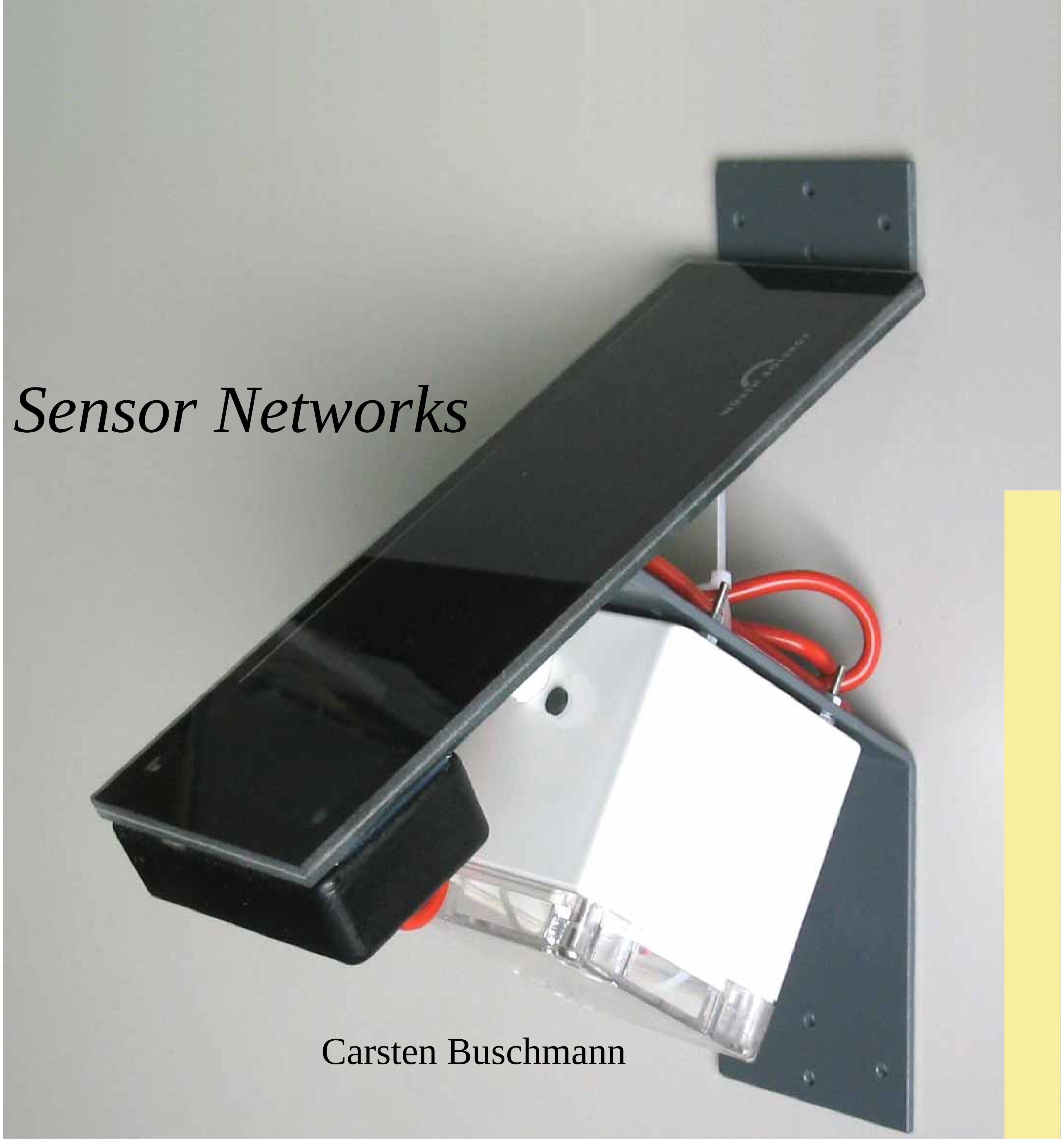
Solar Powered Sensor Networks

Modeling and Experience



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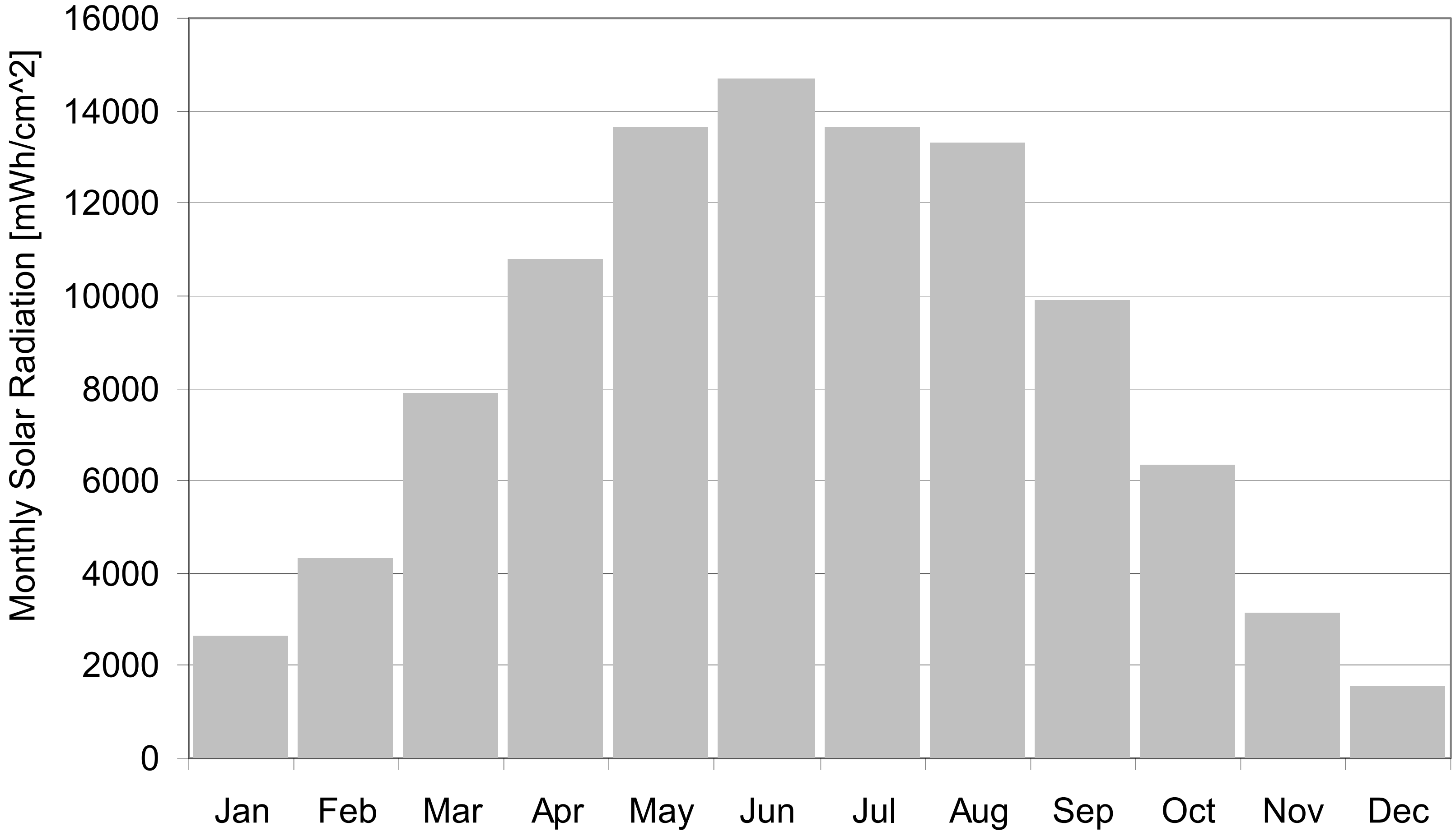
Power to Sensor Networks

