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Street lighting monitoring at cabinet level using open-source tools: a real scenario

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Outline

- Introduction and motivation
- Street lighting monitoring at cabinet level using open-source tools
  - Deployment status
  - Results
- Conclusions and future work

Introduction: Trento situation

- Street lighting numbers (2015)
  - **17.915** street lamps
  - **307** power cabinets
  - **7 mln kWh** per year

- The Municipality is investing in street lighting
  - Complete **street lamp inventory** (*PRIC*)
  - **Experimental WSN**, about 800 lamps (*TEW-IP*)

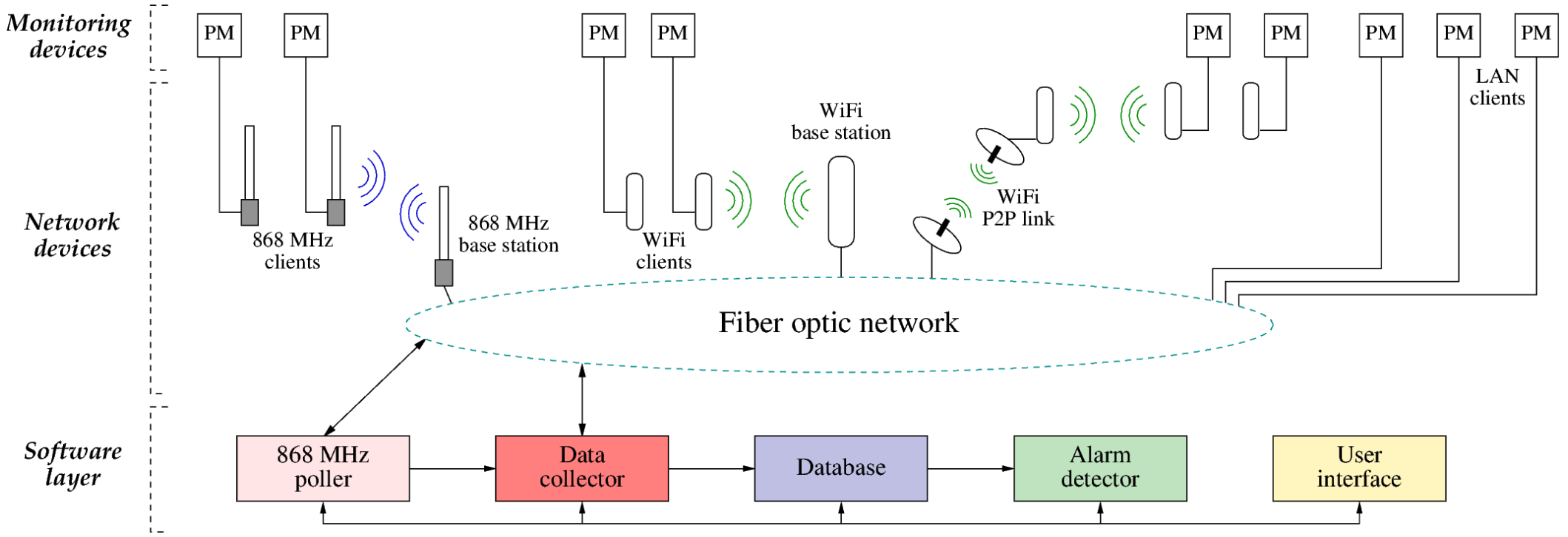
    F. Viani, A. Polo, F. Robol, E. Giarola and A. Ferro, *Experimental validation of a wireless distributed system for smart public lighting management*, ISC2 2016
  - **Monitoring at cabinet level using open-source tools**
    - Completely designed and developed internally
    - Internal funding of the administration

Motivation

- **Rationale**
  - The monitoring of street lighting on the whole territory of the Municipality would really improve street lighting management
  - Lamp-level monitoring and control may be excessive for residential/industrial suburbs
  - A cabinet-level monitoring-only solution may already provide relevant information at a much lower price

- **Requirements**
  - Considerably reduce deployment costs (wrt WSN)
  - Use generic hardware
  - Use free available open-source and/or self-developed software

Street lighting monitoring at cabinet level using open-source tools



Street lighting monitoring at cabinet level using open-source tools

- **Monitoring devices**
  - Standard industrial power meters (PM)
    Voltage/current measurements with 0.5 and 1% max rel. error
  - Three types: 1-phase, 3-phase insertion and 3-phase with CT
  - MODBUS-RTU over RS-485 → RS-485/Ethernet converters
  - Simple installation in existing street lighting cabinets

