Technical Report

Estimating the Battery Life of an Occupancy Sensor

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LUTRON®

Battery Life Determination

To increase accuracy, battery life is determined using multiple methods. Battery life *calculations* combine measurements of current-over-time with technical component data to calculate expected life. Battery life *measurements* use discharge experiments, and measure residual capacity in the battery, to predict expected life.

Battery life calculations were done by Lutron engineers and reviewed by Portable Power Consultants, LLC, (PPC). Battery life measurements were conducted by PPC.

Summary of Results

Battery life calculations yield an expected lifetime of ten years for a CR123A battery (see Table 1) under the same conditions as the aging done in the battery life measurements. Data from the battery life measurements predict slightly longer lifetimes, averaging 12-13 years, and a minimum lifetime of 11.2 years.

The discrepancy is explained as follows. The calculations include self-discharge and worst-case circuit numbers. In addition, the life of the battery depends on the discharge rate (current). The life numbers available from the manufacturer for a CR123A battery are for a continuous discharge current of 20 mA, which is higher than the 12 μA average discharge current of the occupancy sensor. Operating at the lower discharge current results in additional life.

Battery Life Calculations

Battery life is dependent on the average current, which can be calculated by using measured timing numbers and the worst-case current consumption. Data sheets for the various electronic components are used to determine worst-case current consumption. The actual circuit current is measured to verify accuracy for various component-operating conditions.

A precision ammeter measures the current consumption of the individual circuit blocks in each operating state (e.g. the controller uses 1.5 mA while awake and processing—see Figure 1). The time during which this current flows is measured on a digital oscilloscope (to complete the above example, the controller wakes up and processes for 180 microseconds).

These calculations also include the effects of temperature variation and battery self-discharge. The battery used is a Panasonic Lithium CR123A, which has a capacity of 1550 mAh at a discharge rate of 20 mA (as shown in specification table, Figure 2).

Note: The battery tests in this study were performed on Lutron Radio Powr Savr wireless occupancy sensors. Lutron Pico wireless remotes and Radio Powr Savr wireless daylight sensors use the same battery chemistry, and are also estimated to have lifetime greater than 10 years. The Lutron engineering team designed Pico wireless remote and wireless daylight sensors to the same level of quality and reliability. Although this white paper does not cover the detailed calculations for Pico remotes and wireless daylight sensors, the same rigor went into estimating their lifetimes.

