The True Cost of Batteries – why energy harvesting is the best power solution for wireless sensors

Batteries are part of our daily lives and we have become accustomed to changing them as they die. The growth of mobile and wireless applications yields an increasing number of devices powered by batteries. The battery replacement effort becomes more costly and complex as scale increases. Batteries are cheap, replacing them is not.

This is particularly true in systems consisting of several tens, hundreds or thousands of wireless nodes as you find in the field of smart home and building automation. Just think of a hotel, which has equipped each of its 400 rooms with four battery-powered sensors. Every two to three years, each one of these 1,600 batteries needs to be replaced – it is irrelevant if the devices are hard to access or hotel guests might be disturbed. Worse still is when batteries in a light switch or a remote control fail during guest usage. In commercial or industrial operation, a battery cost calculation must therefore be included to generate accurate lifetime costs covering maintenance efforts and proper hazardous materials disposal. Only Total Cost of Ownership (TCO) calculations reveal the true cost of battery-operated systems.

Energy harvesting solutions free building owners, facility managers or contractors from the burden of batteries. They combine the benefits of highly flexible wireless solutions with the same maintenance-free attributes as wired-in devices with a fast, consistent, and repeatable return on investment (ROI).

The Wireless Way

Service calculations on a time and materials basis play a significant role before starting a building automation project. The project site must be evaluated, which includes a determination of how and where to pull wires for sensors and switches. In retrofit buildings, this is a particular challenge. Once the work on the project begins, each day requires setup, tear down, clean-up, and travel, as well as the electrician's time.

These hurdles can be overcome by the use of wireless solutions. Wireless devices can be flexibly placed and eliminate the need to install wiring and conduits. This significantly eases and reduces the planning and implementation effort. However, these wireless devices often still have batteries, but the challenges they present can be overcome.

Batteries mean maintenance

There are typically three methods of battery maintenance:

- Build in a low battery monitor and alarm – such as the beeping smoke detector in the middle of the night. Security systems have a supervisor signal every hour to inform the base station they are alive. In case of a dead battery, no supervisory signal is received, and the alarm triggers. This may also trigger a false call to the alarm monitoring center.
- Change all batteries on a preset timetable, usually at the shorter end of their expected lifespan.
- Wait for the battery to fail, and then debug the failure as a dead battery. This presents some problems if the user is unaware that the device is battery-powered, e.g. thermostat or light switches, which are typically not battery-powered. The consumer only knows that the light does not switch on or the room does not get warm. This reactive method results in user dissatisfaction.

Deploying batteries means additional planning and maintenance overhead that result in measurable effort for facilities managers in order to maintain occupant satisfaction.

"An estimated 20% of U.S. homes have smoke alarms present but none that are working. Nearly all of this 20% involves dead or missing batteries."
(National Fire Protection Association, NFPA)

Difficulties in Changing

Battery-powered devices are mobile, and their location needs to be documented and updated as the location changes. In a large building system, hundreds of sensors are distributed over several floors and offices. Often, the devices are mounted unobtrusively in places that are difficult to reach, e.g. on or above drop ceilings. In addition, each device has a different battery access method and requires different types of batteries. This results in extra work, making the battery replacement a challenging and time consuming effort. Some batteries even require specially trained technicians for replacement as they can explode when handled improperly.

Various devices lifespan

- **The energy demands of finished devices vary from one type to another, causing different battery replacement intervals.**
- **Lifespan varies from those devices in high usage areas versus lower. For example, occupancy sensors in one area see more traffic and more RF signals than in a back room.**
- **Environmental conditions impact on battery performance and lifespan, e.g. cold or warm temperatures.**

Finally, the question remains "who is in charge of changing batteries?" – The facility owner, the tenant, or a paid service provider? The person responsible often requires access to the entire facility and its sensitive security system. For contractors, the maintenance effort of changing batteries causes additional lifecycle costs over the contract period and makes it more difficult for them to fulfill service level agreements. For larger systems, contractors need to calculate long lead times when ordering new batteries and need to store a certain amount of batteries for replacement as Lithium Ion batteries can only be shipped in small quantities and in some countries, for example in North America, not by air.

Costs to Calculate

Devices are typically powered by Alkaline AAA with a lifetime of two to three years or by Lithium Ion at a lifetime between five and seven years. The following table shows an example cost calculation for both:

	Commercial	Residential
	Lithium	**Alkaline**
Life (years)	5	2.5
Cost (US$)	5	0.65
20 year replacement cycles required	3	7
Quantity of batteries per node	1	4
Cumulative battery cost (US$)	15	18.20
Change labor cost per node (US$)	2.50	inconvenience
Cumulative labor cost (US$)	7.50	
20 year lifetime cost (US$)	22.50	
20 year quantity of batteries disposed	4	32
Batteries purchased and disposed for 50 nodes	200	1,600

A large system, for example in an office comprising 10,000 wireless units each powered by two batteries with a lifetime of two years, could require the facility manager to change approximately 30 batteries each day.