- Motivation
  - Sensor Networks are to work autonomously in remote areas
  - Main limitation: battery power
- Issues
  - Amount of delivered solar power
  - Panel size and type
  - Management of power flows
  - Battery size and type
- Model to estimate the power that can be harvested
- First experimental results

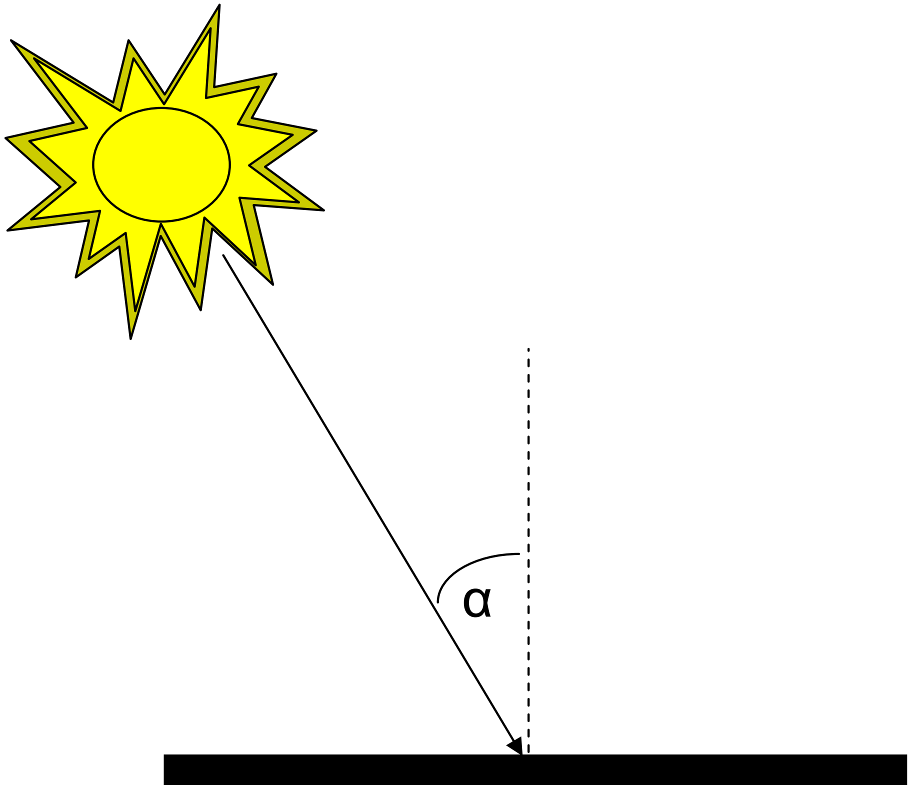
Modeling the Solar Power

- Factors of Influence
  - Monthly received solar radiation per square centimeter $R(M), M \in \{1, \ldots, 12\}$



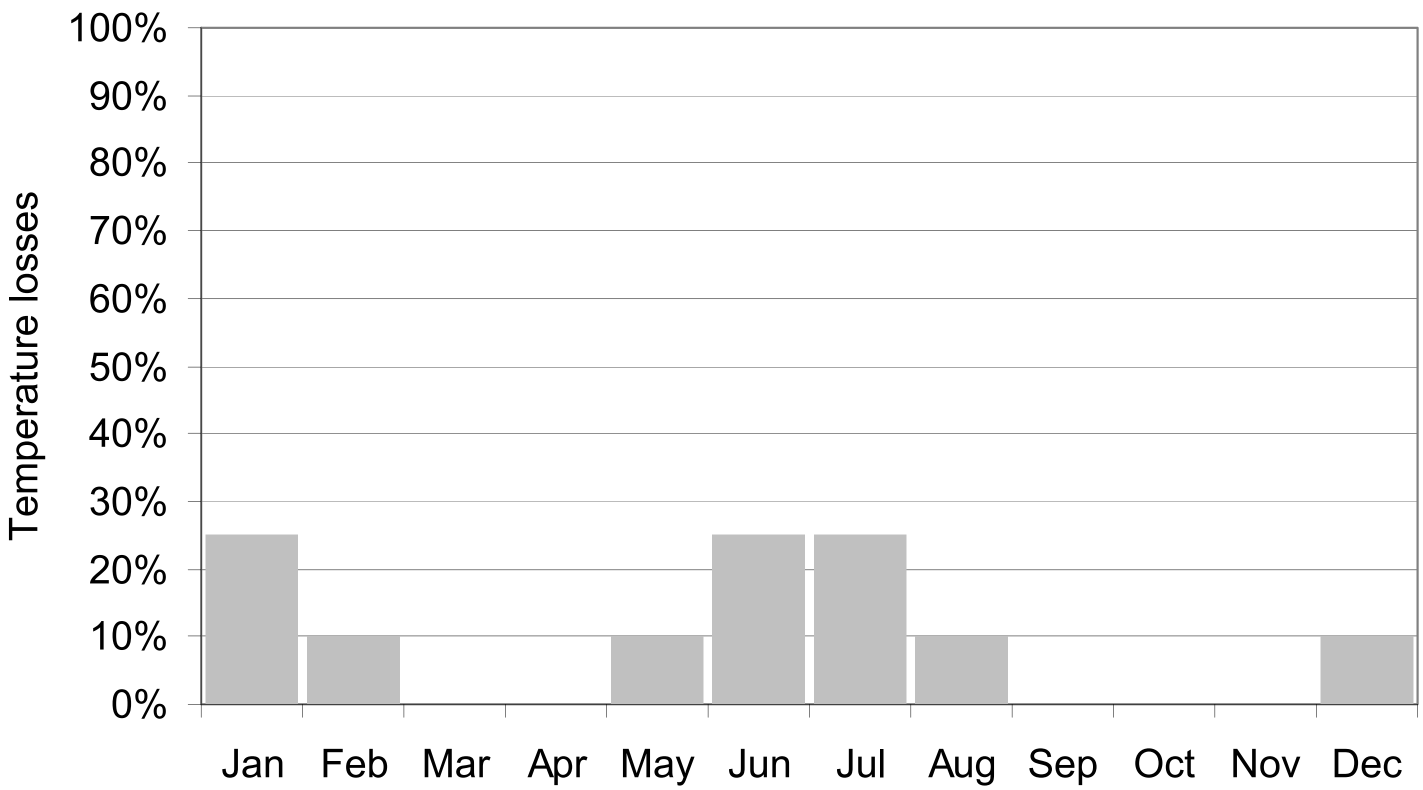
Modeling the Solar Power

- Factors of Influence
  - Monthly received solar radiation per square centimeter $R(M)\,,M \in \{1,...,12\}$
  - Angular loss $a = \cos(\alpha)$



Modeling the Solar Power

- Factors of Influence
  - Monthly received solar radiation per square centimeter $R(M), M \in \{1, ..., 12\}$
  - Angular loss $a = \cos(\alpha)$
  - Efficiency of electronics and panel $e_{el}\ e_{panel}$
  - Temperature losses $L(M)$