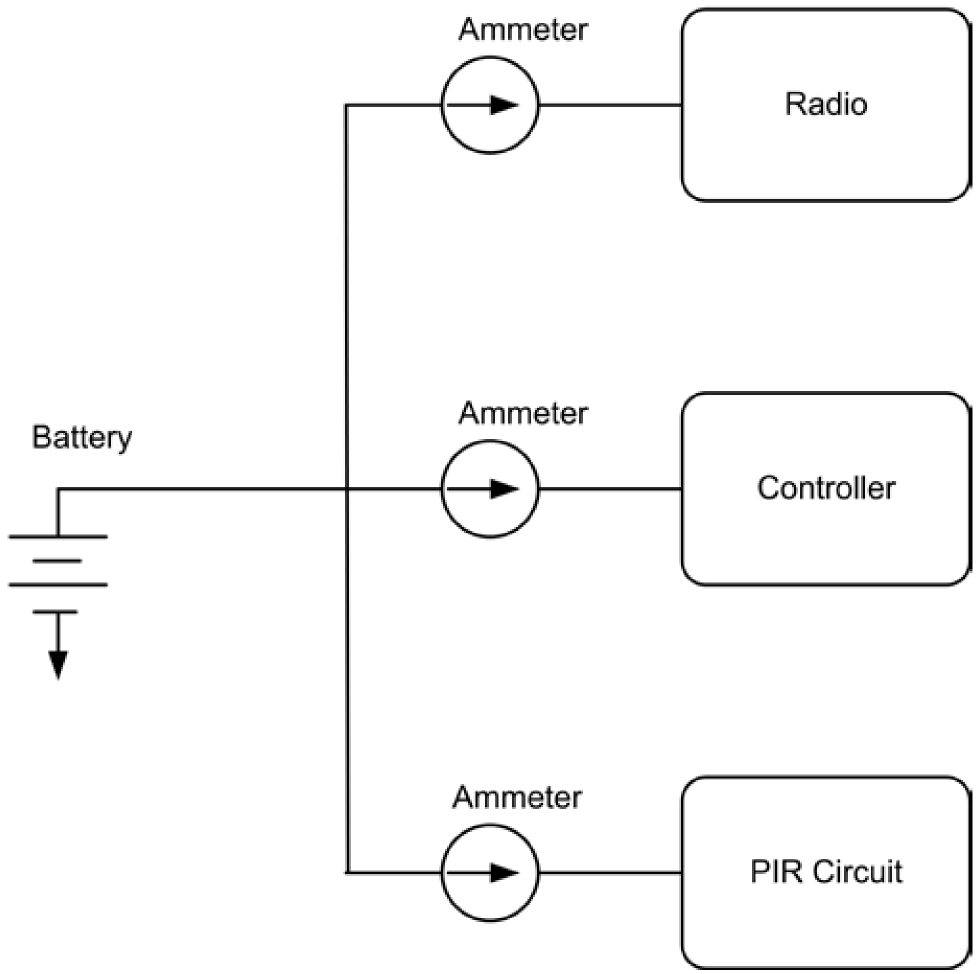
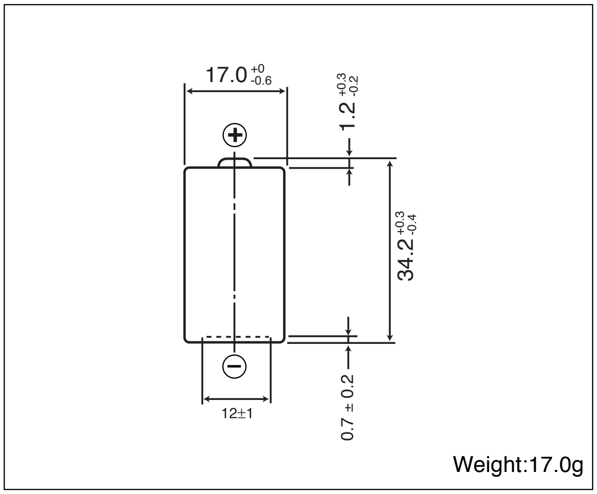


Fig. 1. System block diagram.

Manganese Dioxide Lithium Cylindrical Batteries: Individual Specifications

CR123A

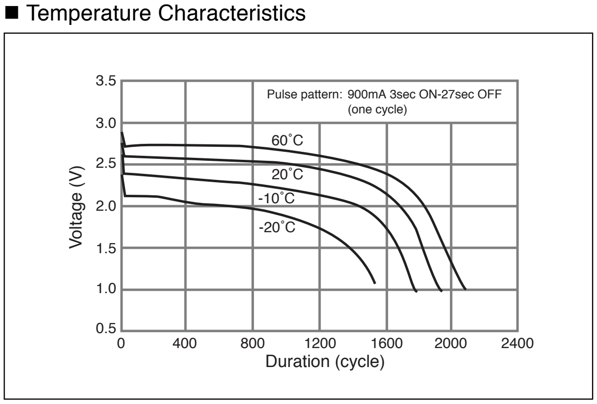
Dimensions (mm)



■ Specification

Nominal voltage (V)	3
Nominal capacity (mAh)	1,550
Continuous standard load (mA)	20
Operating temperature (C)	-40 ~ +70*

■ Temperature Characteristics



* Please consult Panasonic for use below and above -20°C to +60°C

Panasonic **LITHIUM HANDBOOK** **AUGUST 2005**

This information is generally descriptive only and is not intended to make or imply any representation, guarantee or warranty with respect to any cells and batteries. Cell and battery designs/specifications are subject to modification without notice. Contact Panasonic for the latest information.

Fig. 2. Panasonic battery data sheet.

