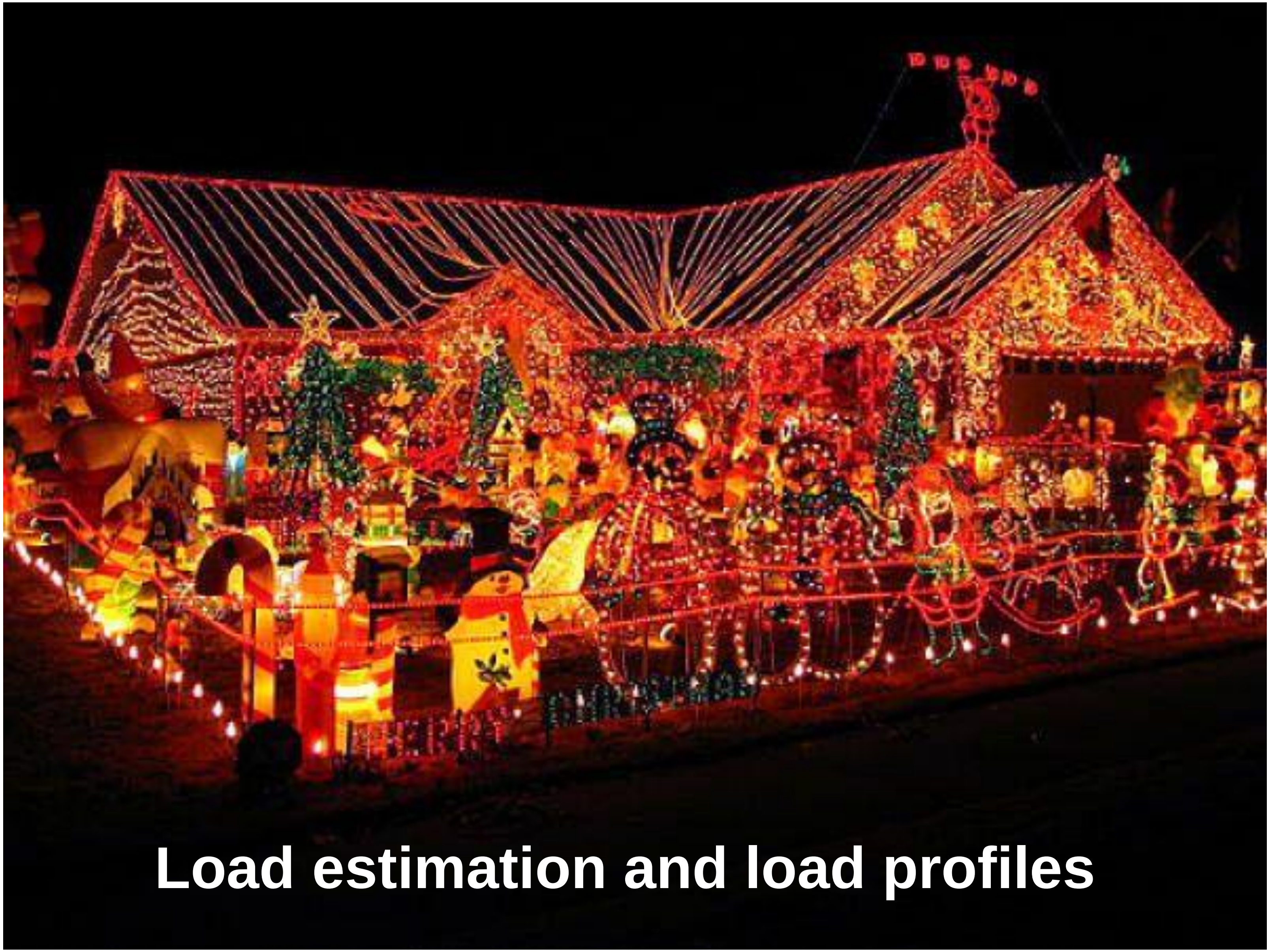


Load estimation and load profiles

Juan de Santiago
jusa@angstrom.uu.se

1TE726, 1TE303 Analysis of Power Distribution Grids

Goal for today

- How to size your loads for the assignment

- What if you need to make a load forecast

- What if you need a load profile to test your grid or control.