Modeling the Solar Power

- Factors of Influence
  - Monthly received solar radiation per square centimeter $R(M), M \in \{1, ..., 12\}$
  - Angular loss $a = \cos(\alpha)$
  - Efficiency of electronics and panel $e_{el}\, e_{panel}$
  - Temperature losses $L(M)$

$$E_{solar}(M) = (1 - L(M))\, e_{el}\, e_{panel}\, A\, a\, R(M)$$

Battery Charge Model

- Impact factors
  - Monthly harvested energy $E_{solar}(M)$
  - Average node power $P_{node} = d\,P_{running} + (1-d)\,P_{sleep}$
  - Monthly dissipated energy $E_{diss}(M) = P_{node}\,24\,DiM(M)$
  - Battery capacity C

$$
\begin{aligned}
E(t) &= min\{C, E(t-1) + E_{solar}(M(t)) - E_{diss}(M(t))\} \\
M(t) &= ((t-2+t_{start})\ mod\ 12) + 1
\end{aligned}
$$

Battery Charge Model

t	((t -2+t_{start}) mod 12)+1	E(t) [mWh]	E_{solar} [mWh]	$E_{dissipate}$ [mWh]
0		21120		
1	6	21120	104958	24683
2	7	21120	97390	25506
3	8	21120	114211	25506
4	9	21120	94248	24683
5	10	21120	60500	25506
6	11	21120	29988	24683
7	12	8895	13280	25506
8	1	2203	18814	25506
9	2	16350	37185	23038
10	3	21120	75256	25506
11	4	21120	102816	24683
12	5	21120	116868	25506
13	6	21120	104958	24683
14	7	21120	97390	25506
15	8	21120	114211	25506
16	9	21120	94248	24683
17	10	21120	60500	25506
18	11	21120	29988	24683
19	12	8895	13280	25506
20	1	2203	18814	25506
21	2	16350	37185	23038
22	3	21120	75256	25506
23	4	21120	102816	24683
24	5	21120	116868	25506

$$E_{solar}(M)$$

$$P_{node} = d\, P_{running} + (1-d)\, P_{sleep}$$

$$E_{diss}(M) = P_{node}\, 24\, DiM(M)$$

$$C$$

$$) + E_{solar}(M(t)) - E_{diss}(M(t))\}$$

$$mod\ 12) + 1$$

Battery Charge Model

t	$((t - 2 + t_{start}) \bmod 12) + 1$	E(t) [mWh]	E_{solar} [mWh]	$E_{dissipate}$ [mWh]
0		21120		
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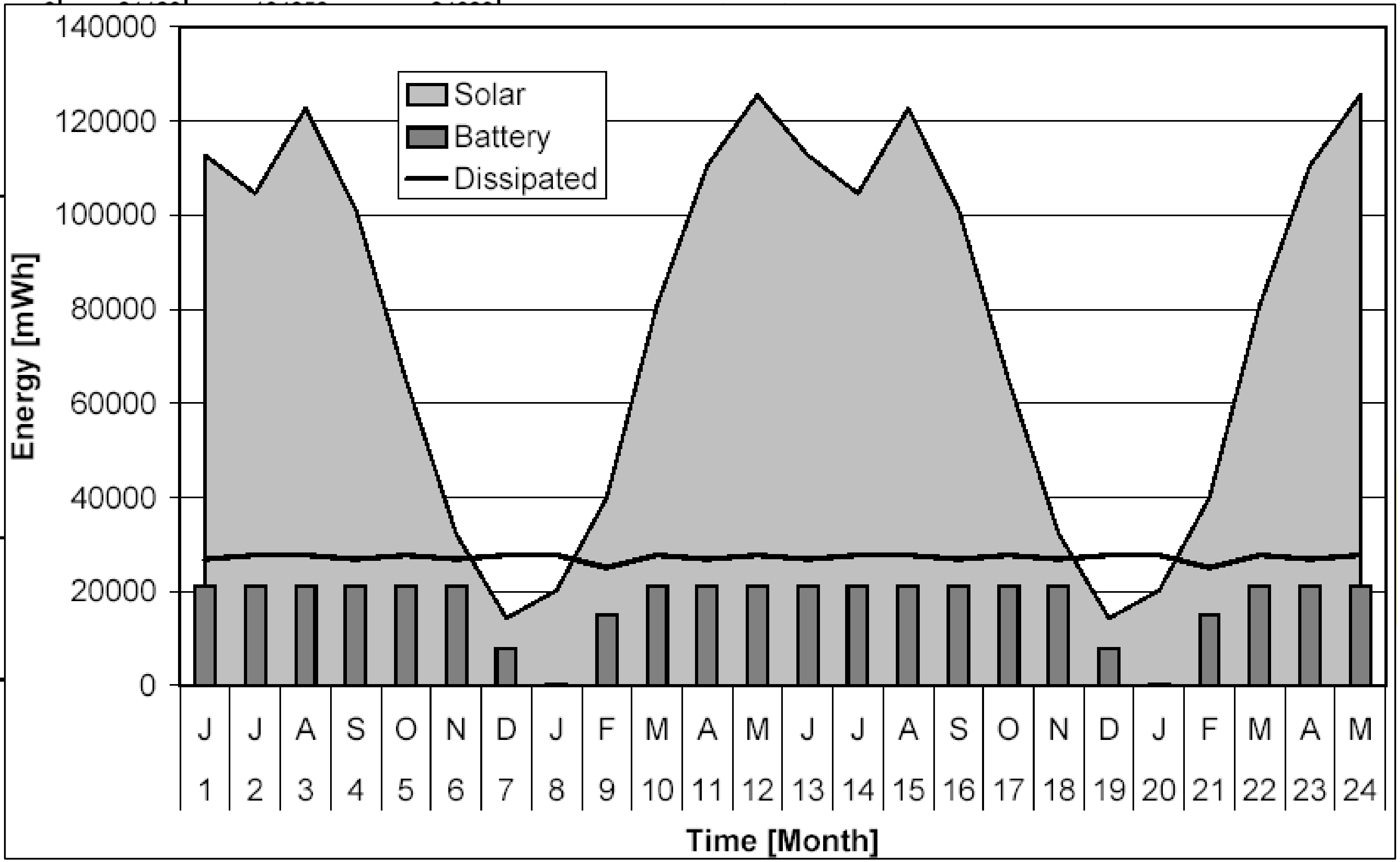
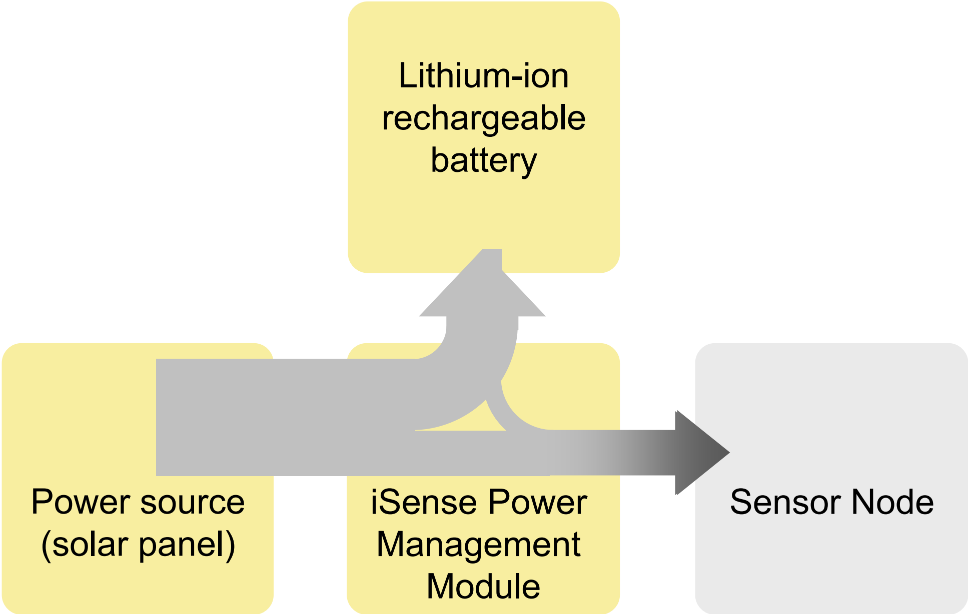
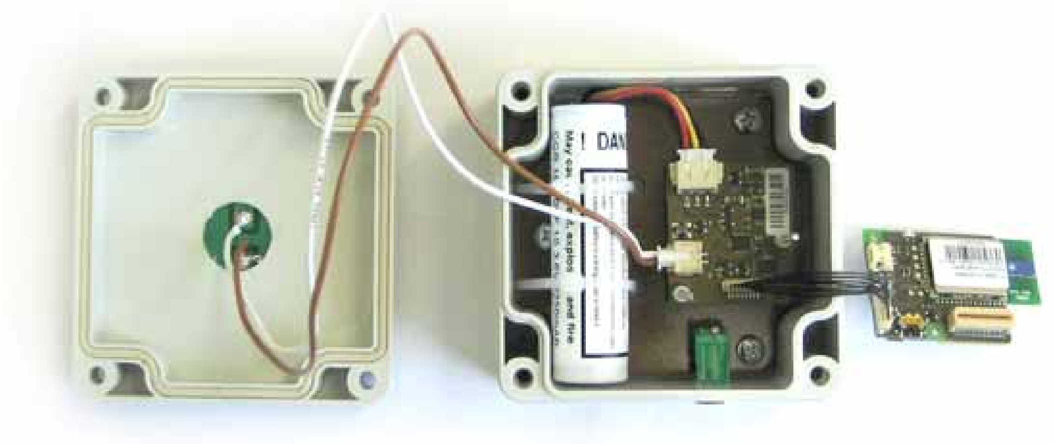
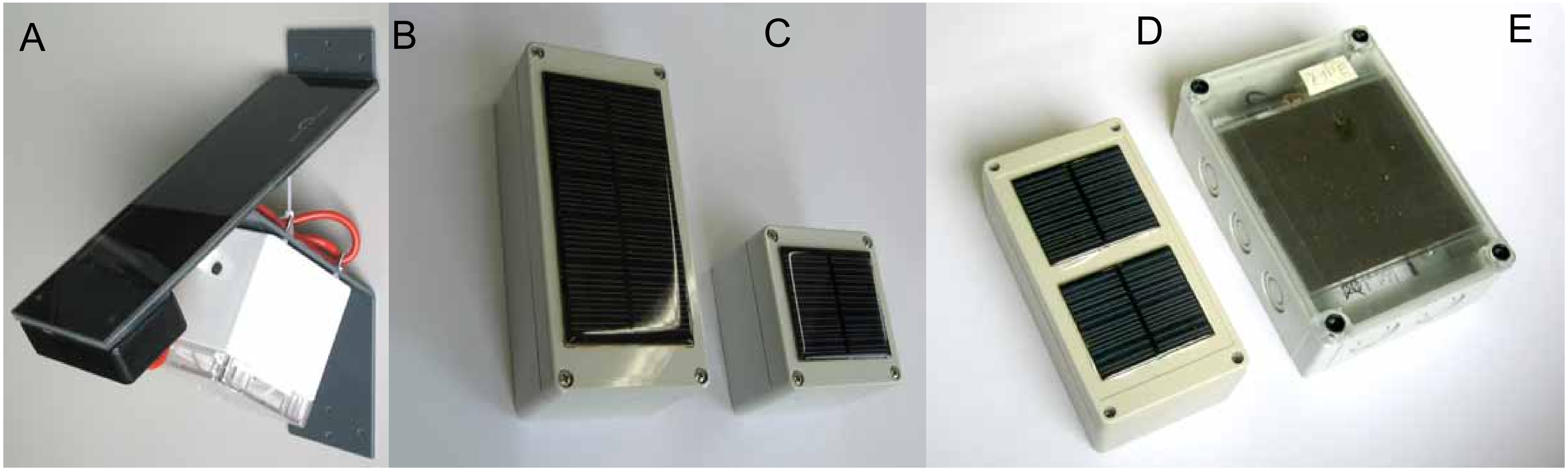