Calculations for various conditions are shown in Table 1. The conditions are as follows:

- Occupied for a specified number of hours per day
- Building is operational a specified number of days per week
- The timeout is fixed and the unit immediately transitions from occupied to vacant, and then right back to occupied (this is a worst-case scenario, equivalent to someone entering the room, leaving the room, and then immediately returning)
- The temperature is fixed

Table 1. Life Calculations

Occupied hours per day	Occupied days per week	Timeout, minutes	Temperature, °F/°C	Life, years
10	5	15	72°/22°	11.9
10	7	15	72°/22°	10.7
10	7	15	104°/40°	8.8
12*	7	15	72°/22°	10.0
24	7	15	72°/22°	7.1
24	7	15	104°/40°	6.2

* Same conditions used for battery life measurements

Verification of Calculations

A second spreadsheet calculator was created to verify the accuracy of the numerical methods used. It is essentially the same as the first spreadsheet, except that it does not use the worst-case current consumption data. Values in the second spreadsheet are calculated using the measured currents and times for the individual states of operation (e.g. sleeping or processing).

The three modes of operation are: vacant, occupied, and transmission. A precision integrator (as shown in Figure 3) was used to measure the average current in each mode. The results from the integrator and the spreadsheet correlate to within 5%.

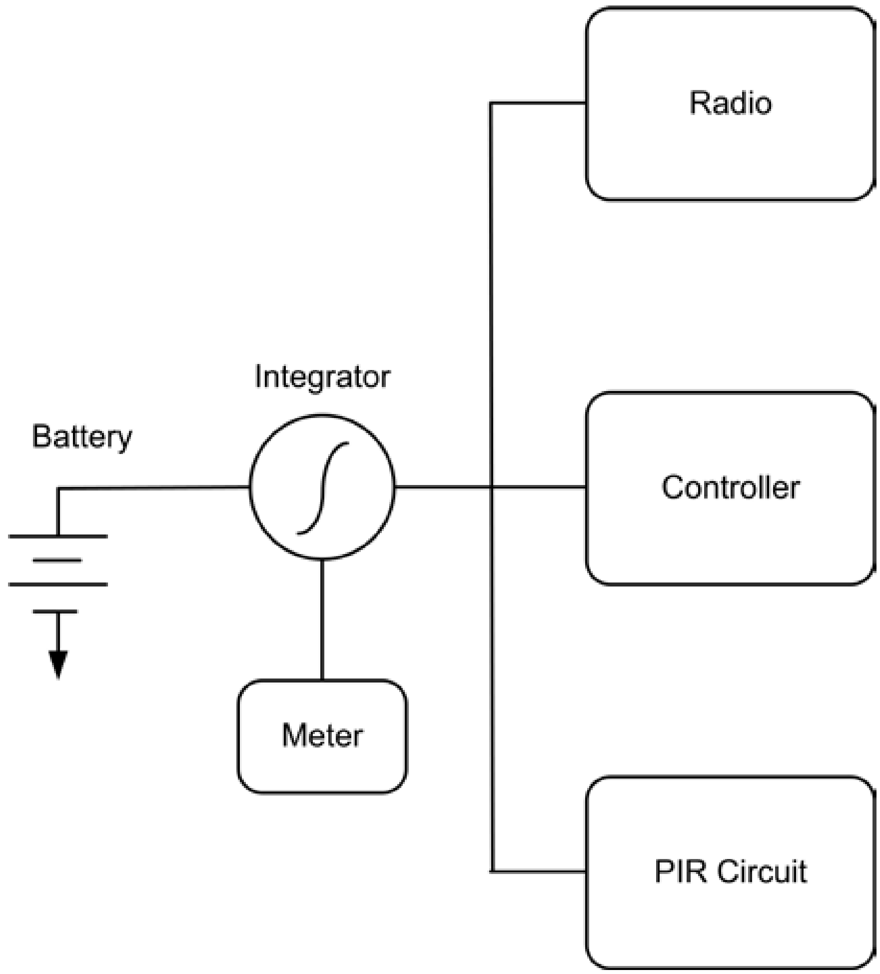


Fig. 3. Calculation verification block diagram.

