

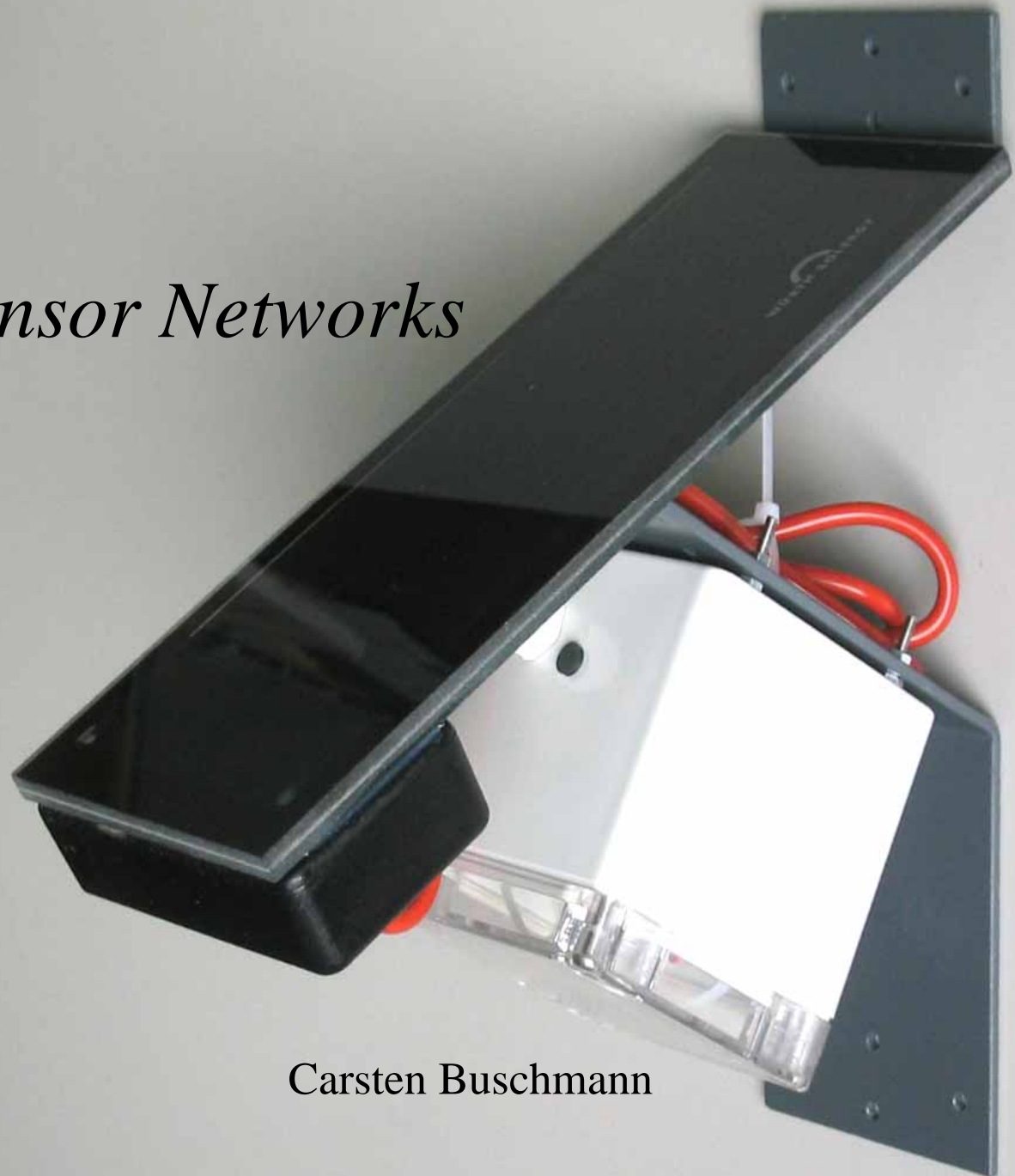
# Solar Powered Sensor Networks

Modeling and Experience



Institute of Telematics  
University of Lübeck

coalesenses  
*research to innovate*



Carsten Buschmann

## ■ 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

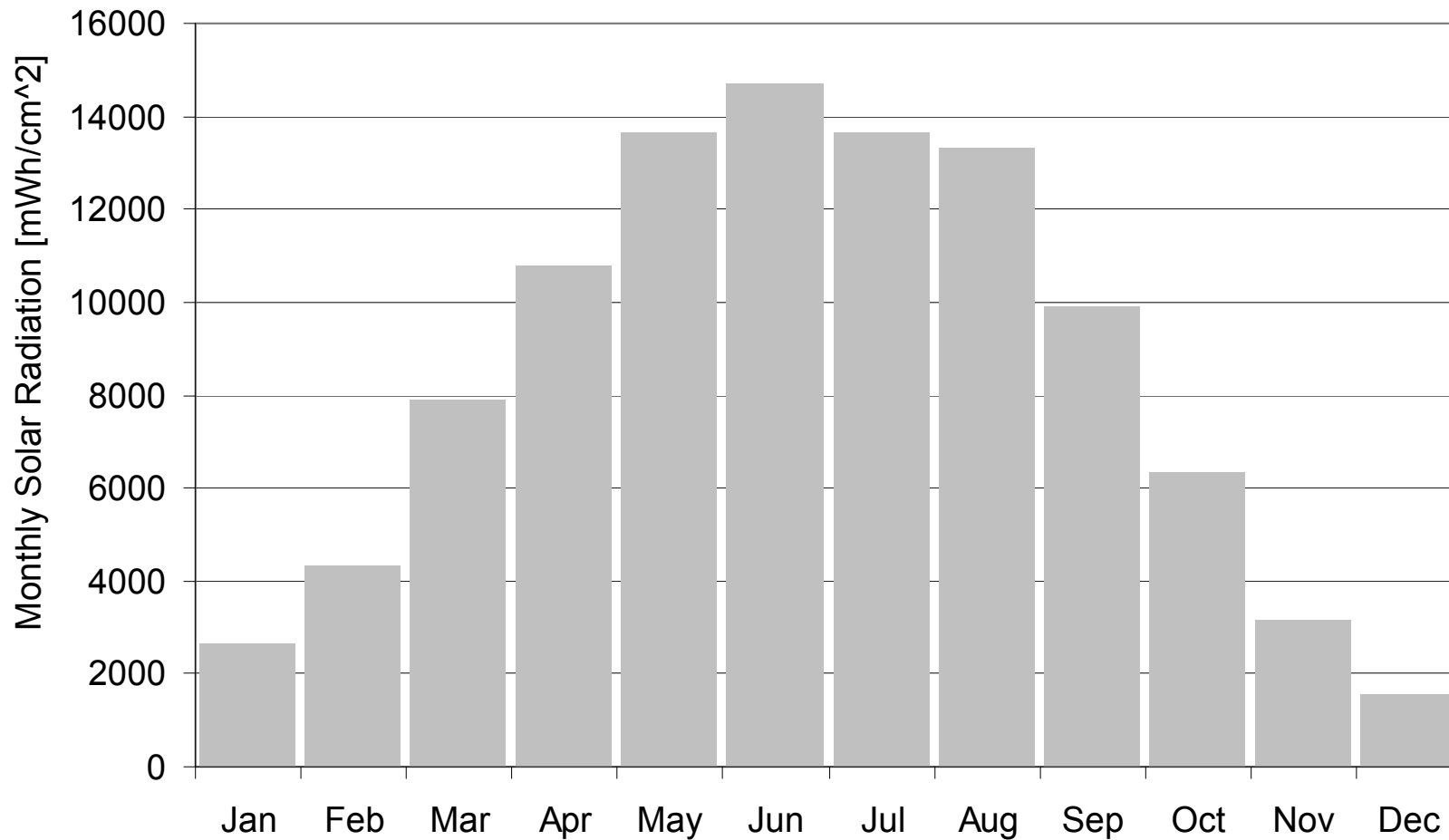
## ■ Model to estimate the power that can be harvested