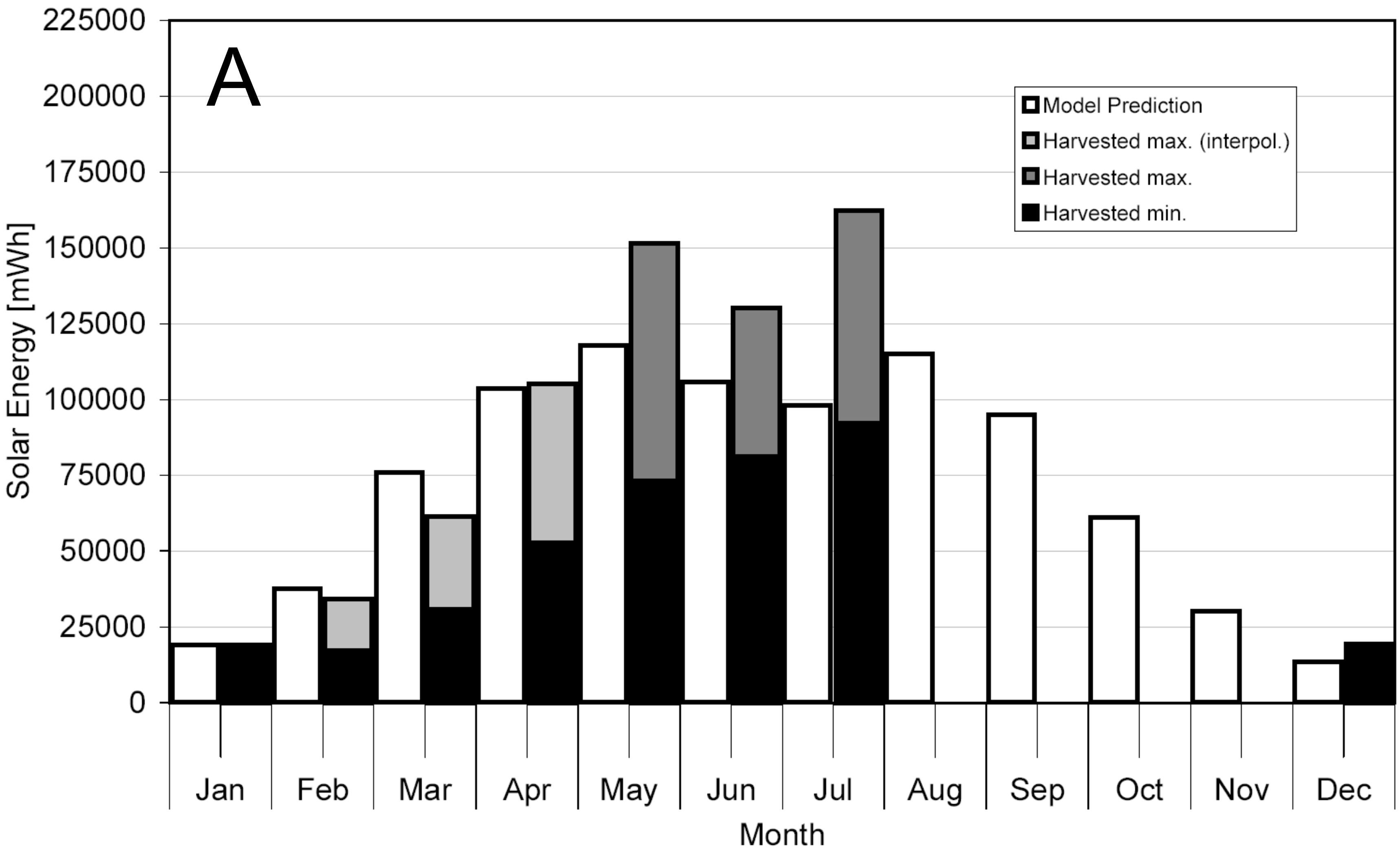
Hardware

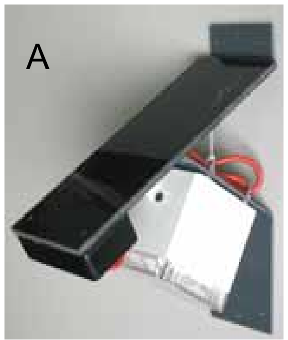

Lithium-ion rechargeable battery
Power source (solar panel)
iSense Power Management Module
Sensor Node



