will be interpolated between the last data point before the connection was lost and the first point after the connection is restored.

9. Power meter recommendations

It is up to you which power meter to use, but BlueMesh recommends three power meters:

- Agilent U1273A
- Brymen BM233
- Aze LE-02

The following figure shows example power measurements of a luminaire made by these power meters.



Contact information

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For more information please visit:	**www.bluemesh.us**