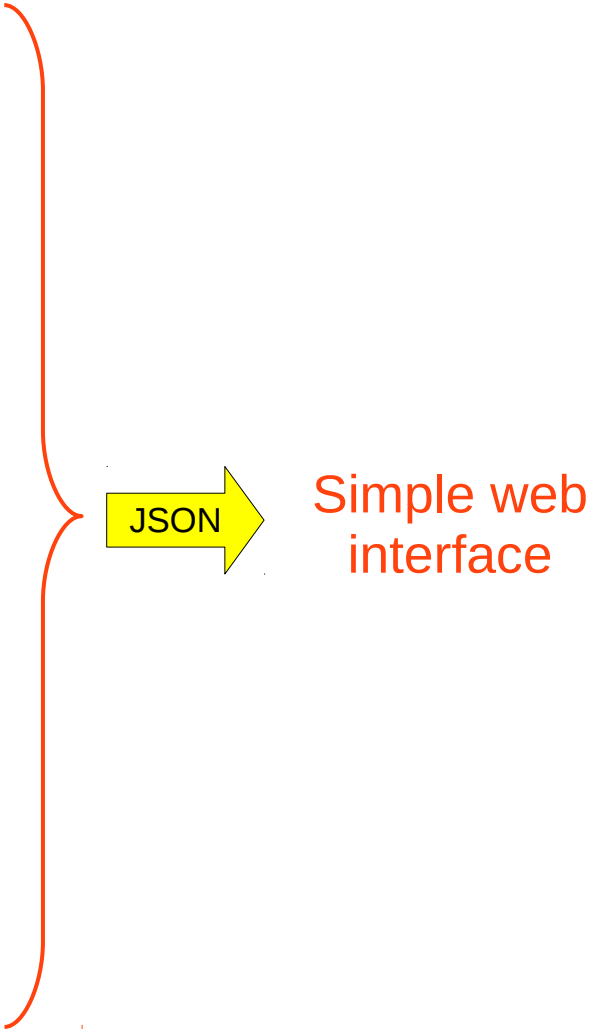
- **Network infrastructure**
  - The Municipality of Trento owns a large fiber optic network
    (about 47 km of backbone cables)
  - The backbone network has been extended by means of:
    - **Ethernet**
    - RS-485
    - **5 GHz 802.11n WiFi**
    - 868 MHz (experimental)

Street lighting monitoring at cabinet level using open-source tools

- **Software layer**
  - ***Data collector***
    - Standard open-source SCADA software *Nagios*, measurement retrieval
    - Self-developed plugins for querying PMs
    - 20 s sampling for each PM
  - ***Database:*** open-source Round Robin Database (RRD)
  - ***Alarm detector***
    - Self-developed auto-tuning routine, main source of information for end users
    - **Automatically** detects major faults on street lighting lines
    - Highlights anomalies in the retrieved electrical measurements
    - Derives high-level information for each phase
  - ***Web-based user interface***
    - Self-developed using open-source JavaScript libraries
    - Management of the system
    - Data querying, alarm detector output visualization
    - Manual running of the alarm detector with specific parameters

Alarm detector: outputs

- **Times of switch-on/off** of a power line
  - Automatic detection of unwanted switch-on/off events
- **Total energy** consumption of a cabinet
  - Automatic detection of faulty dimming devices
  - Automatic detection of faulty street lighting lines
- **Instant power** anomalies
  - Periods with increased/decreased instant power with respect to reference data
  - Automatic detection of dimming profile anomalies
  - Automatic detection of temporary line faults
- **Voltage** anomalies
- Low **power factor** alarms



Web-based user interface: example

Numero inventario	Nome	3/3 - 4/3	4/3 - 5/3	5/3 - 6/3	6/3 - 7/3	7/3 - 8/3	8/3 - 9/3	9/3 - 10/3	% riduzione media per fase			Energia media per giorno	Disp. media dati durante il periodo
									1	2	3		
234	Povo via Mesiano universita								3%	4%	5%	86 kWh	96%

Quadro 234 - Povo via Mesiano universita, periodo 5/3 -

Riepilogo

Affidabilità dati: 97%
Numero max ON per fase: 1
Numero max OFF per fase: 1
Consumo totale kWh: 67.23