## ■ First experimental results



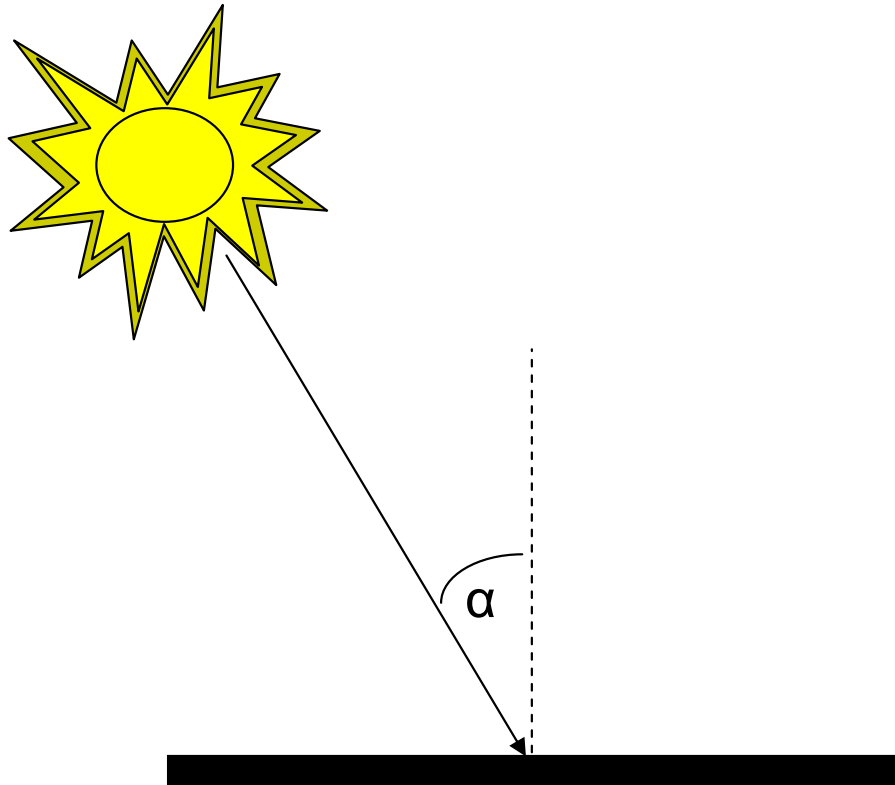
## Factors of Influence

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



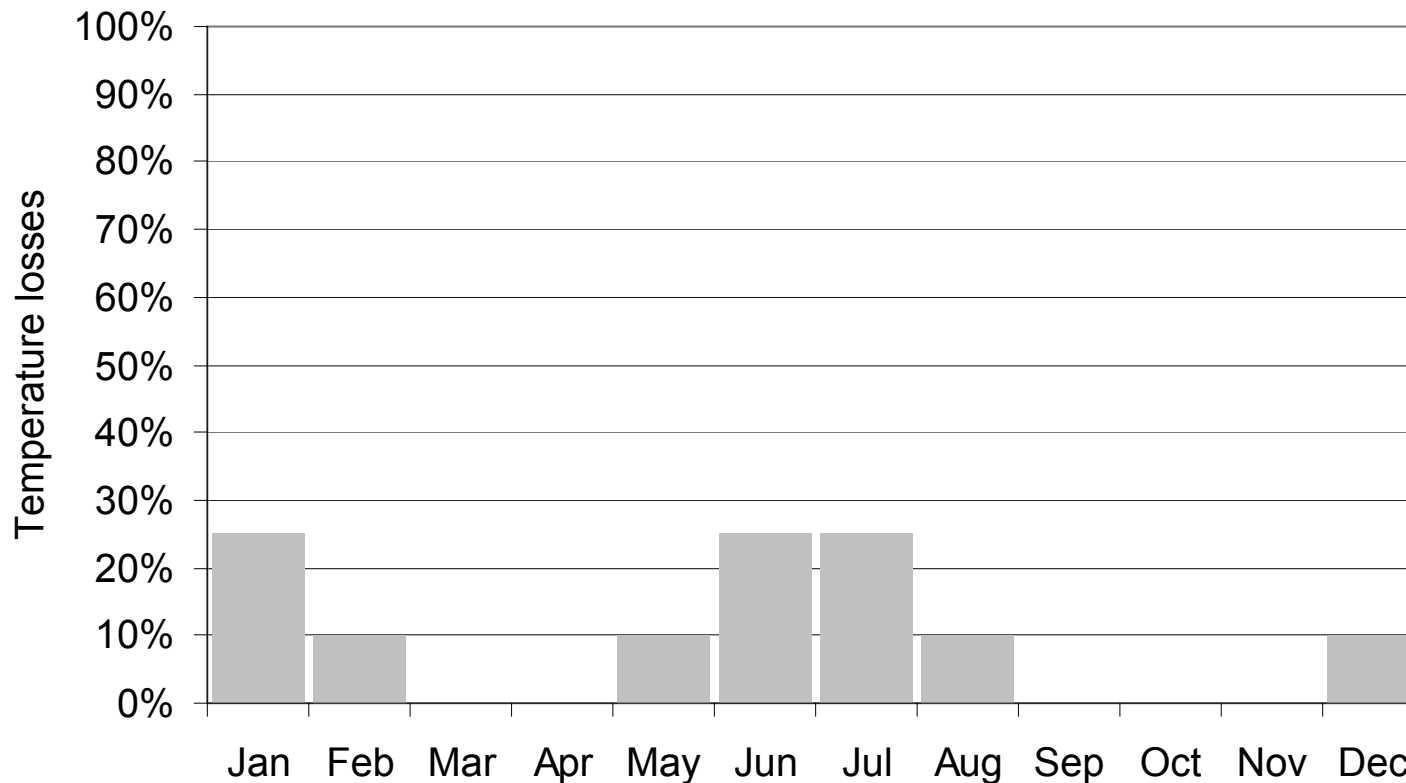
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- Angular loss  $a = \cos(\alpha)$



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- Temperature losses  $L(M)$