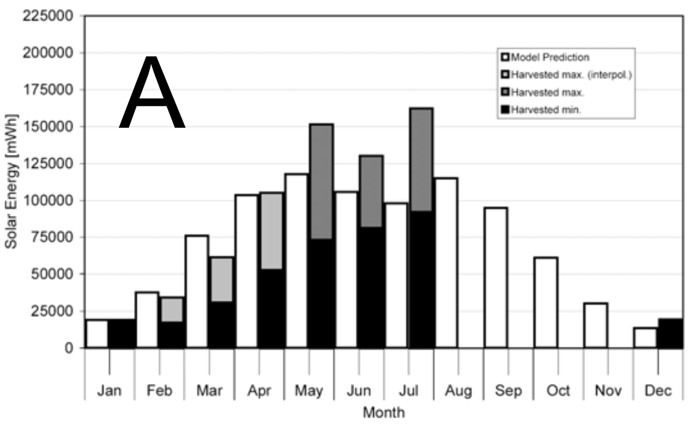

A
B
C
D
E

Experimental results

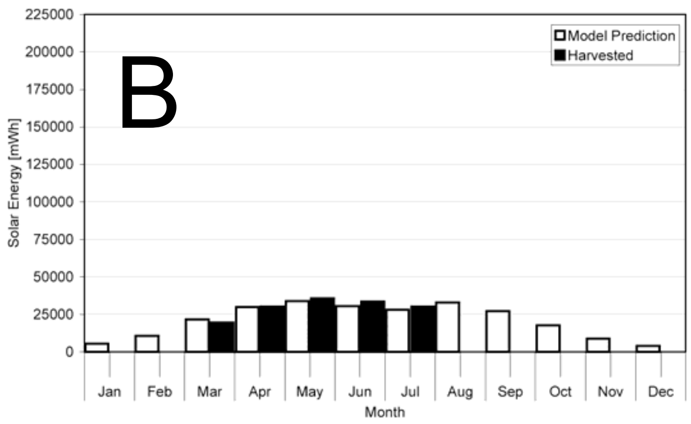




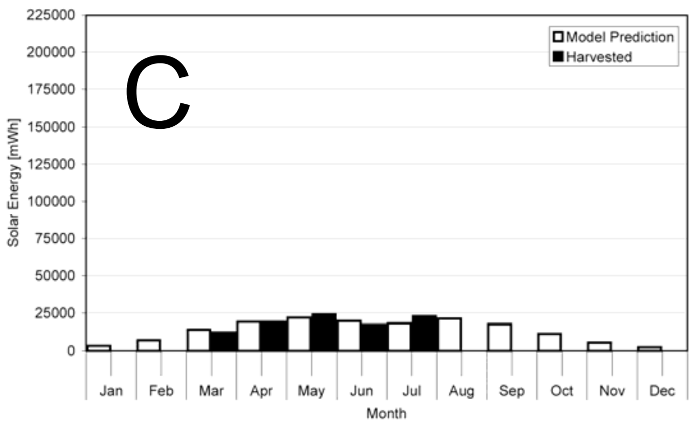
Experimental results



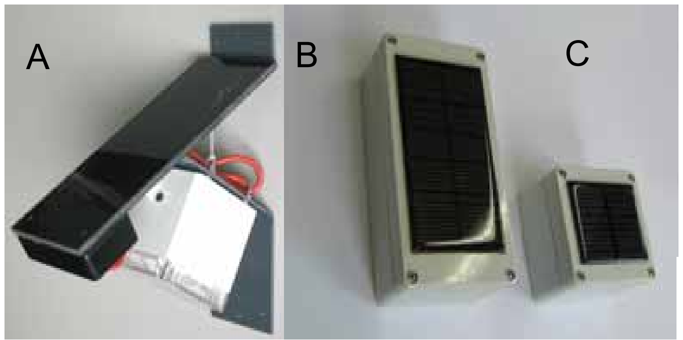
P_{max}=1500mW



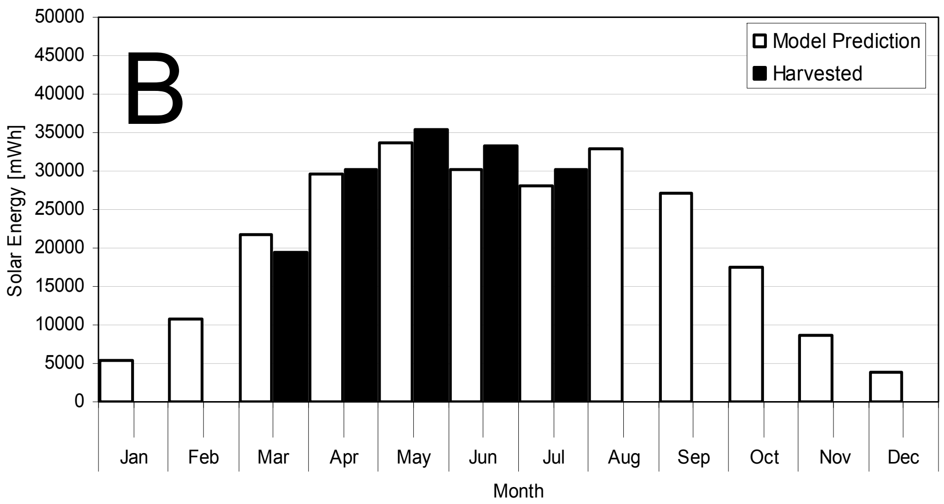
P_{max}=981mW

