Industry Session 15: Energy Harvesting

APEC 2019

Power Sources Manufacturers Association
The Multinational Power Electronics Association

United Technologies Research Center

Perspectives on Energy Harvesting for Aerospace Sensors

Presented by

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Outline

1. Introduction – UTC aerospace and BEM (building energy management) applications
2. Why Energy Harvesting for aerospace?
3. Unique aerospace challenges for Energy Harvesting
4. Reduced energy consumption – needs and opportunities
5. Similar challenges and opportunities in the BEM Environment
6. Conclusions

Introduction – United Technologies (UTC) Portfolio

Otis

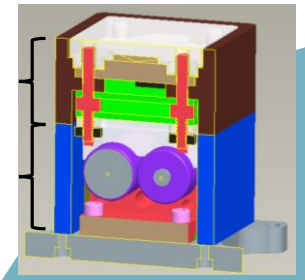
Pratt & Whitney

UTC Climate, Controls & Security

Collins Aerospace

Why Energy Harvesting for Aerospace?

Wireless Sensor Module



Battery replacement every 227 operational hours!

Wiring Example: A380
- 530km of wire
- 40,000 connectors

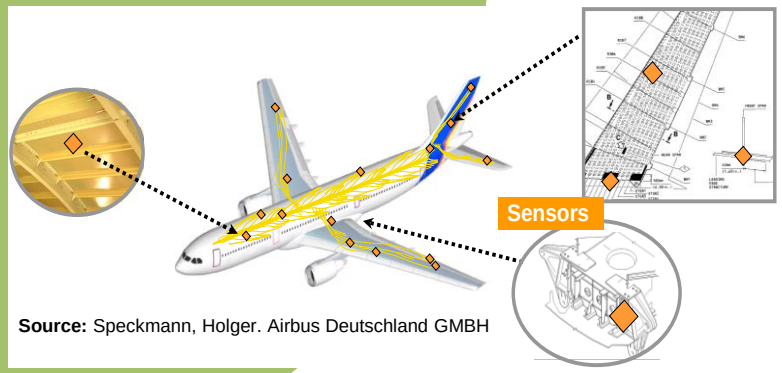
Batteries
- Initial and replacement battery cost $
- Battery change cost – A/**C**/D checks $$$$
- Battery volume

Wiring or Battery Replacements

Re-certifications

Sensors in Powerless Locations

PHM Example:
- Problem: failing ACM fan motors in flight
- Solution: simple real-time accelerometer spectrum analysis detects failure before catastrophic loss
- New problem: galvanic connection to sensor system requires re-cert
- New solution: wireless self-powered sensor



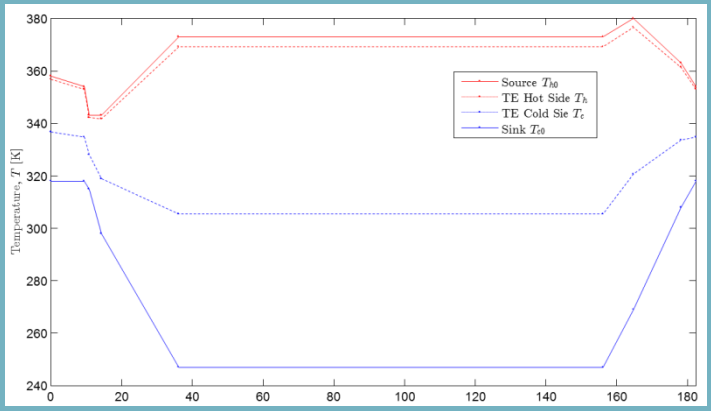
Source: Speckmann, Holger. Airbus Deutschland GMBH

Wings, fins, nacelles, and landing gear have need for sensors without extra wiring