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

# Battery Charge Model

## Impact factors

- Monthly harvested energy
- Average node power
- Monthly dissipated energy
- Battery capacity

$$E_{solar}(M)$$

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

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

$$C$$

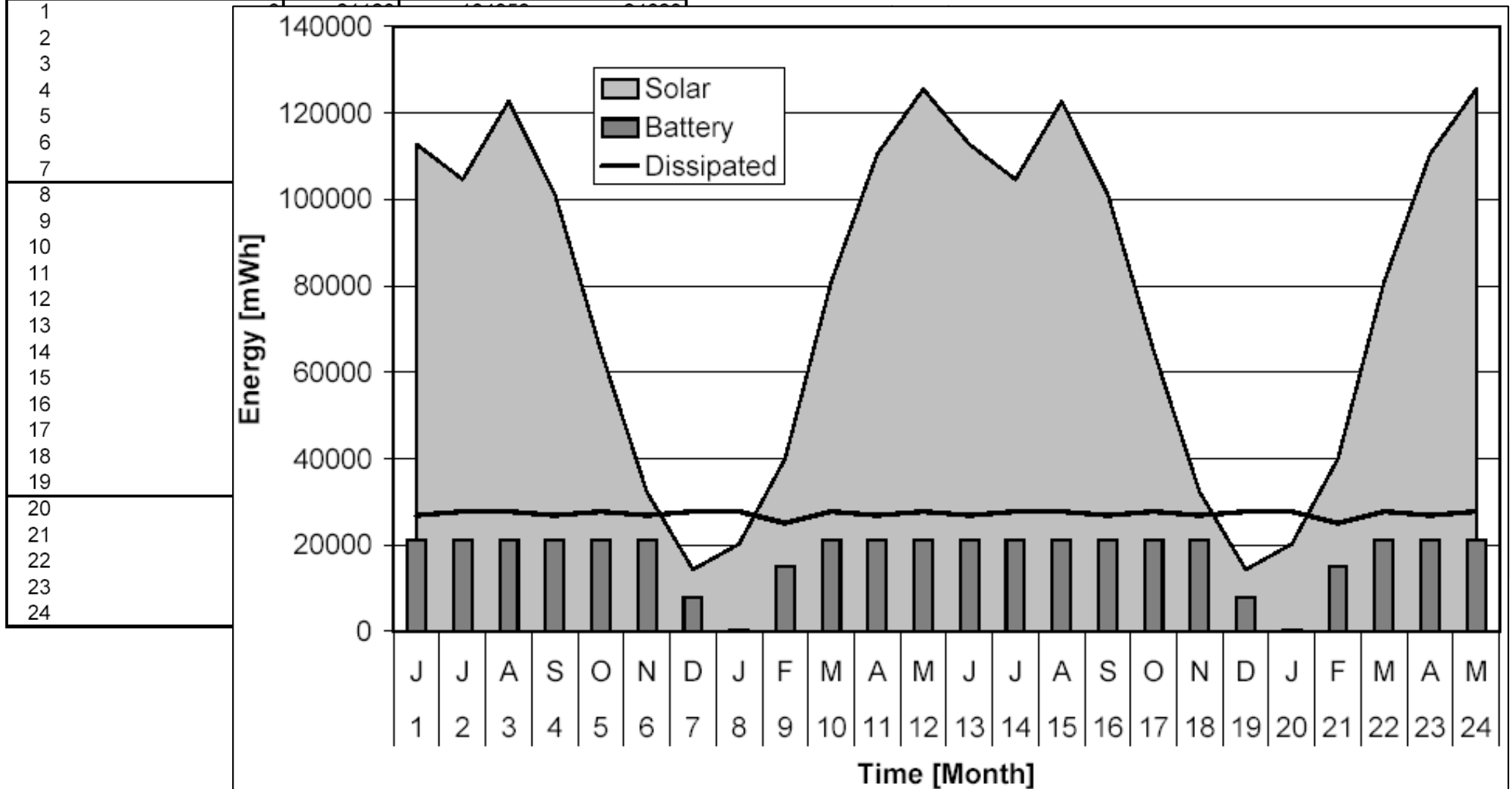
$$E(t) = \min\{C, E(t-1) + E_{solar}(M(t)) - E_{diss}(M(t))\}$$