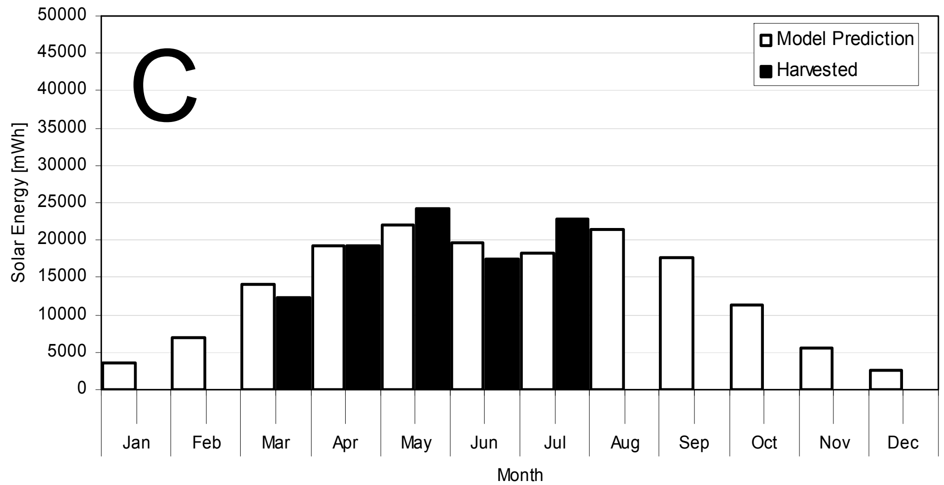


P_{max}=405mW



Experimental results





P_{max}=981mW

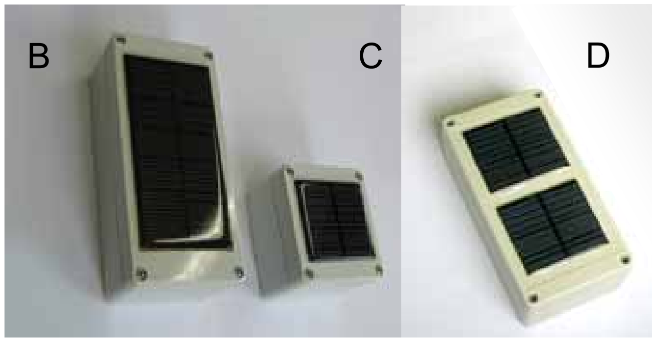
I_{max}=109mA

V_{max}=9V

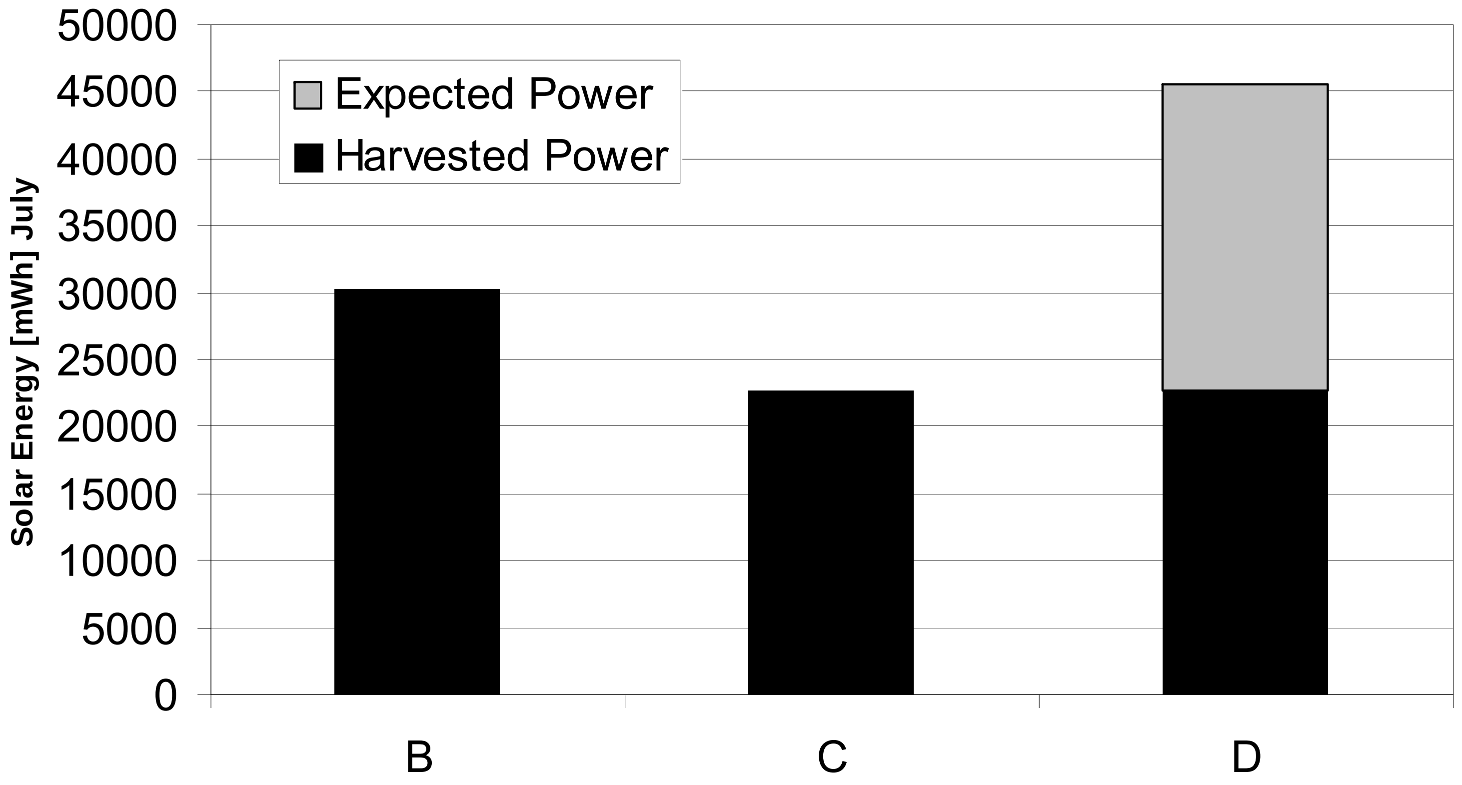
P_{max}=405mW

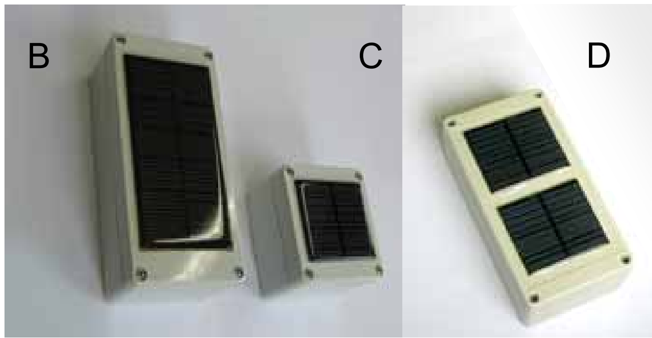
I_{max}=81mA

V_{max}=5V



Experimental results