Unique Aerospace Challenges for Energy Harvesting

Environmental

-55 to 85°C
10 to 100 kPa
4 LTO cycles/day



LTO Cycles Affect Components, Materials, and Energy Sources

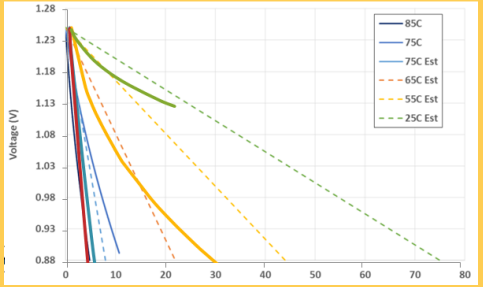
Component Leakage

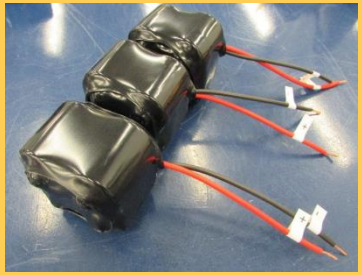
Parameter	0.01uF 16V	0.1uF 6.3V	1uF 6.3V	10uF 6.3V	2.5F 5V	500mA 20V	1A 40V
Component type	Capacitor	Capacitor	Capacitor	Capacitor	Super-Capacitor	Diode	BJT
Component size	0805	0201	0603	0402	"Can"	0603	SOT-563
Component material	Film	Ceramic X6S	Ceramic X7R	Ceramic X5R	Electrolyte	Si Schottky	Si PNP
Applied voltage	4.1V	4.1V	4.1V	4.1V	4.1V	4.1V	4.1V
Leakage current	0.08uA	0.14uA	0.13uA	0.12uA	15.6uA	12uA	55uA

Typical Sensor Component Leakage at 25°C

Problems at Temperature Extremes
- Rechargeable battery lifetime is poor at 85°C
- Super-capacitors stop operating below -40°C

Wide Temp Range Super-cap Development





Carbon Nanotube-based Structure
- Leakage current 10x lower than conventional
- Operates below -55°C, above 85°C

Unique Aerospace Challenges for Energy Harvesting

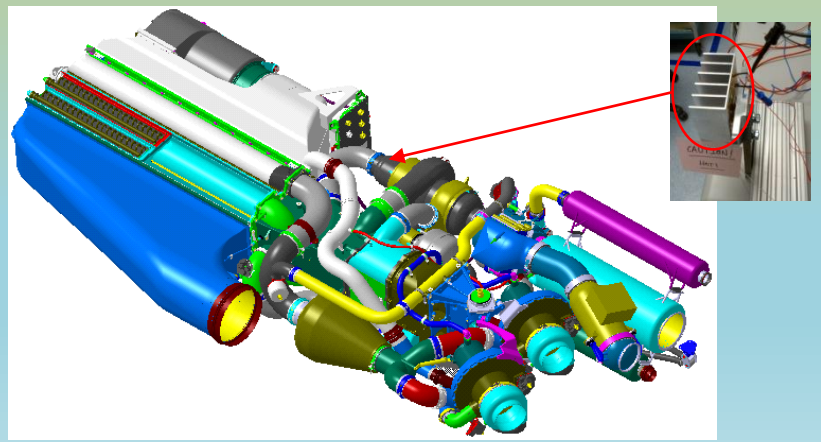
Energy Sources

Harvesting Estimates by Technology

Method	$\mu W/cm^3$	
Solar (outside)	15,000	Has potential, esp. on wings
Air flow	380	Parasitic, little access
Human power	330	Not likely
Vibration	200	Fixed wing aircraft have little
Temperature	40	Numerous thermal systems
Pressure Var.	17	Numerous, difficult access
Solar (inside)	10	Very intermittent