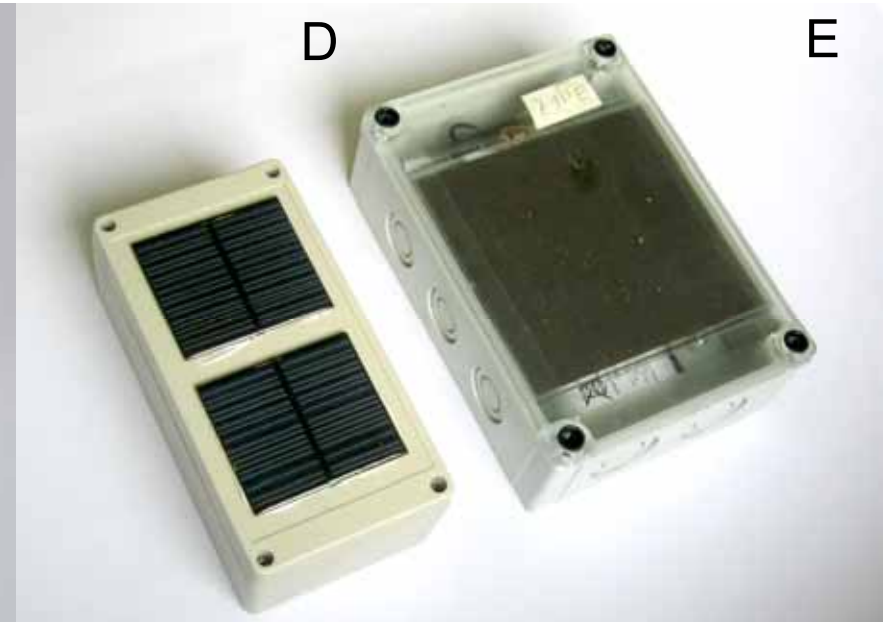
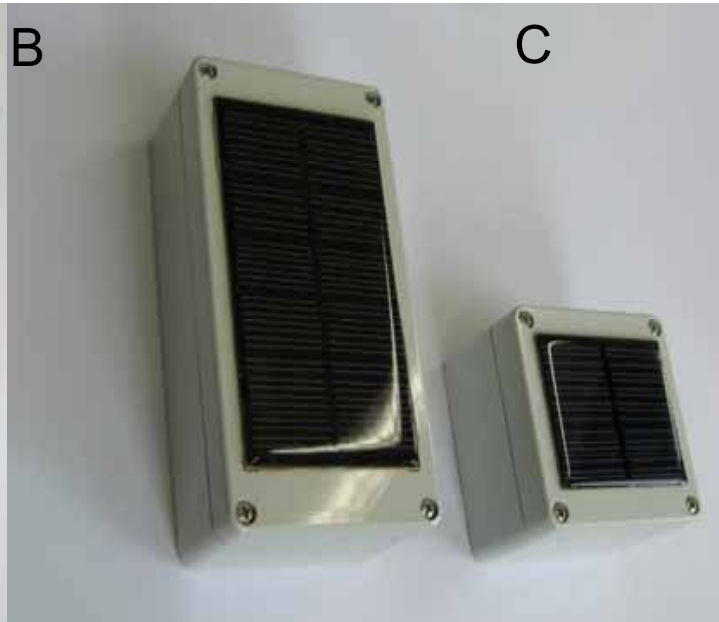
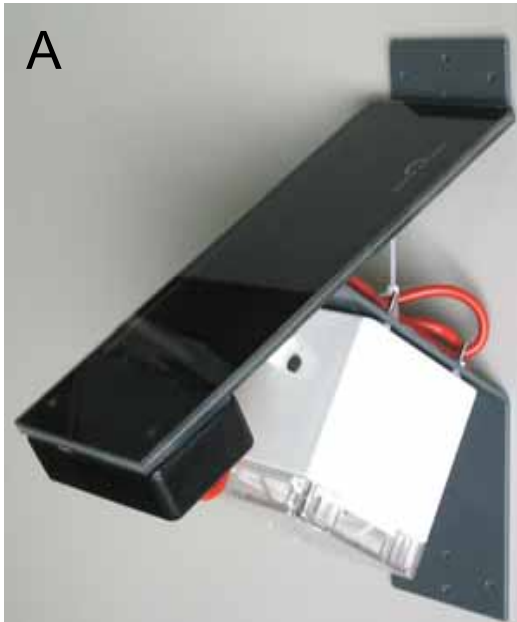
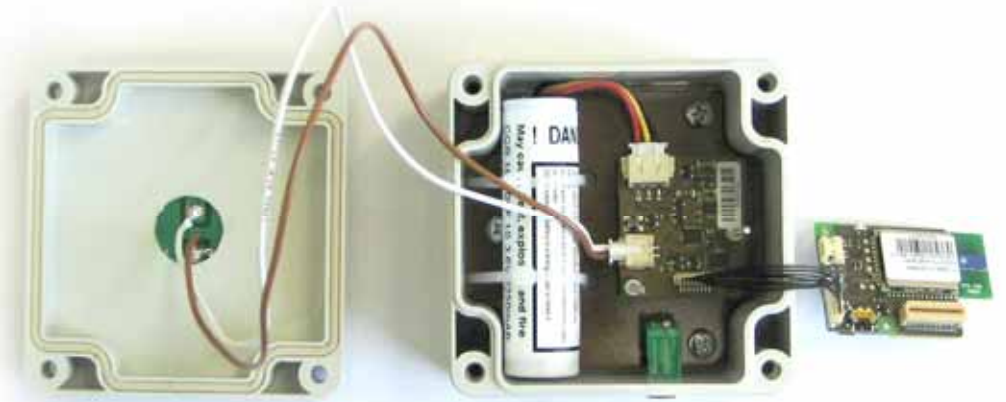
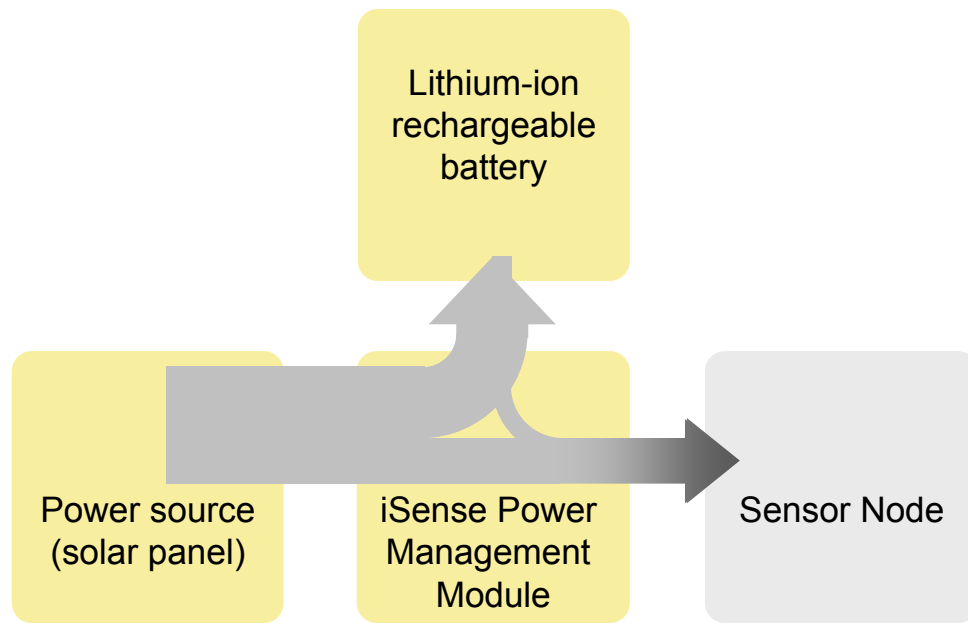
$$M(t) = ((t - 2 + t_{start}) \bmod 12) + 1$$



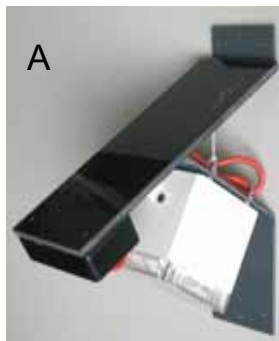
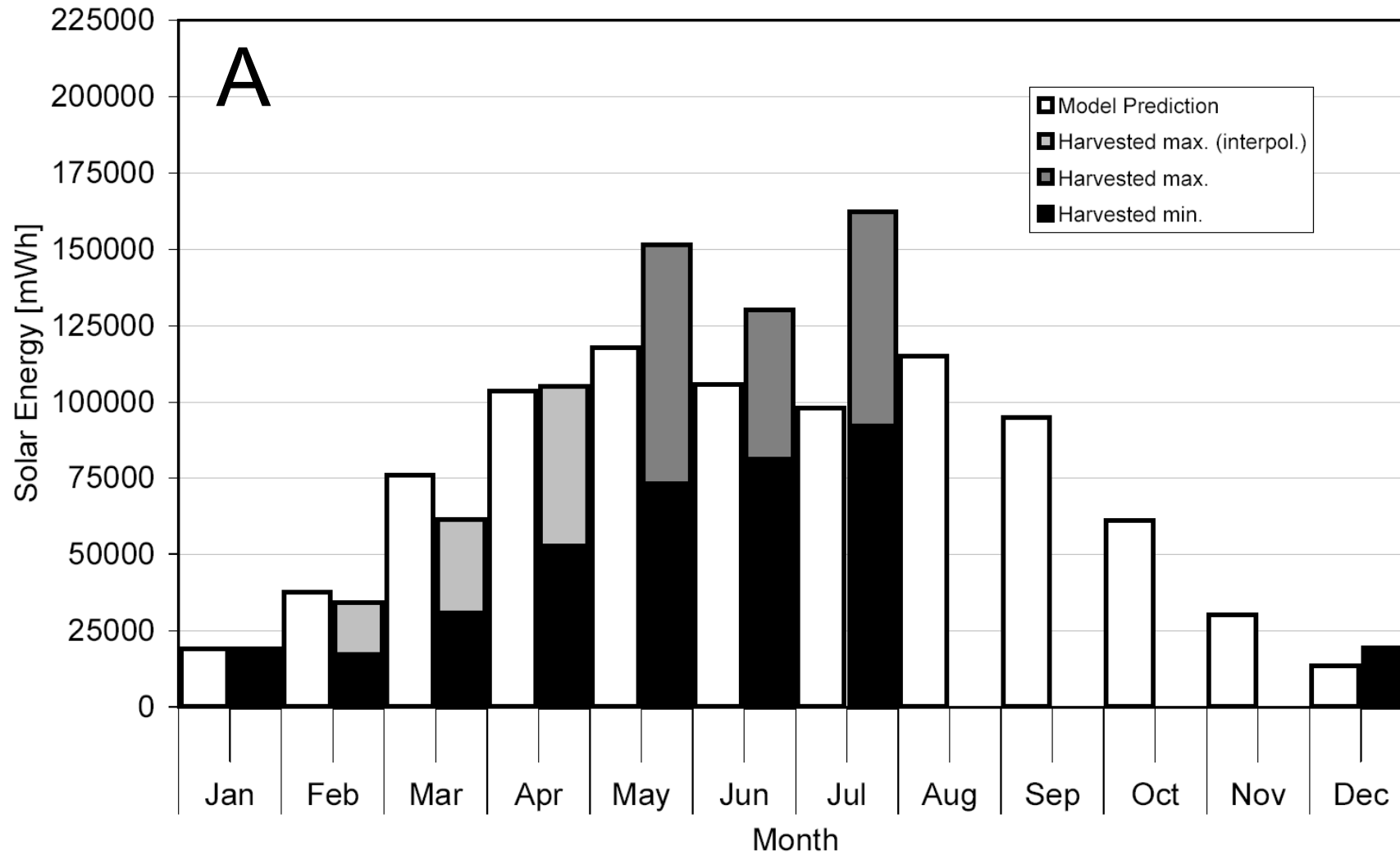
# Battery Charge Model