- Resear questions and ideas

Agenda

- Load sizing
- Load profiles and simulation
- Load profile generation and forecast: Top-down and bottom up models
- Regulation and demand
- A case example
- Smart meters

Top-down and bottom up methods

Top-down

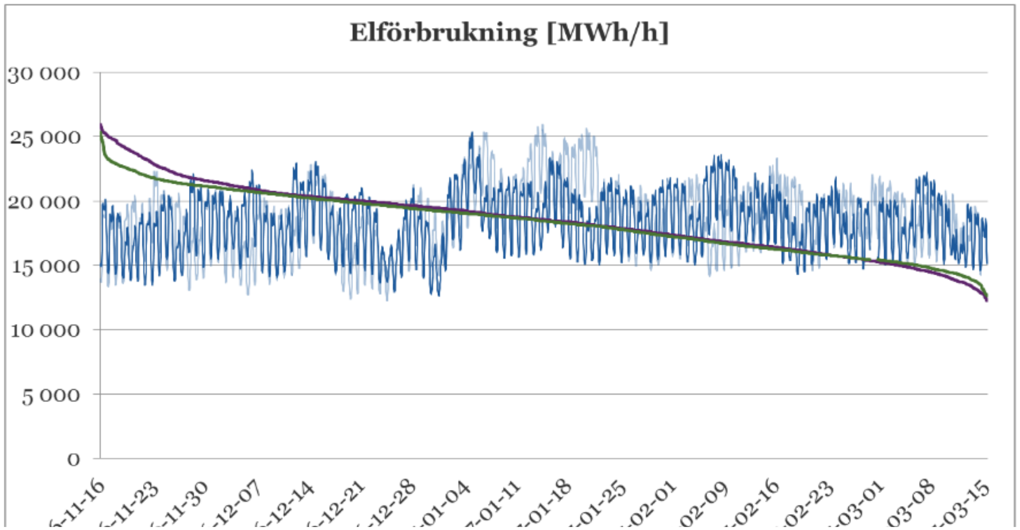
I don’t know the details, but the numbers depend on…

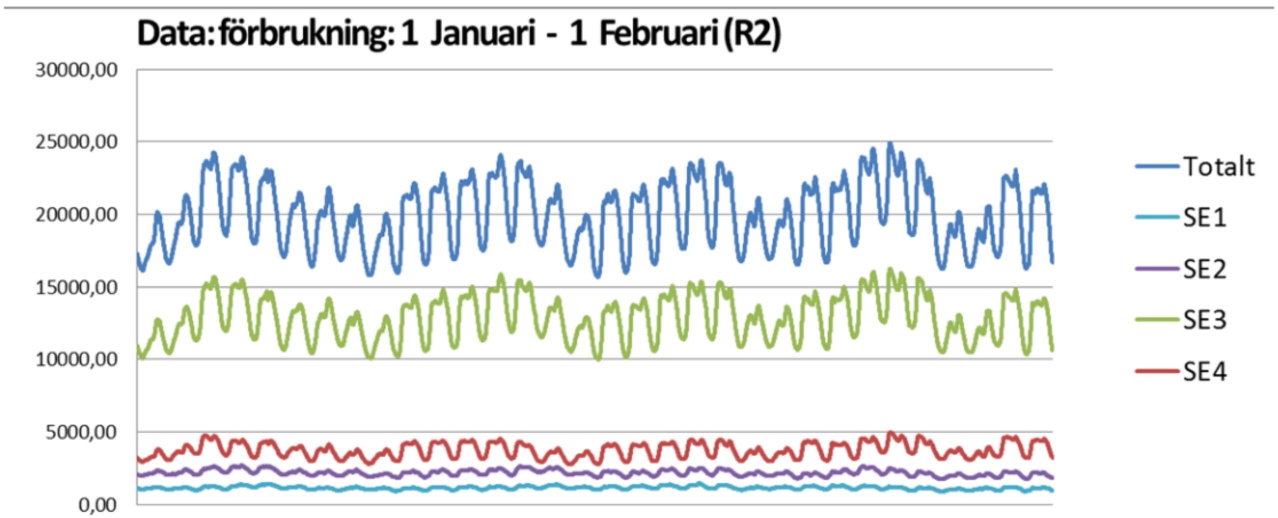
Bottom up

I count every little consumption and I add them up.