Battery Life Measurements

Battery calculations indicated an expected 10-year life for the sensor fitted with a commercial CR123A (Lithium Manganese Dioxide) battery, and were supported by conducting several experimental, accelerated-lifetime measurements. Acceleration factors were obtained by modifying the sensor software, using smaller capacity batteries of the same chemistry, or using batteries that were partially discharged under controlled conditions.

Table 2. Test Descriptions

	Acceleration method	Lifetime acceleration factor	Details
A	Modifying sensor software	1	Simulates different use conditions
B	Reduced capacity	7	CR2032 batteries rated for 220 mAh used in place of CR123A (1550 mAh); both have same Li/MnO_2 chemistry. Reduced capacity factor 1550/220 = 7x lifetime acceleration
C	Partial discharge	10	Batteries discharged to 90% capacity*

* To determine the 90% discharge state (10% remaining runtime) and to support the analysis of the results for the battery life measurements, a group of ten CR2032 (220 mAh) batteries were discharged with a 1000 Ω resistor (approximately a 3 mA current) to a 2.0 V cut-off. The run time for each battery was measured and the average run time computed. Similar measurements were made with CR123A (1550 mAh) batteries discharged at 30mA.

Table 3. Acceleration Factors

Test	Methods used	Acceleration factor	Battery, capacity
1	A, B	7	CR2032, 100%
2	A, B, C	70	CR2032, 90%
3	A	1	CR123A, 100%
4	A, C	10	CR123A, 90%

Voltages were monitored using test equipment manufactured by Maccor. Product tests were run in the home/office environment. Test results are summarized in the following pages.

Test 1

For the first test, the software was modified to spend half the time in occupied mode and half the time in vacant mode for seven days a week.

At prescribed times, some of the batteries were removed from the product and the remaining capacity in each battery was measured. For example, battery 1 and battery 2 were removed at the 90-day mark, leaving eight units under test. Since 12% was consumed in three months, the units should last 25 months (3 months/12%= 25 months). Using the acceleration factor of 7 the units are estimated to 14.6 years.

Table 4. Remaining capacity of CR2032 batteries under accelerated aging and reduced battery capacity.

Battery use	Remaining capacity	Estimated product life
90 days (batteries #1, 2)	64.6 hours, 88.0%	14.4 yrs
330 days (batteries #3, 4)	39.0 hours, 53.1%	13.5 yrs
705 days (batteries #5-10)	00.0 hours, 0.0%	13.5 yrs
	Weighted Average	**13.6 yrs**

Six cells were run to failure (V < 2.0), with an average lifetime of 705 days and the maximum 788 days. This average value, multiplied by an acceleration factor of 7 due to decreased battery capacity of the CR2032 vs. the CR123A, gives an estimated life of 13.5 years. The weighted average of all 10 batteries in this test yields a 13.6-year battery lifetime measurement.*

* This should be compared to the calculation in Table 1 for 12 hours per day. It should be noted that these results do not include the self-discharge of the battery and worst-case circuit numbers. The accelerated test relies on an extrapolation of the circuit usage (including self discharge) based on 705 days of operation. In addition, the lifetime depends on the discharge rate (current). The specified 1550 mAh battery capacity reported by the manufacturer is based on a continuous discharge rate of 20 mA. The actual discharge current of the occupancy sensor is a pulsed discharge with a time average of 12 μA. Reduced discharge current will result in additional life.