Thermal Harvester in Application

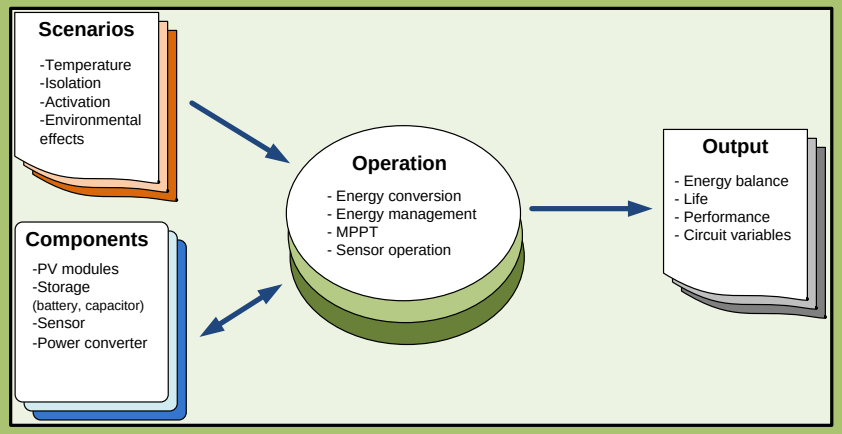
TEG ΔT	TEG Voltage	TEG Current	TEG Power	Matched Load	Peak Load Power	Average Load Power	Overall Efficiency
42°C	0.510V	41mA	21mW	37mW	52mW	6mW	29%
55°C	0.315V	76mA	24mW	60mW	52mW	8mW	33%