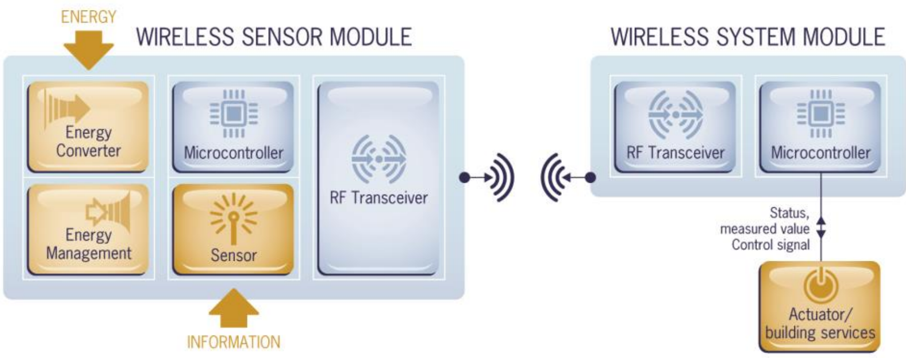
Battery-less Performance

These costs for battery replacement are a significant disadvantage to the growth of wireless sensor networks and open the door to EnOcean energy harvesting wireless technology. Due to the energy harvesting principle, these wireless modules harness their power from the surrounding environment and therefore work without batteries. There are a variety of energy sources, an electrodynamic energy converter uses mechanical motion, or a miniaturized solar module generates energy from indoor light. Additionally, combining a thermoelectric converter with a DC/DC converter taps heat as an energy source.

EnOcean modules can be powered by the same energy sources as all other traditional wireless switches and sensors, line voltage, and batteries; however, it is the only technology that consumes low enough power to operate with the ultra-low power provided from energy harvesting.

Powerful Energy Converters

In general, traditional battery-powered technology consumes ten times the amount of energy as self-powered devices. However, due to optimized energy management, energy converters are unexpectedly powerful. Inside buildings, with eight hours of average light intensity (400 lux), an economical mini-solar cell with an efficiency of less than 5% and an area of 10 cm2 supplies approximately one ampere-hour (Ah) of energy over the course of 15 years – the same amount as five CR 2032 Li button cells. Outdoors (8000 lux), this intensity is as much as 20 Ah over the same period of time, which equals the power of more than 100 Li button cells. While in this typical example users must change the batteries of battery-operated devices every three years and every two months, respectively, energy harvesting makes equipment truly maintenance-free.



Reliable Operation

Tapping renewable energy sources enables a power output of 10 mW for radio frequency (RF) transmission of device data. However, the wireless transmission used has an energy requirement of only 50 microwatt seconds for a single telegram. This enables energy harvesting wireless technology to be scaled to different applications.

At the same time, the energy-optimized radio protocol at sub 1 GHz frequencies provides a strong signal-to-noise ratio and less interference from other devices at a reliable long range wireless communication of up to 100 feet (30 meters) indoors. This is often twice the range in comparison to battery-powered devices, which typically have 1 mW power output to extend battery life.

The reliable operation of battery-less devices contributes to another key factor: user satisfaction. It’s not acceptable that an air conditioning system can’t be switched on in the summer or that a user can’t turn on lights at night because a battery-powered sensor or switch stopped working. The use of energy harvesting wireless devices avoids frequent support calls, which has a positive impact on the users' satisfaction with the system. This perception of reliability can result in valuable word of mouth recommendations or repeat buys when building owners decide on a system extension.

Install and Forget

Battery-less sensors and switches free building owners, facility managers, occupants, and contractors from maintenance effort and costs for typically 20 years or more. This "no maintenance" characteristic significantly reduces the TOC over the system's whole lifecycle. It enables wireless components to be installed and forgotten just like wired-in controls, even in places that are difficult to reach.
The elimination of battery access doors also simplifies embedding the wireless sensors and switches in door locks, window panes or cable locks while the energy harvesting modules allow smaller device form factors and environmentally sealed enclosures at the same time.

Benefits of energy harvesting

- **Reduced planning and installation costs, no wires needed**
- **Maintenance-free for > 20 years, no battery replacement needed**
- **Equivalent functionality as wired devices**
- **Flexible positioning and updating**
- **Reliable, long range communication**
- **No hazardous waste disposal**

The Environmental Factor

When considering battery costs, the environmental impact needs to be included as well. Batteries contain heavy metals such as mercury, lead, cadmium, and nickel, which are detrimental to the environment. At the end of their lifetime, batteries are hazardous waste due to the toxicity (chromium D007), ignitability (D001) and reactivity (D003) and need to be carefully and expensively disposed of by the manufacturer or the user. Depending on the battery technology in use, a user will dispose between 200 and 1,600 batteries over 20 years in a residential home with only 50 nodes.

"Battery recycling is energy-intensive. Reports reveal that it takes 6 to 10 times more energy to reclaim metals from some recycled batteries than it does to produce it through other means, including mining." (Battery University)

The safe storage of batteries requires high standards and can be a real challenge. Batteries stacked carelessly on top of one another can burst or generate heat. All of the negative environmental impacts and challenges related to battery disposal and storage are eliminated by utilizing EnOcean energy harvesting technology.

Technology with a Future

Energy harvesting offers significant advantages over batteries when it comes to ecobalance and maintenance-free operation. Based on the battery-less wireless technology, a wide range of self-powered applications are available today, including switches, intelligent window handles, temperature sensors, humidity and particle sensors, light sensors, occupancy sensors, relay receivers, heating valves, control centers, and smart home systems. For all of these wireless devices, the self-powered technology eliminates the dependency on batteries. For more power-hungry devices such as programmable thermostats with LCD panel and backlight, the energy-efficient EnOcean radio can extend battery lifetime significantly over traditional radios.

Batteries will not disappear and for some applications they will remain a necessity. But from a design, environmental and reliability standpoint, energy harvesting is the technology of the future. In the years to come, energy harvesting will increase its lead over batteries further – especially since energy converters and storage elements continue to improve their performance and costs.

Someday, it might be that up to 10 trillion wireless sensors deliver the needed data for the Internet of Things. 10 trillion battery-powered sensors would require 1 million tons of Lithium – the combined worldwide Lithium production of 10 years. Based on a 10 year average battery life time, 10 million maintenance workers would be requested to change batteries, each of them 100,000 per year.