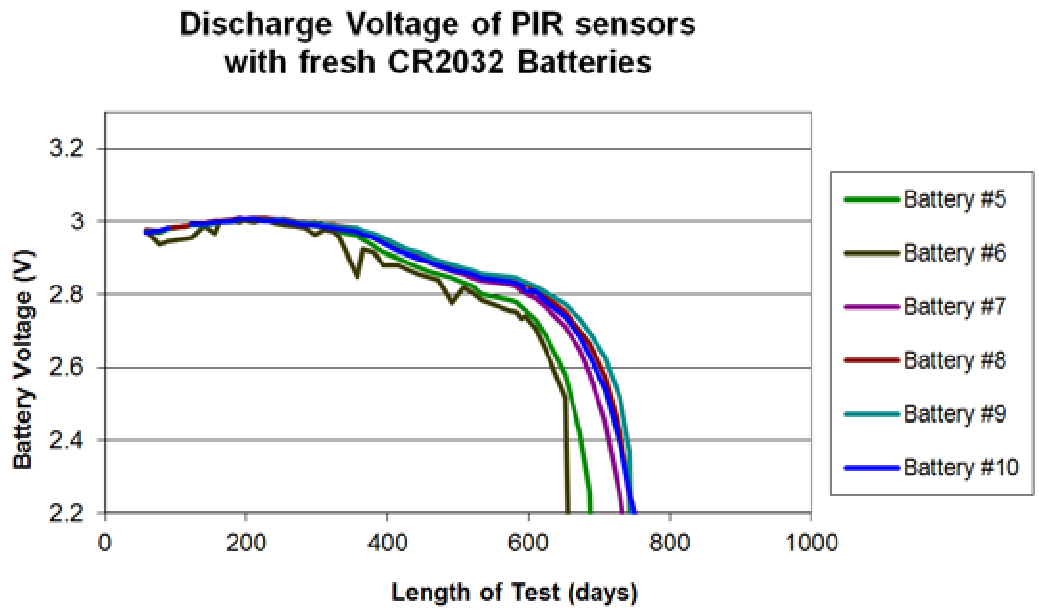


Fig. 4. Voltage profile of batteries in the accelerated test using fresh CR2032 batteries.

Test 2

These cells failed (voltage <2.0V) after 184 and 211 days (see Figure 5). The product life can be estimated from the average daily use (0.312 mAh/day) obtained in Test 1 to calculate the number of days to consume 90% of the battery capacity, plus the days until battery failure as determined in the test. This calculation is based on the nominal capacity (220 mAh) available in the Energizer CR2032 battery. In this test, the estimated product life is 12.7 years.

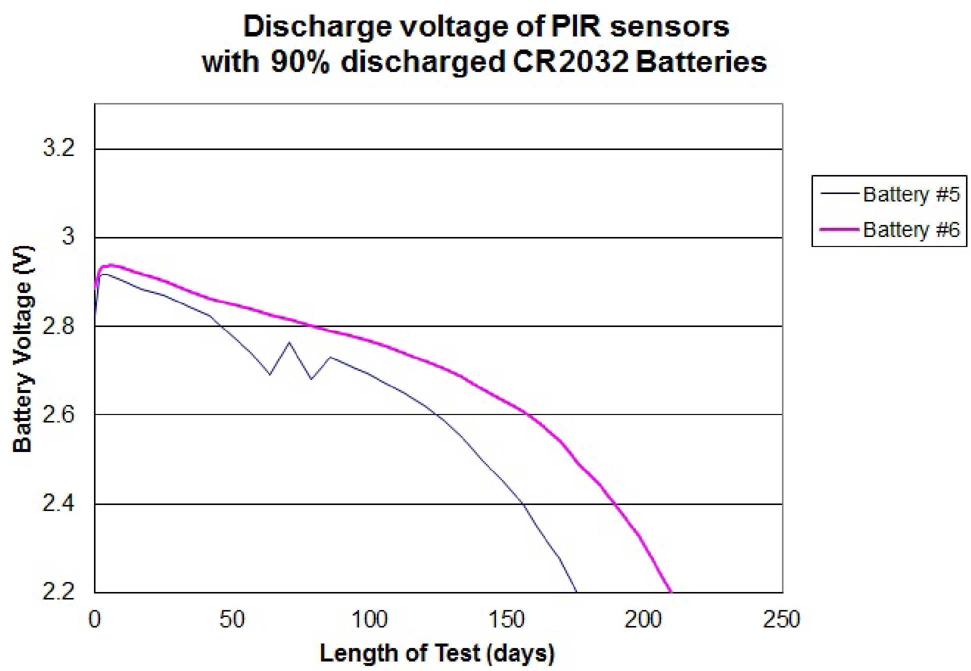


Fig. 5. Voltage profile of batteries in the accelerated test using CR2032 batteries discharged to 90%.