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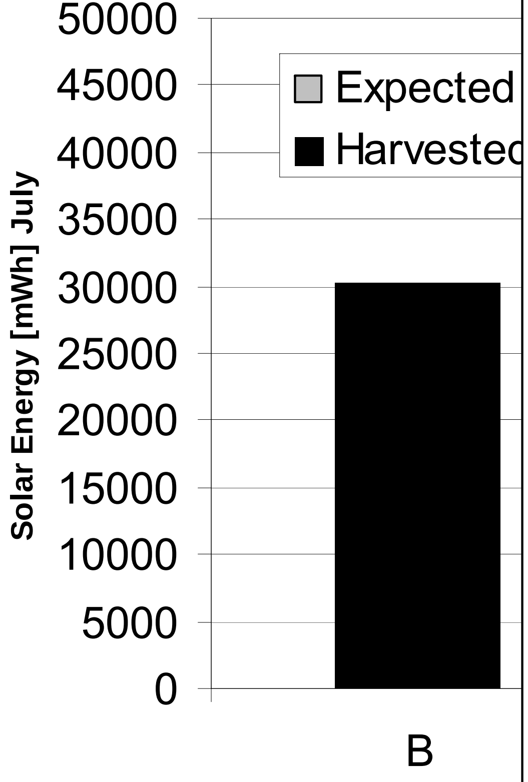
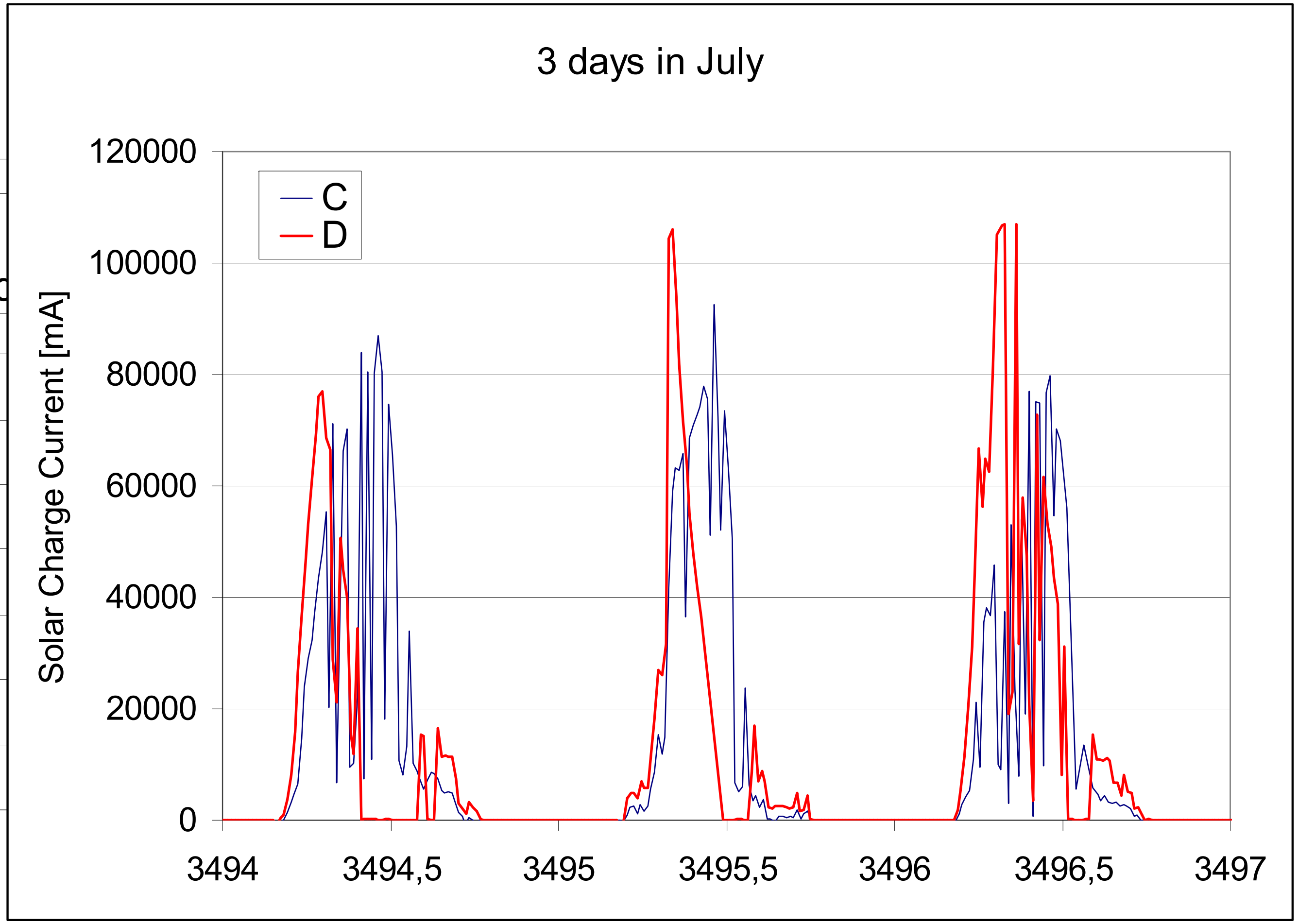
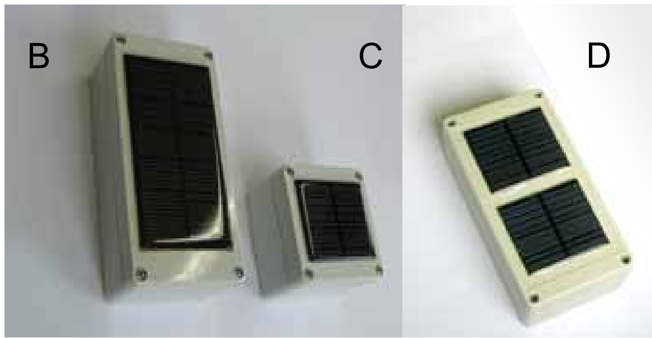
Experimental results







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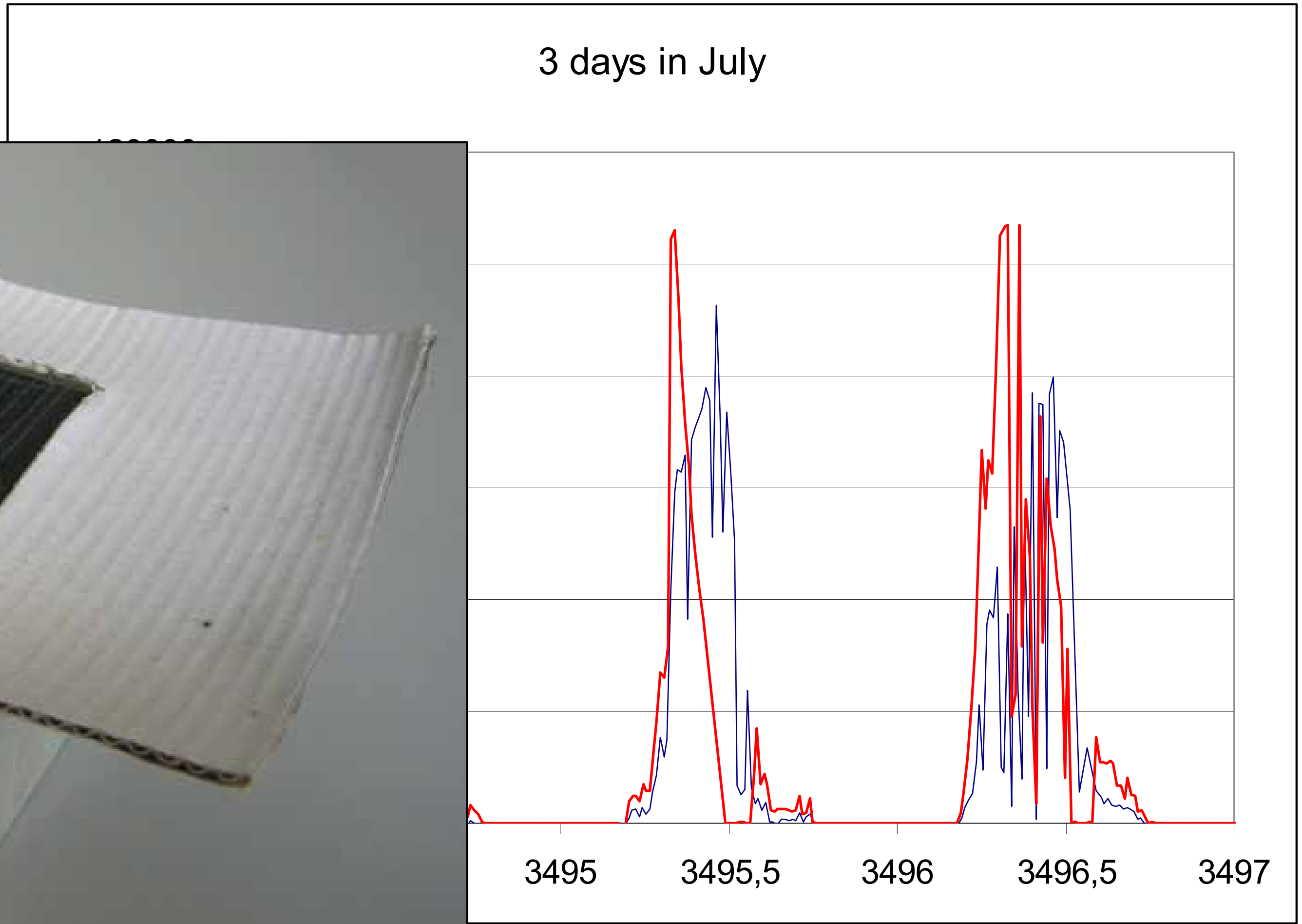