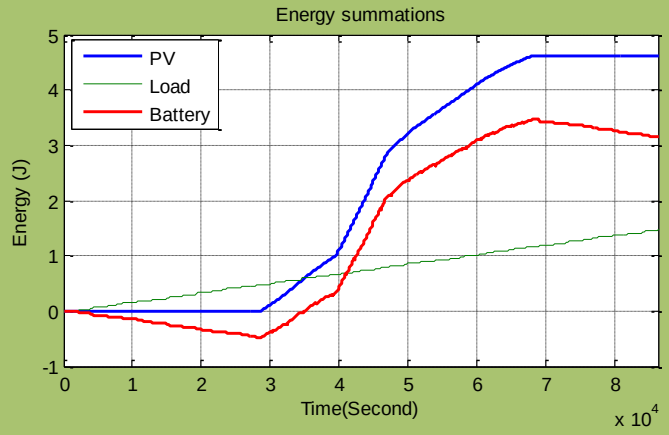


Unique Aerospace Challenges for Energy Harvesting

Proving Sensor Availability

Extensive Component, Circuit, and Scenario Simulations

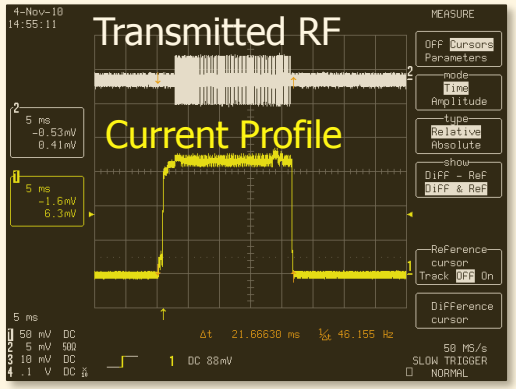




Some Scenarios Not Possible

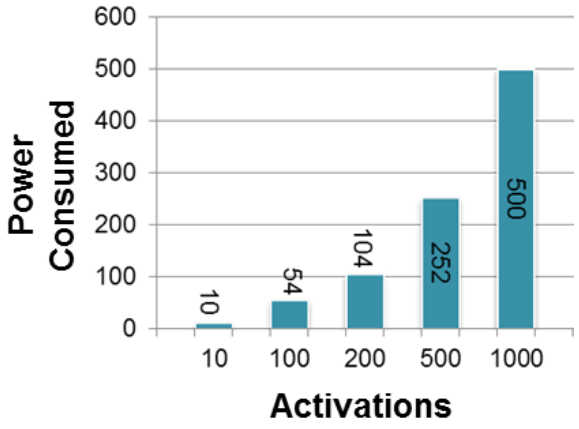
Need for Reduced Energy Consumption

In Practice, Sensors Consume More Energy Than Predictions

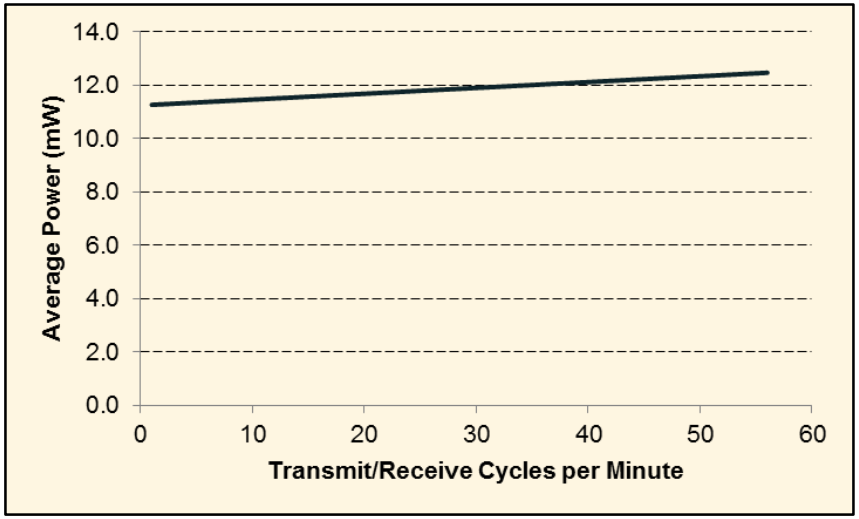


Sensor energy measurement

1µA Standby Current
22-27 ms packet duration
4ms startup
95% at 30 mA, 3.3V
J/packet=0.74 µJ
11.88 µJ/event
~10 nJ/bit (1 nJ/bit academic)



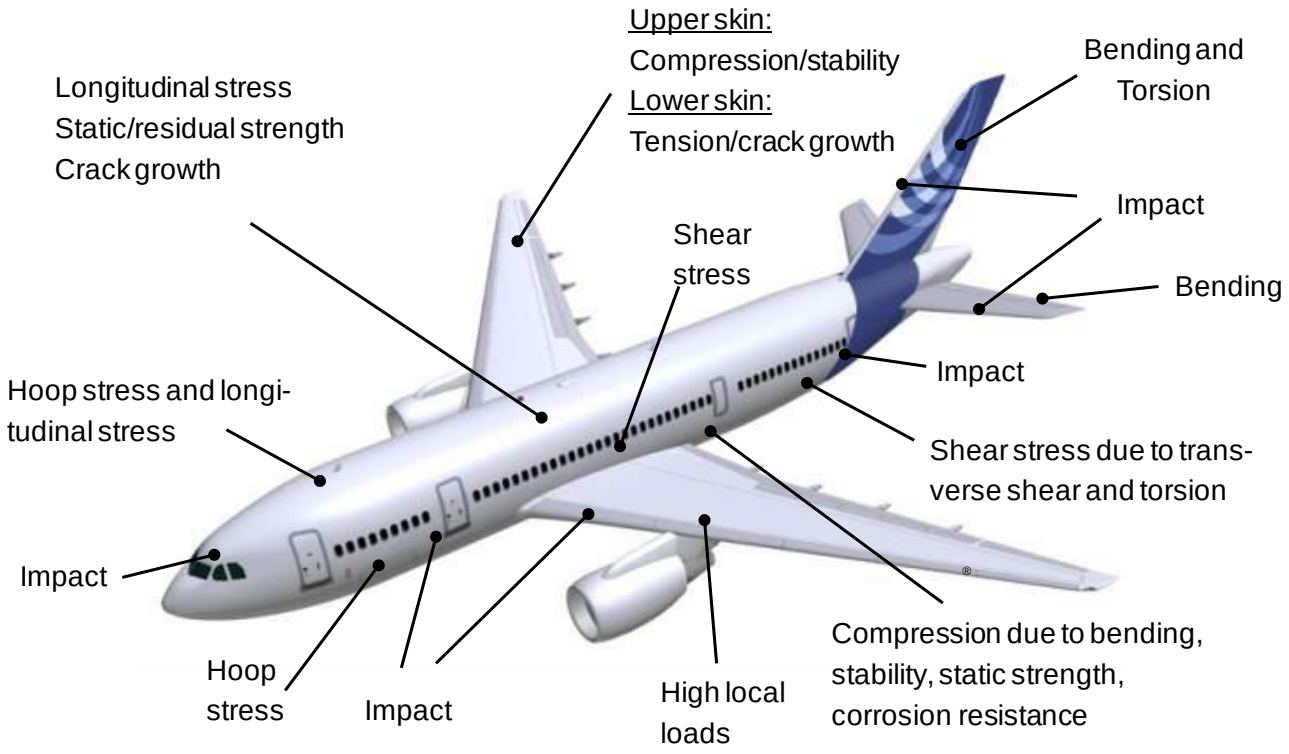
Wireless Sensor Activations Limited to Save Power