Test 3

Battery #13 was removed for residual capacity test at 220 days. Battery #14 was removed for residual capacity testing at 657 days. Computation of expected battery life in PIR sensors, based on residual capacity measurements, is shown in Table 5.* In both tests the estimated product life exceeds 10 years.

Table 5. Remaining capacity of CR123A batteries under accelerated aging.

Battery use	Remaining capacity	Estimated product life	mAh/day
220 days	1466. mAh, 94.6%	11.2 yrs	0.382
657 days	1431. mAh, 92.3%	23.4 yrs	0.181

* The large differences in the estimated product life (11.2 years and 23.4 years, respectively) arise due to the uncertainty of the value of the actual battery capacity under test. The nominal capacity, 1550 mAh, was used to determine the capacity consumed. The actual values will be a bit larger or smaller. These individual variances, when added to, or subtracted from, the experimentally determined capacity consumed, will make a significant impact on the product life estimates even when only small amounts of capacity are consumed.

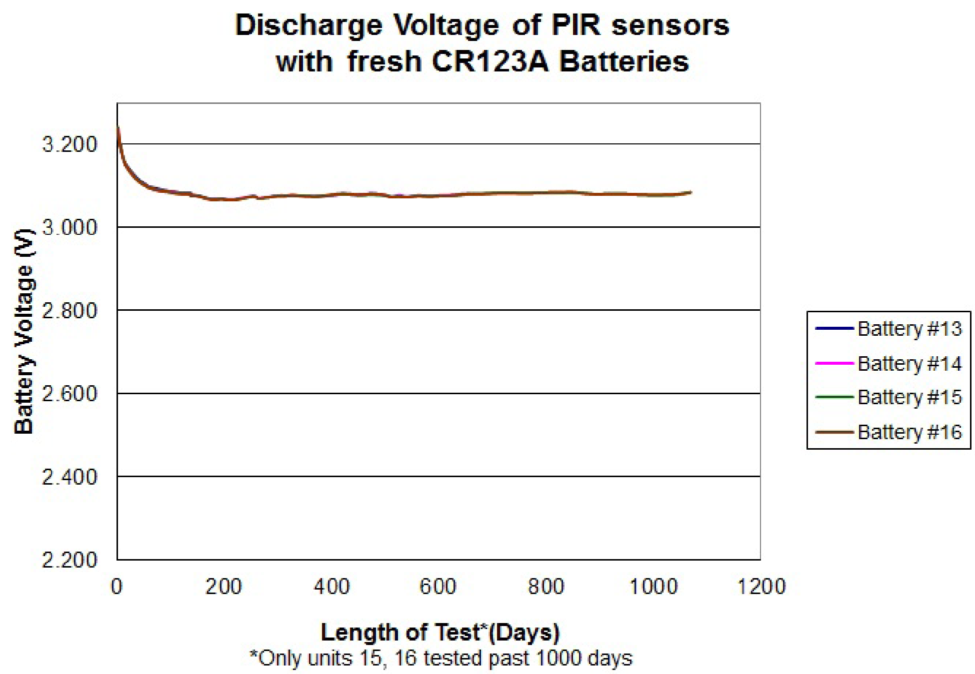


Fig. 6. Voltage profile of batteries in the accelerated test using fresh CR123A batteries

Test 4

Computation of expected battery life in PIR sensors, based on residual capacity measurements of Battery #9, is 13.5 years. This calculation is based on the nominal capacity of 155 mAh available in the 90% discharged cell, and is summarized in Table 6. Battery #9 was removed for the residual capacity test at 220 days. The remainder of the 90% discharged batteries suddenly failed between 224 and 306 days. Batteries #10 through #12 failed abruptly during the test leaving no measurable residual capacity. However, product life was estimated using the daily capacity usage (0.314 mAh/day) measured on battery #9.*

The estimated number of days required to consume 90% of the battery capacity (1395 mAh) is added to the measured number of days to battery failure. In all tests, the estimated product life exceeds 12 years.