t	$((t-2+t_{\text{start}}) \bmod 12)+1$	E(t) [mWh]	E <sub>solar</sub> [mWh]	E <sub>dissipate</sub> [mWh]
0		21120		

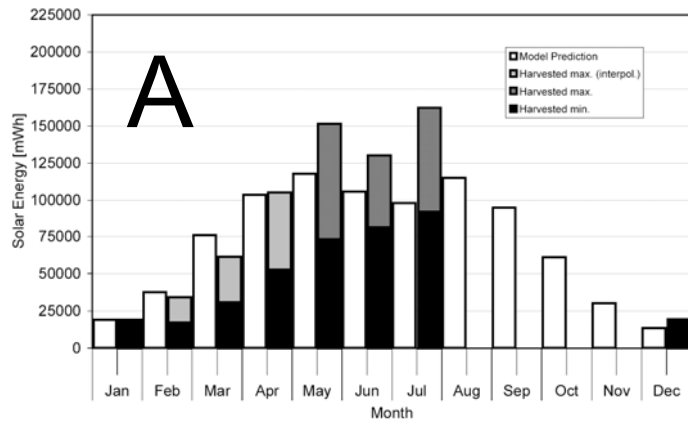




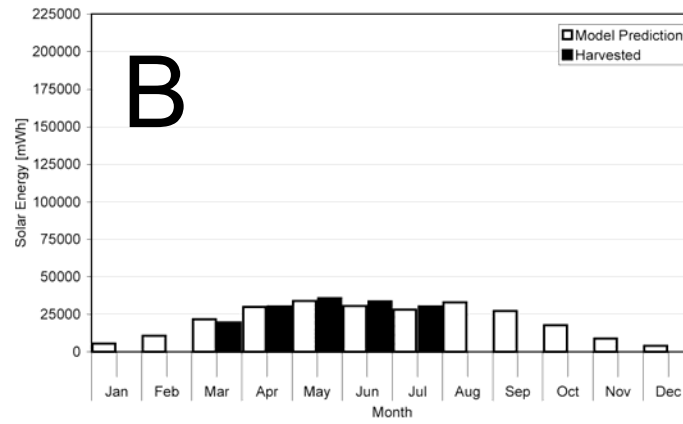
# Experimental results



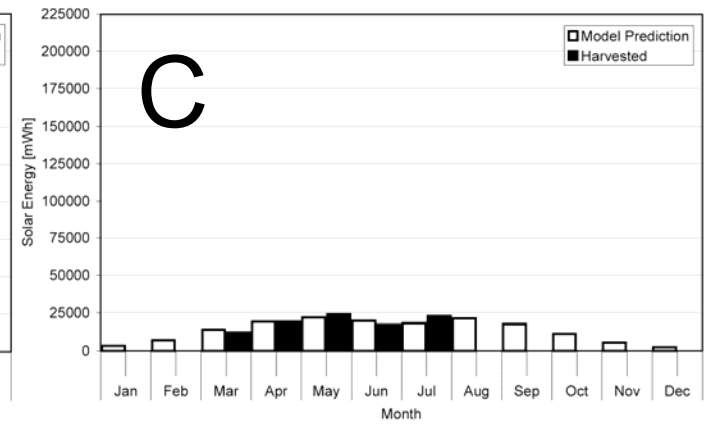
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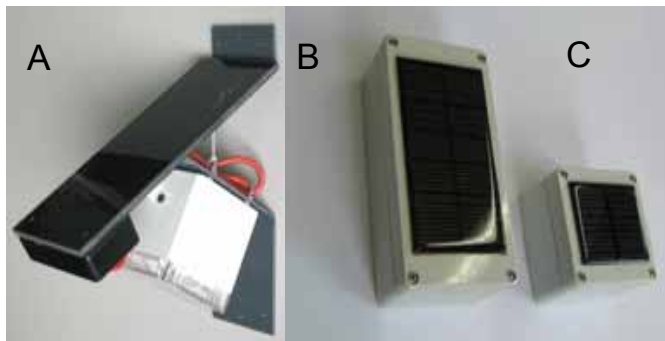
$$P_{\max} = 1500 \text{ mW}$$