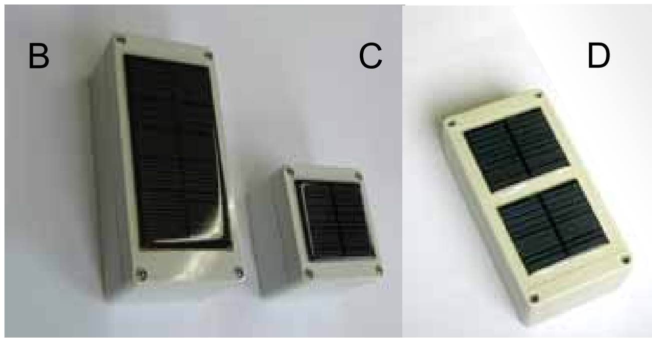

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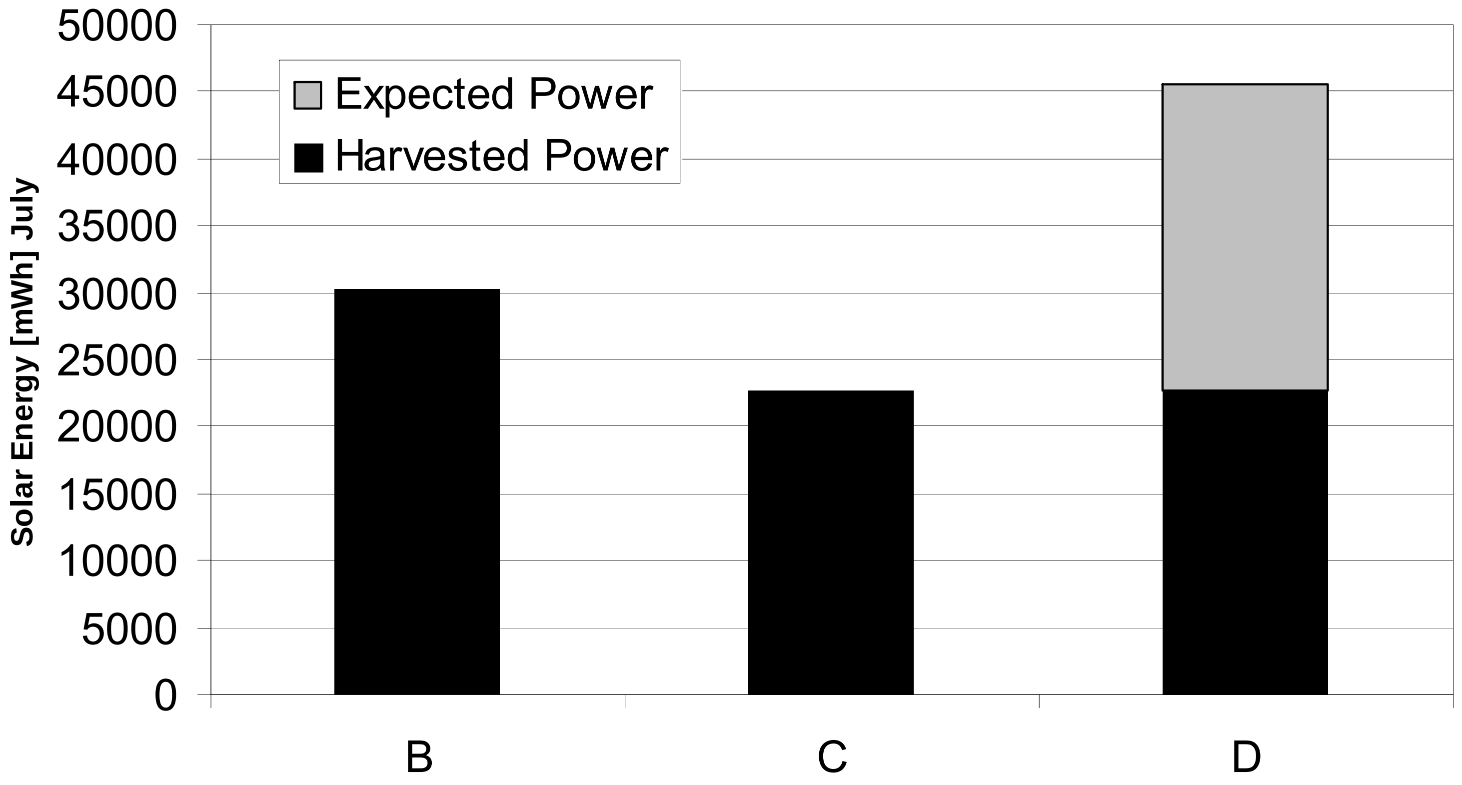

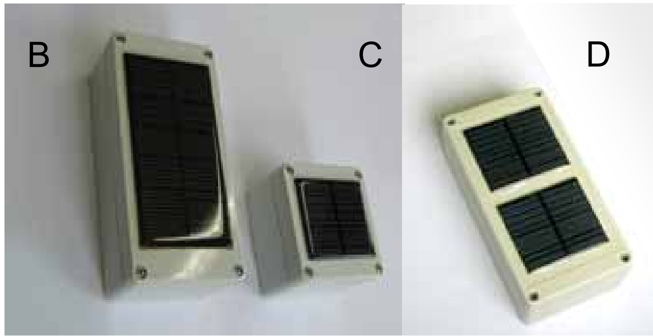

Conclusion

- Model seems appropriate but not perfect yet
- Even housing characteristics important
- Solar driven WSNs are possible
- Northern Europe:
  - Large panel:
    - 25% duty cycle in winter
    - 100% duty cycle in summer
  - Small panel:
    - 10% duty cycle in winter
    - 25% duty cycle in summer
  - 2 small panels: about double
- New panels will allow smaller and/or more powerful nodes

Thank you.Please ask!

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