* This failure is explained by the chemical safety switch (described in US Patent 6,391,488 B1) built into CR123A cells, which cuts through the Lithium anode at the last stages of discharge to prevent further cell discharge and potential voltage reversal. The Panasonic data shows the switch activating during a continuous 3 mA discharge after about 75% of the cell capacity has dissipated, but Lutron's reduced current consumption delays the onset until 90% of the cell energy is used. Additional testing shows that the rapid-discharge currents used to set up the 90% discharge tests do not influence the activation of the chemical switch termination (Table 6).

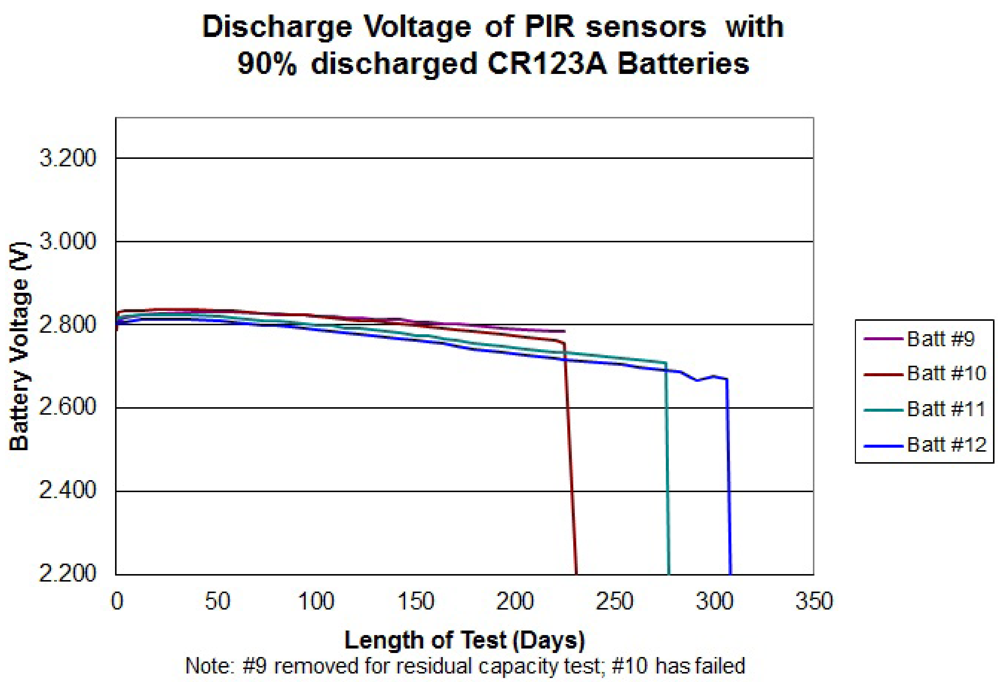


Fig. 7. Voltage profiles using 90% discharged CR123A batteries.

Table 6. Remaining capacity of CR123A batteries under accelerated aging.

Battery #	Run time (days)	Remaining capacity		Capacity used (mAh/day)	Estimated life (years)
		mAh	%		
9	220	85.9	55.4	0.314	13.5
10	224	0	0		12.10
11	275	0	0		12.23
12	306	0	0		12.32

Conclusions

Extensive testing has been carried out with the Lutron PIR occupancy sensor to estimate the product lifetime when powered by the Panasonic CR123A Li/MnO2 battery. Accelerated tests were carried out with both the CR123A battery and a smaller capacity CR2032 battery of the same chemistry. Tests included fresh cells and cells with 90% of the capacity pre-discharged. All test results exceed the desired 10-year lifetime. The minimum estimate measured was 11.2 years with the majority of the estimates falling in the 12- to 13-year range. Two CR123A batteries remain on test and have completed more than 720 days of continuous operation.

There is experimental evidence that the chemical safety switch built into the Panasonic CR123A cell is activating and terminating sensor operation. This early termination does not occur until after more than 90% of the battery capacity has been consumed and the product life target exceeded.

Table 7. Battery lifetime measurements summary

Test	Acceleration factor	Lifetime measurement (years)
1	7	13.6
2	70	12.7
3	1	17.3
4	10	12.5