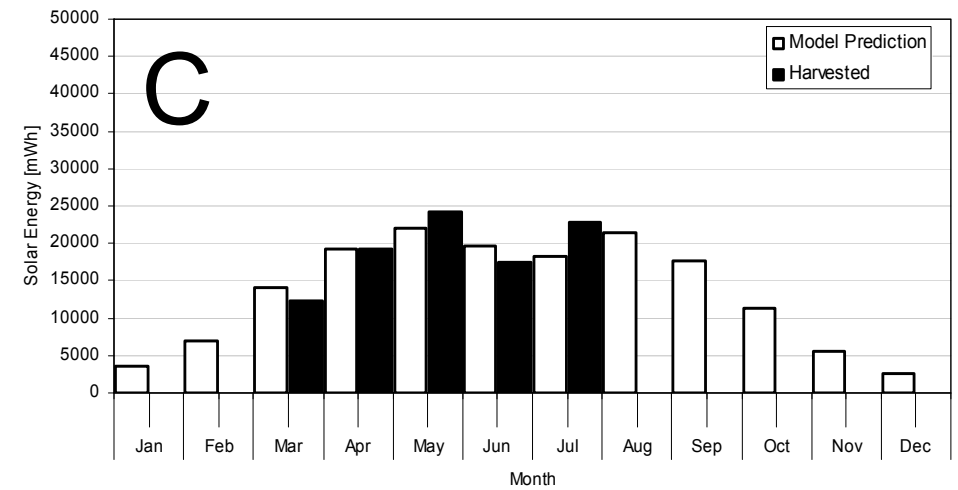
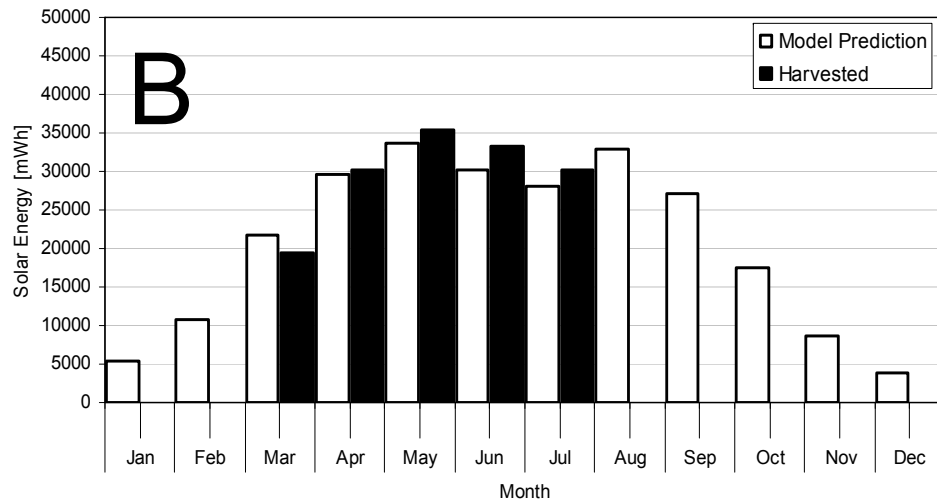
$$P_{\max} = 981 \text{ mW}$$



$$P_{\max} = 405 \text{ mW}$$



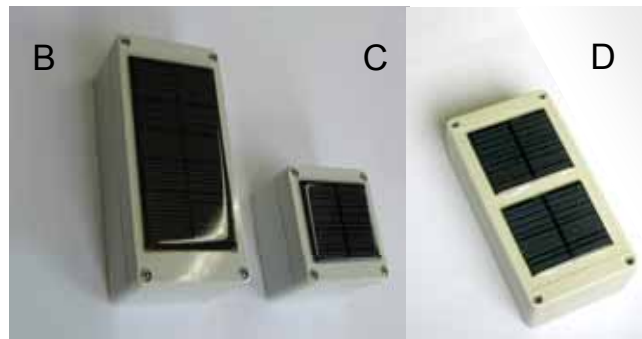
# Experimental results



$$P_{\max} = 981 \text{ mW}$$

$$I_{\max} = 109 \text{ mA}$$

$$V_{\max} = 9 \text{ V}$$

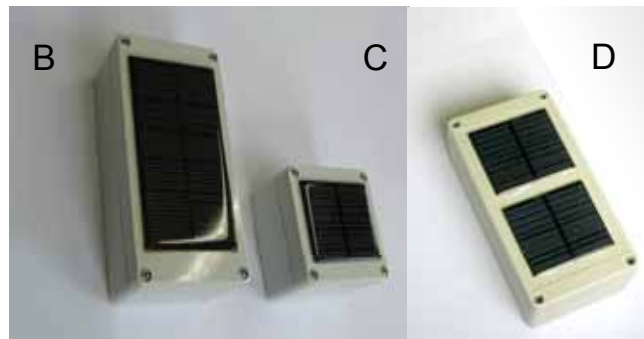
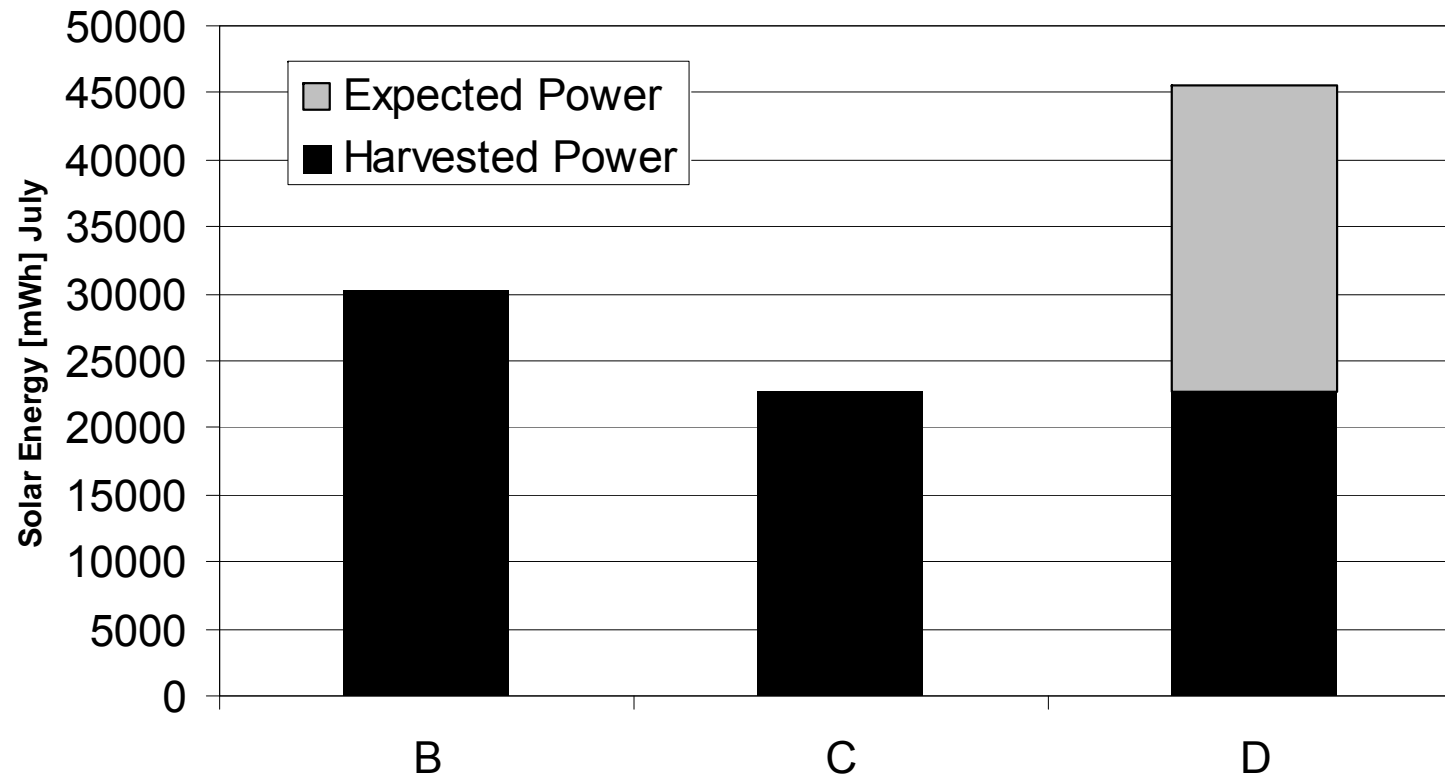