Riduzione fase 1: 3%
Riduzione fase 2: 24%
Riduzione fase 3: 37%

Tensione: regolare
Cosfi: regolare

Affidabilità dati giorni di riferimento: 96%
Numero max aumenti potenza per fase: 0
Numero max cali potenza per fase: 1

Dettaglio

Accensioni/spegnimenti impianto

Fase	ON	OFF
1	18:17	06:37
2	18:17	06:37
3	18:17	06:37
impianto	18:17	06:37

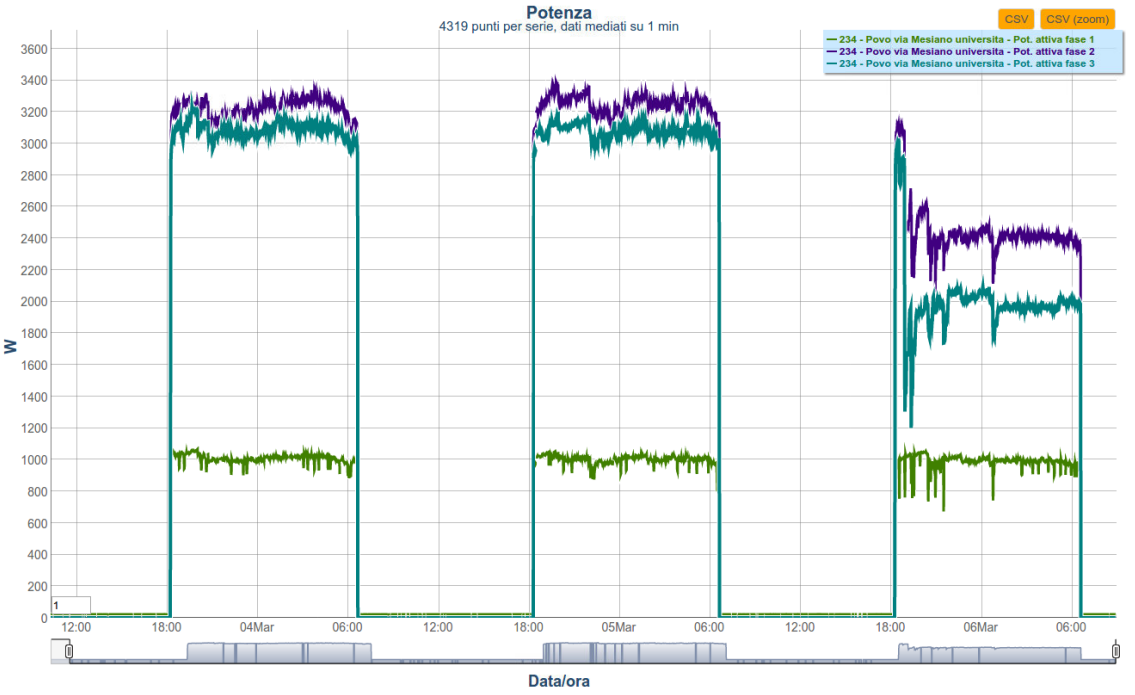
Allarme diminuzione consumo totale
(probabile linea spenta)

Consumo rilevato nel periodo analizzato: 67.23
Consumo medio rilevato nel periodo di riferimento: 91.07