Example of Startup Energy Dominating – Not Designed for Energy Harvesting

Opportunities from Reduced Energy Consumption

Airframe Structural Health Monitoring (SHM) Sensors Enabled by EH



Existing Energy Sources and Storage Elements Will Not Support SHM Networks Without Sensor Energy Consumption Reduction

Why EH for Building Energy Management (BEM)?

UTC CCS – Fire Safety, Security, Building Automation, & HVAC

Smoke/CO Detectors

Locks, Intrusion Sensors

HVAC Controllers, Sensors

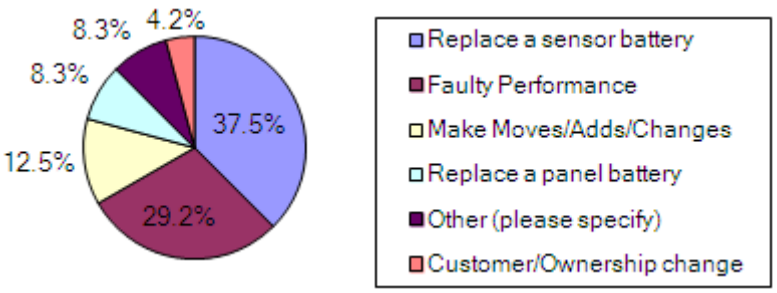
Why EH for Building Energy Management (BEM)?

Example: Door/Window Intrusion Sensor (DWS)

Residential Market Snapshot
(about 2/3 of total 1.5M sales per year):

- 2 to 3 door/window sensors per site
- $100/trip for maintenance calls ("truck rolls"), much more for commercial truck rolls
- Installers are majority of customers
- Installers profit from service contracts: fewer visits = more profit
- Large percentage of truck rolls due to dead batteries
- Sensor changes are "discouraged"

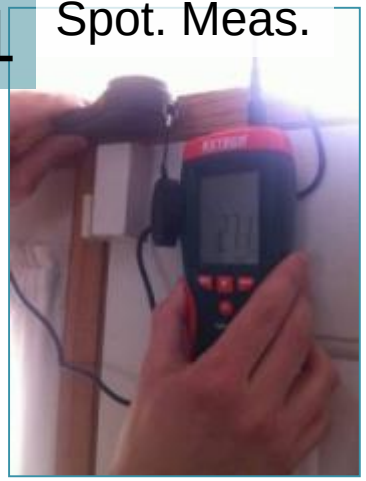
- 1x CR123 battery
- 5-10 year life
- <5 commercial