$$P_{\max} = 405 \text{ mW}$$

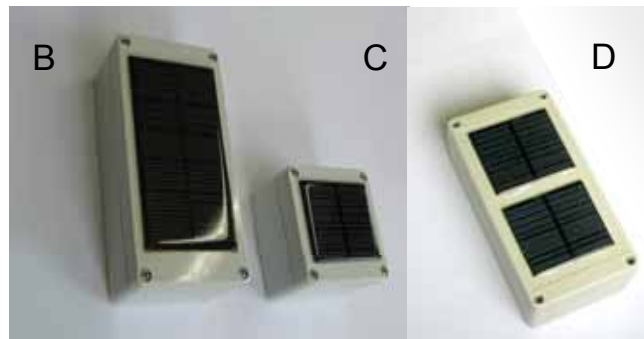
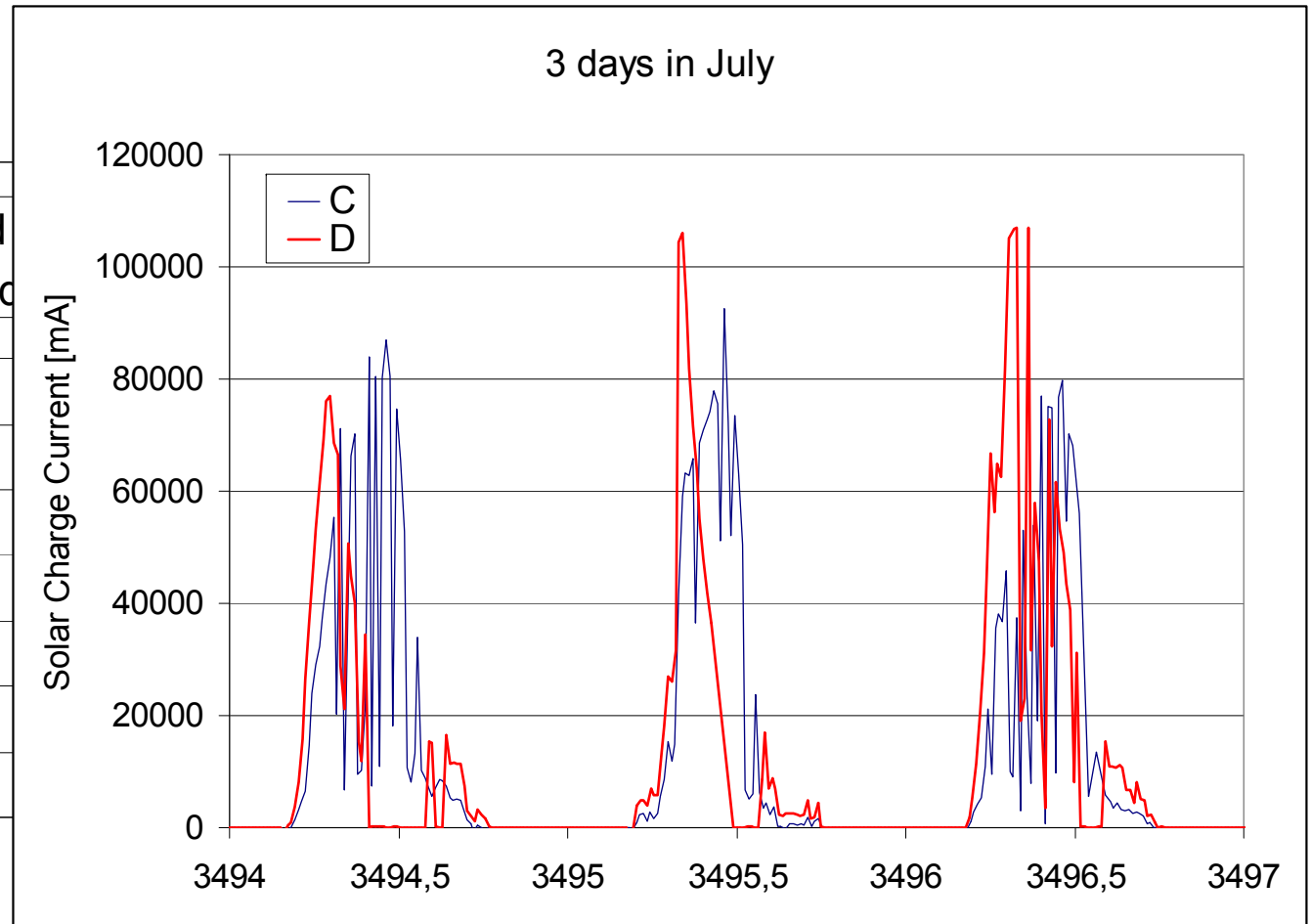
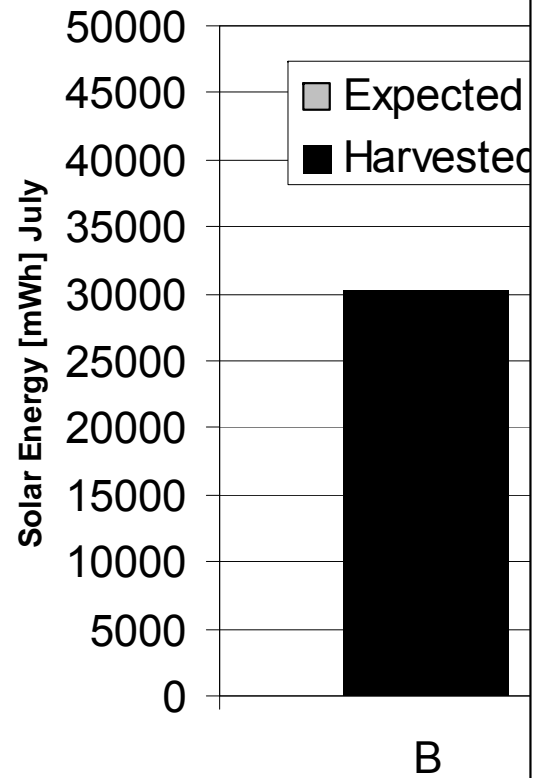
$$I_{\max} = 81 \text{ mA}$$