Top-down and bottom up methods

Top-down example, what is the consumption for tomorrow?





Figur 7 Elförbrukning för de 4 areorna i Sverige under januari 2011.

Top-down and bottom up methods

Top-down example, what is the consumption for tomorrow?

Is it weekend? Is it cold

Take the same as the closet Wednesday from last year,

Reduce 3% because of economic factors

Adjust plus, minus 5% for the weather forecast

Top-down and bottom up methods

Top-down example, what is the power demand of your customer “single-family house”

Check SCB (Official statistics of Sweden)
Check Swedish Energy Agency’s publications:

Make a guess based on heating system

Top-down and bottom up methods

Statistiska centralbyrån:

One family house (villa)
~ 20.000 kWh/år with electricity heating
~ 5.000 kWh/år with other heating system
(små hus)
~ 6.700 kWh/år
Apartment
~ 2.000 - 4.000 kWh/år.

https://www.energimarknadsbyran.se/el/dina-avtal-och-kostnader/elkostnader/elforbrukning/normal-elforbrukning-och-elkostnad-for-villa/

Top-down and bottom up methods

Statistiska centralbyrån:

Uppvärmning (cirka 15 000 kWh)
Varmvatten (cirka 5 000 kWh)
Hushållsel (cirka 5 000 kWh)

https://www.bixia.se/energi-i-fokus/vad-ar-en-normal-elforbrukning-for-en-villa

Top-down and bottom up methods

Bottom up example, what is the consumption for tomorrow?

Make a list of all your appliances.
Make a list of all activities that you are planning.
Make a list of all the consumptions.

Load sizing for homes

Different approaches:

a) The grid support the demand of each customer.
If the customer has a 16 A contract, we deliver 16 A.

b) We estimate the peak that each customer needs.
Like in E-On Network Design Manual, “transformer size calculation”, page 50:
Load = N * A * Ft * F2
(A = After Diversity Maximum Demand)
(Ft * F2 – there is a table depending on the n. of loads)

c) Statistic analysis: Velander’s equation.
d) Standard Load profiles for different categories
e) Probabilistic, statistic analysis: machine learning…

Load for each customer

There are two types of contract in Sweden:

a) Individual contract: The usual everywhere in the world. You have your individual electricity meter and you pay by installed power and energy used. Tariffs from Vattenfall:

Fast pris	Enkeltariff E4	Tidstariff T4
Grupp**	1 665 kr/år	1 665 kr/år
16	3 920 kr/år	3 920 kr/år
20	5 485 kr/år	5 485 kr/år
25	6 870 kr/år	6 870 kr/år
35	9 425 kr/år	9 425 kr/år
50	13 530 kr/år	13 530 kr/år
63	18 240 kr/år	18 240 kr/år

https://www.vattenfalleldistribution.se/kund-i-elnatet/elnatspriser/elnatspriser-och-avtalsvillkor/

Load for each customer

There are two types of contract in Sweden:

b) “Gemensamt el”: The house community has a contract directly with the electricity company (for example 250 A). The house community decides how to divide the cost and handles the individual meters. The tariff usually has three parts: monthly fee + energy used + Peak power used