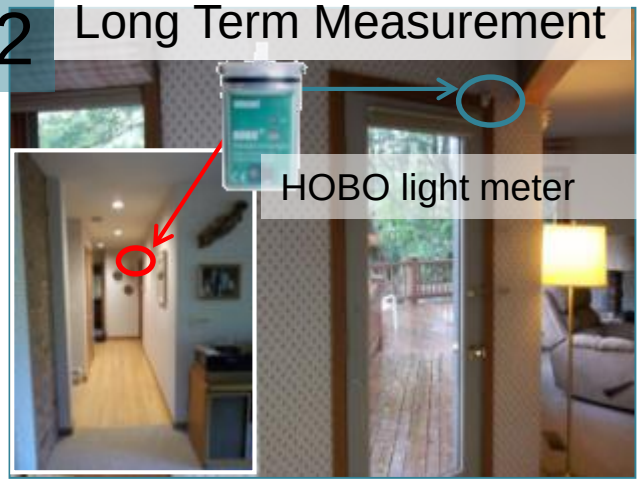
BEM DWS Challenges for Energy Harvesting

Determining Minimum Light Levels Available

1 Spot. Meas.

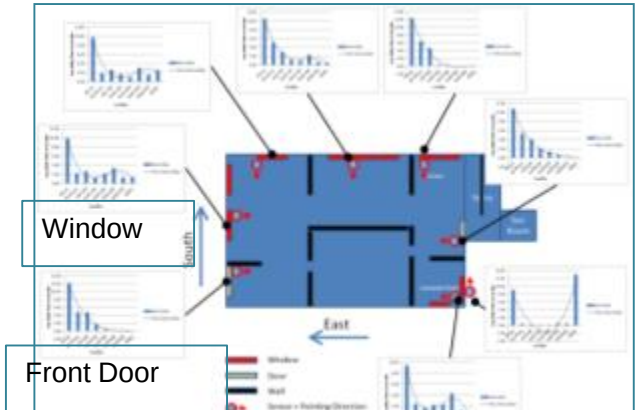


2 Long Term Measurement



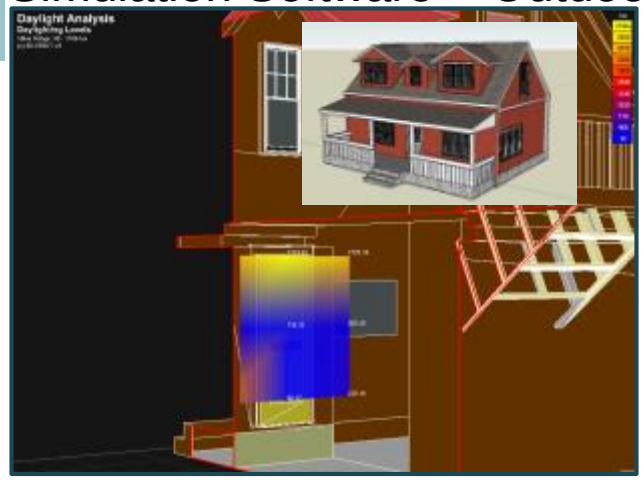
⇨Expanded Light Measurements

- Use small, easy, HOBO meters
- 6 Unique homes
- 5-8 simultaneous meas. per home
- Sensors mounted in D/W, PIR locs.