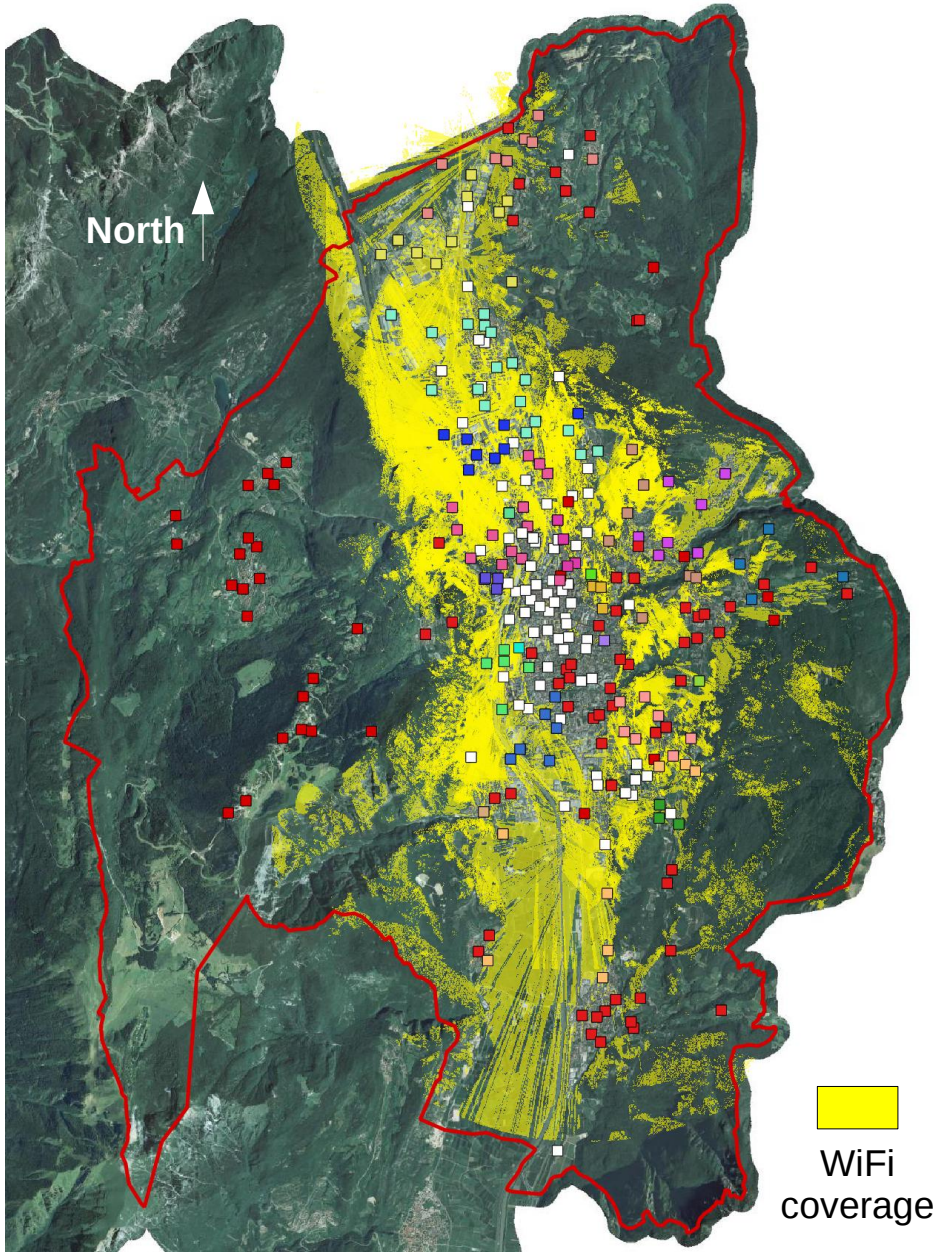
Aumenti/cali di potenza

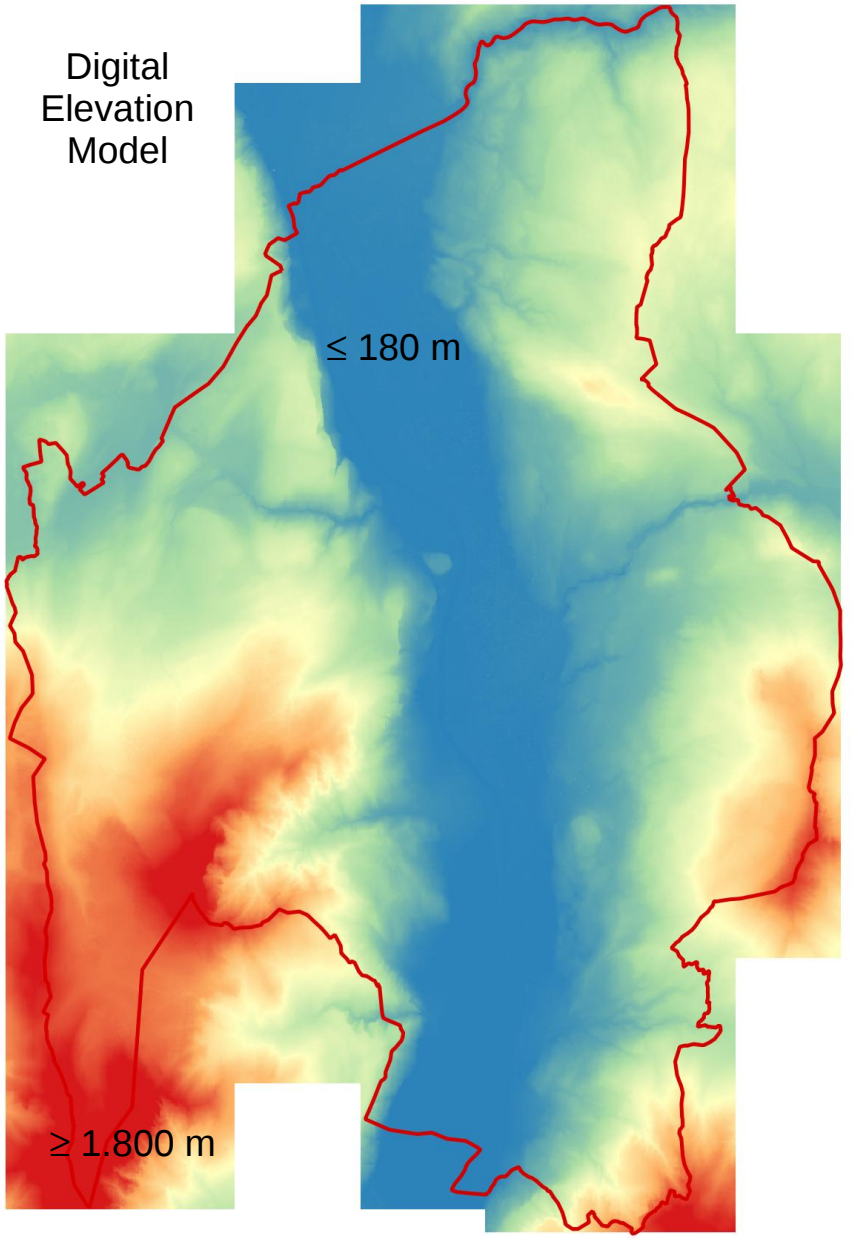
Fase	aumenti			cali		
	ora	durata	potenza	ora	durata	potenza
1	-			-		
2	-			18:56	691 min	1177 W
3	-			18:56	691 min	2049 W

Chiudi



Deployment status





Deployment status and results

Number of monitored cabinets at Sep. 14, 2016

PM type	Connection				Total
	Ethernet	RS-485	WiFi	868 MHz	
1-phase	5	2	23	0	**30**
3-phase dir.	55	4	55	2	**116**
3-phase CT	2	0	0	0	**2**
Total	**62**	**6**	**78**	**2**	**148**

Number of automatically detected major faults in one year

Month	N. of monitored cabinets (whole month)	Detected bypass events	Detected line/cabinet faults