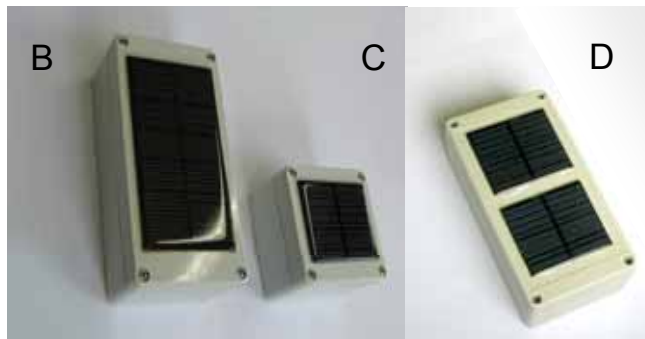
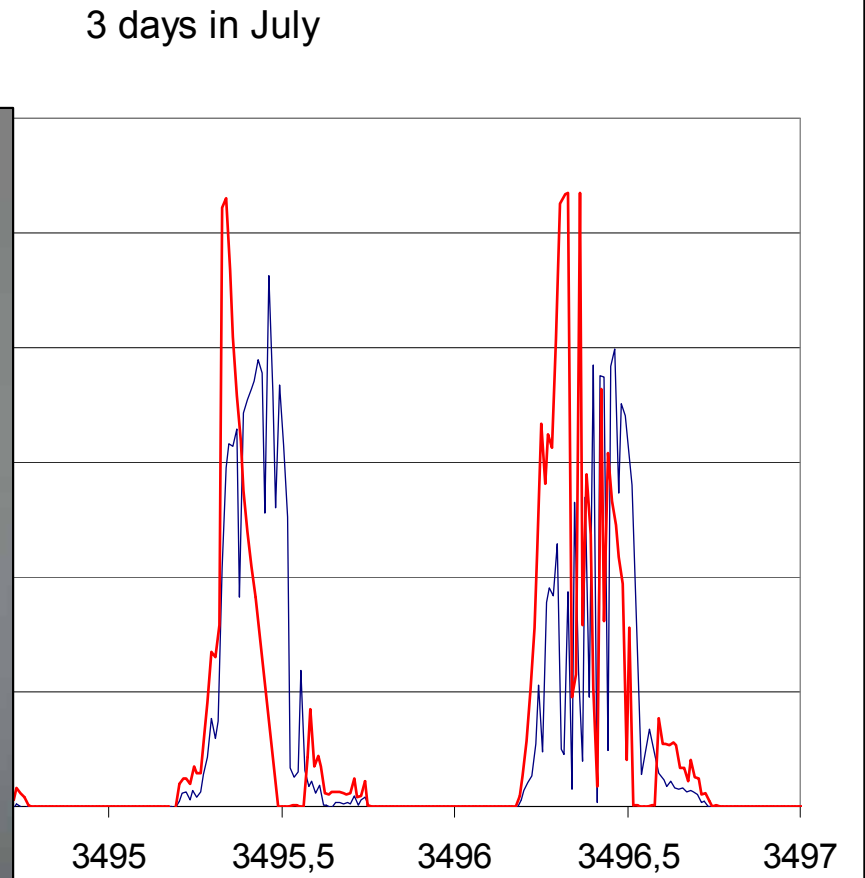
$$V_{\max} = 5 \text{ V}$$

# Experimental results

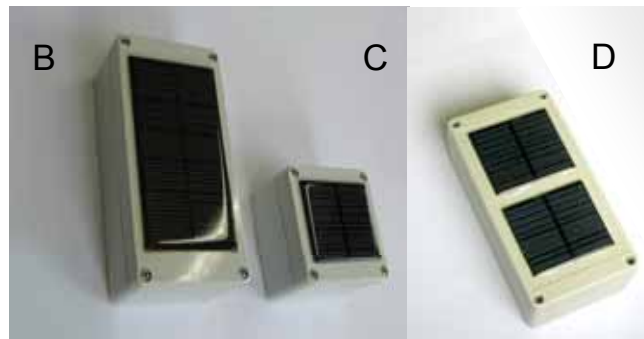
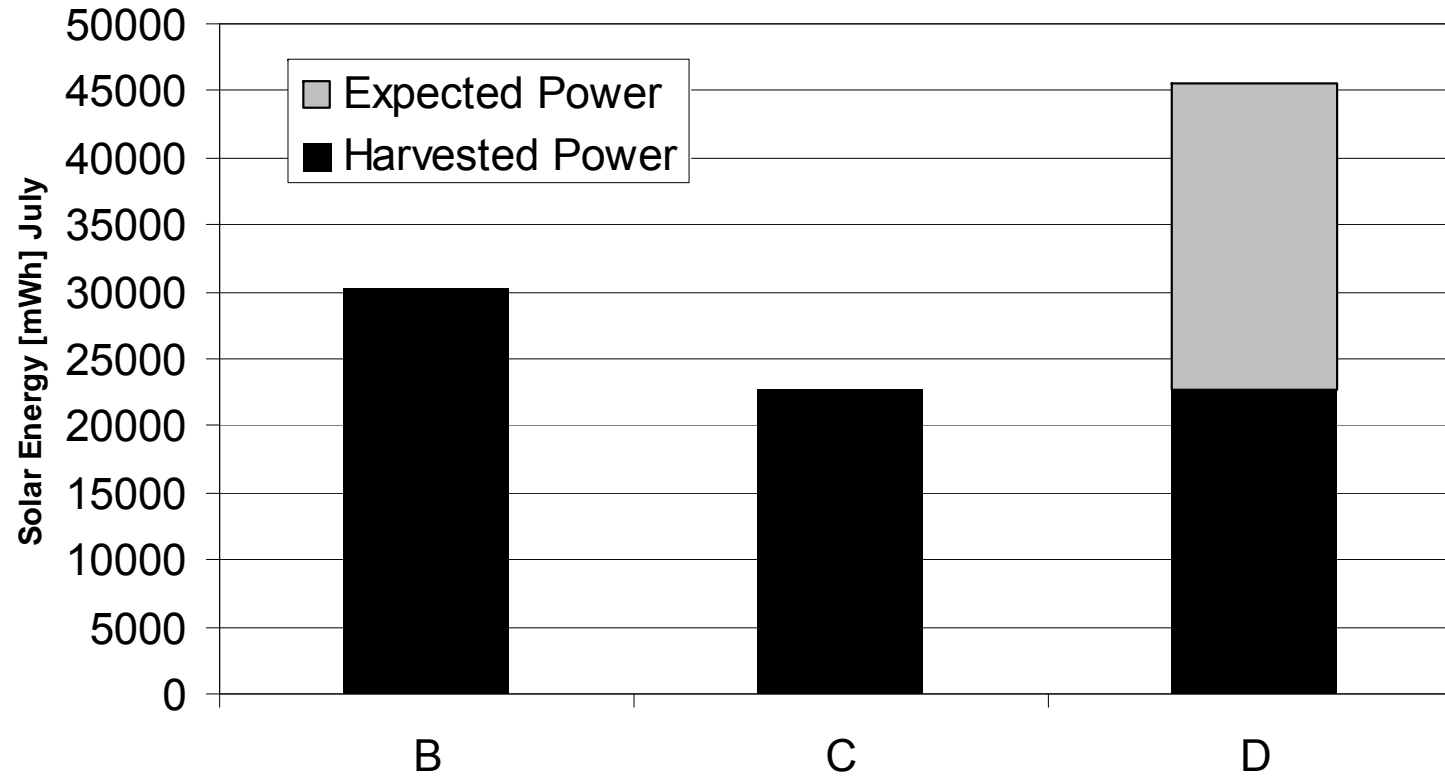


# Experimental results





# Experimental results



# 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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