Floor plan + Light meter locations

3 Simulation Software + Outdoor NREL Data

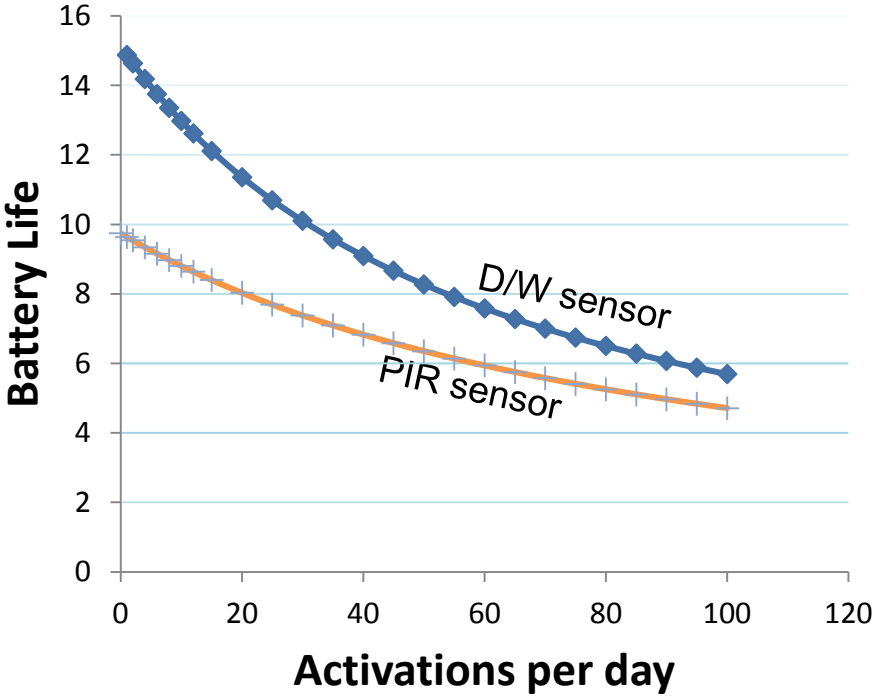


3D Light Simulation

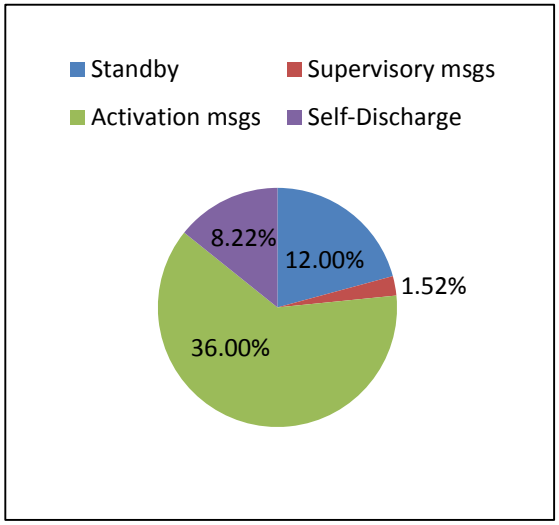
- Capitalizes on >10 years of NREL measurements
- Provides flexibility to see light at any position
- Light levels over entire season
- Con: Tough to cover every home geometry/config.

BEM DWS Challenges for Energy Harvesting

Power Requirements of Sensor Based on Battery Life



Energy Pareto of DWS w/100 activations



Power Source

Solar	Area (cm^2)	Eff. (%)	Cost ($)	Voc (V)	*Power@Lux (μW)				
					10000	1000	500	200	50
Amorton AM-1801	15	6-8	$1.00	4.1**	N/A	735	350	77	33
***Amorton* 417CA**	15	6-8	$1.10	1.2**	N/A	750	360	88	35
***Amorton* AM-5904**	15	6-8	$1.25	4.5**	10500	-	-	-	-

BEM DWS Challenges for Energy Harvesting

Business Case Not Supported by Technical Solution

	Location	Average Lux	Activations/day supported
Home 1	Living Room Window	727	>100
	Bedroom Porch door, facing inside	257	>100
	Main door, facing inside	85	12
	Living room corner, facing away from window	108	28
	Living room corner, facing towards window	488	>100
Home 2	Porch door, facing inside	15	0
	Kitchen door	61	2
	Front door	108	12
	Living room window	1127	>100
	hall corner, facing outside	221	>100
Home 3	Kids room window	301	>100
	Kitchen door	45	0
	Dining room door	33.6	0
	Computer room window	185	70
	Basement	11	0
Home 4	Living Room Window	9	0
	Living room door	8	0
	Porch door, facing inside	16	0
	Door near dining room	16	0
	Hallway location of PIR	10	0