September 2015	56	1	-
October	65	3	2
November	72	10	2
December	75	7	2
January 2016	78	7	1
February	88	4	2
March	104	14	5
April*	121	1	-
May	122	3	2
June	124	14	5
July	134	3	3
August	147	6	2
	TOTALS	**73**	**26**

* 1 week down for maintenance

Examples of automatically detected faults

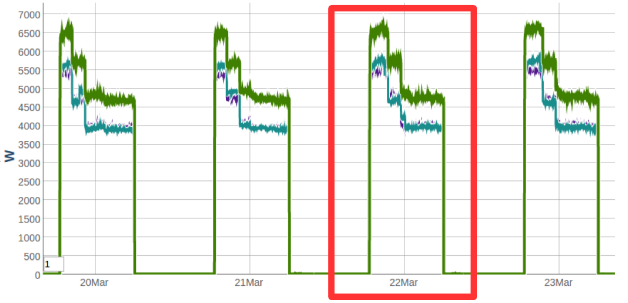
Detected dimming device in bypass mode

$$|E/E_{ref} - 1| \geq e_{\text{alarm}}$$

Unexpected dimming profile change

$$|P_i(t_{an}) - P_{i,ref}(t_{an})| > P_{\text{alarm}}$$

$$\frac{|P_i(t_{an}) - P_{i,ref}(t_{an})|}{P_{i,ref}(t_{an})} > p_{\text{alarm}}$$



Faulty RCDs** with automatic re-connection

$$P_i(t_{on} - 1) \leq P_i^{off} \wedge$$

$$P_i(t_{on}) > P_i^{off}$$

**RCD: residual-current device

Results

- **Energy and cost saving**
  - Without monitoring, a device in bypass mode could be detected only after a periodic manual check (after 1-6 months)
  - Examples of energy/cost waste:
    (night = 12 hours, correction after 3 months from event, average energy price for street lighting in Trento)

System instant power	Estimated energy waste	Estimated cost waste
5 kW	1.620 kWh	330 €
15 kW	4.860 kWh	990 €
30 kW	9.720 kWh	1.980 €

- **Reduction of security issues**
- **Support to street lighting management**
  - Automatic detection of faulty twilight switches and RCDs with automatic re-connection (temporary faults)
  - Automatic detection of low power-factor lines
  - Automatic detection of voltage anomalies from distribution network
  - Possibility to verify the correctness of dimming profiles
  - Possibility to verify the homogeneity of switch-on/off times in adjacent areas

Conclusions

- The developed solution proved to be **very effective**
  - Suitable for the direct use of technicians/workers without specific training
  - Automatic fault detection drives extraordinary maintenance
  - Data storage/querying/analysis allows the improvement of ordinary maintenance

- Deployment and maintainance with **low impact and cost** (where a cabinet-level monitoring is sufficient)
  - Simple installation of devices
  - Use of standard equipment, no brand dependence
  - Use of open-source free software, no annual fees

Future work

- **Extension to the remaining street lighting power cabinets** of the Municipality in the next months
  (work in progress)
- **Extension of other services** enabled by the parallel deployment of a WiFi network
  (already planned: video surveillance, free WiFi to citizens of suburbs)
- Further improve the alarm detector software, e.g.:
  - Automatically detect not uniform switch-on/off times in adjacent areas
  - Automatically detect single/groups of faulty lamps (e.g.: detection of on/off patterns at lamps end of life)
- Distribute the internally developed software under GNU General Public License

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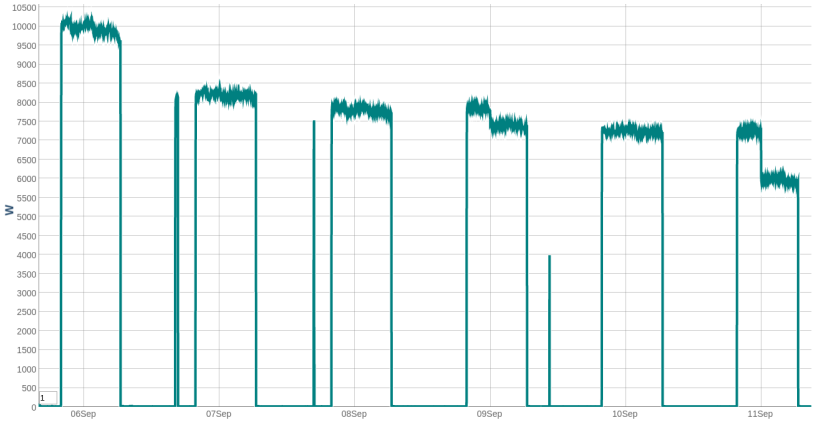
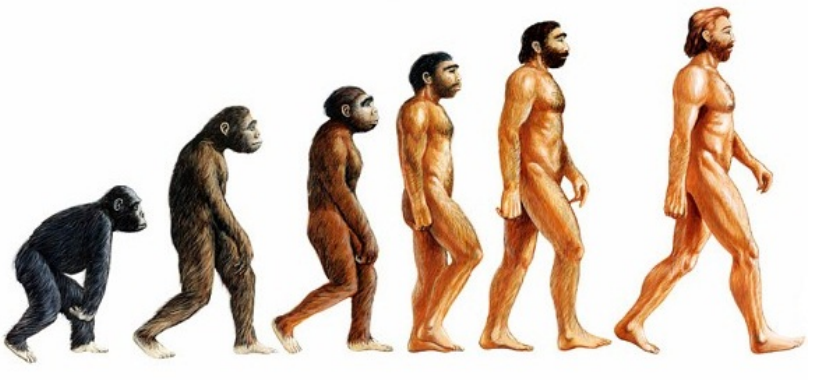
Thanks for your attention!



- questions?
- suggestions?
- **want to make Trento your new testbed?**



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