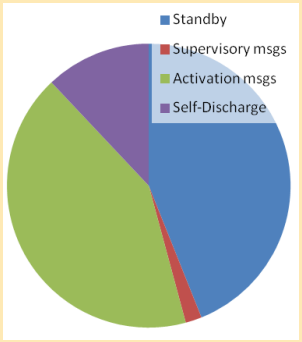
Summary: less than 20% of homes have sufficient light to power greater than 50% of DWS

Reasons: vegetation, angle, DWS location

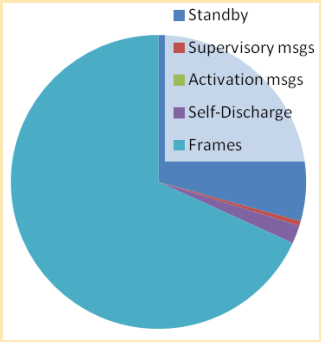
BEM DWS Opportunities for Energy Harvesting

Other Products, New Materials, Improved Sensor Designs

Outdoor PIR and PIR+camera



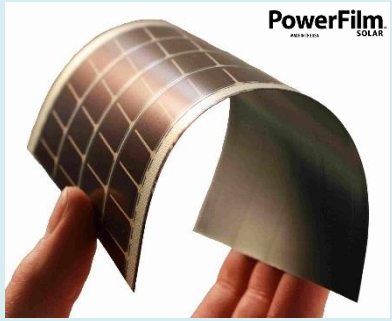
Outdoor PIR
300 Lux for 8 hours
0.4 mAh/day



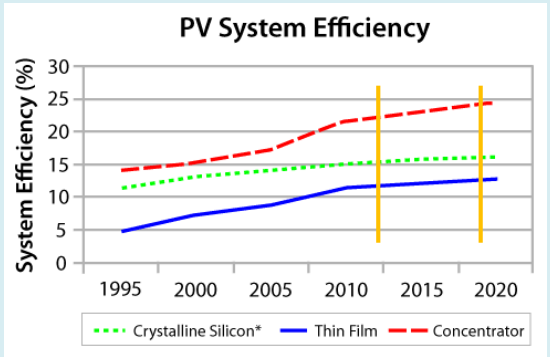
Outdoor PIR+Camera
5 frames/day
783 Lux for 8 hours
2.1 mAh/day

New Materials, Technology

Solution to sensor angle issue



Improvements since project inception



Smaller, more dense batteries

Conclusions

- Energy harvesting has significant potential in aerospace applications, to reduce wiring and provide remote power
- New materials are important to support environmental conditions
- Business cases are not guaranteed, especially on the commercial side
- EH best when it solves a technical challenge

Thank you!
Questions?

Contact: savulas@utrc.utc.com

Backup

Harvesting Technology		Available (Theoretical)	Currently Harvestable	Harvestable w/3 cm^2 or 1cm^3
Solar	Cloudy	150 $\mu W/cm^3$	1000 $\mu W/cm^2$	**3 mW**
	Bright	15000 $\mu W/cm^3$	100000 $\mu W/cm^2$	**300 mW**
Indoor Light	Hallway floor (50 lx)		1 $\mu W/cm^2$	**25 µW (25** cm^2**)**
	Office - Middle (200 lx)		5 $\mu W/cm^2$	**5.0 µW**
	Office - Window		16 $\mu W/cm^2$	**16.0 µW**
Vibration	Human	200 $\mu W/cm^3$	4 $\mu W/cm^3$	**4.0 µW**
	Machine	-	800 $\mu W/cm^3$	**800 µW**
	Wall	-	0.04 $\mu W/cm^3$	**40 nW**
Thermal	2°C Differential	10.00 $\mu W/cm^3$	60 $\mu W/cm^2$	**180 µW**
Airflow	2.5 m/s	360 $\mu W/cm^3$	100 $\mu W/cm^2$	**3 mW**
Kinetic	Door Handle	1.6 Joules		**0.075 Joules**
Chemical	Lithium Primary	1900 Ws/cm^3		

Source: Roundy et. al