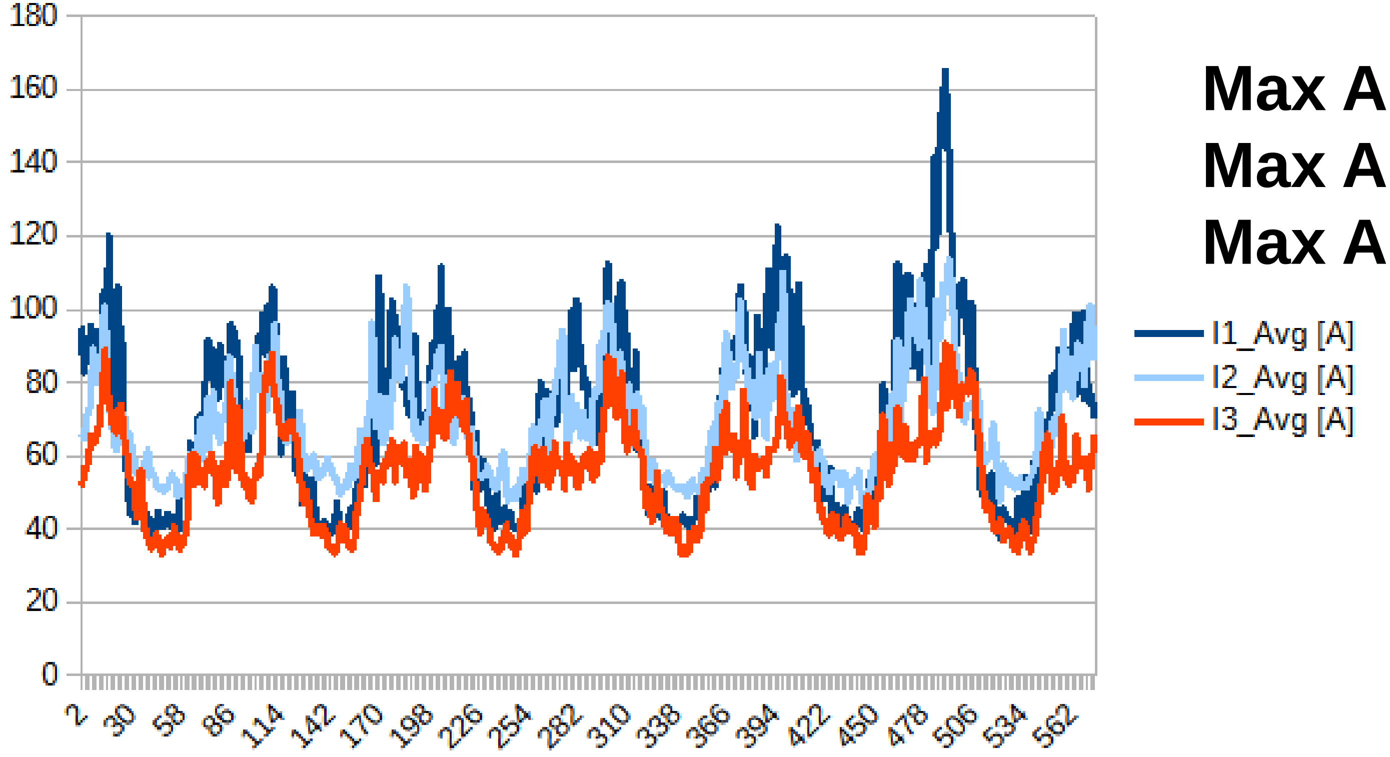
Prislistor fr.o.m. 1 januari 2022

Effektabonnemang norr prislista

Effektabonnemang söder prislista

Nättariff lågspänning*	**N3T**	**N4**	
Fast avgift	4 000	468,75	kr/månad
Månadseffektavgift	33,75	46,25	kr/kW, månad
Högbelastningsavgift	83,75	0	kr/kW, månad
Överföringsavgift högpristid**	26,5	60,0	öre/kWh
Överföringsavgift övrig tid**	10,5	18,0	öre/kWh

Measurement of a house with 63 apartments (current)

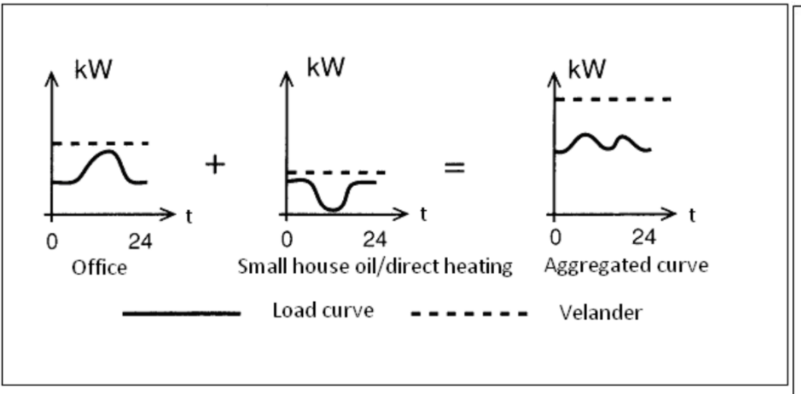


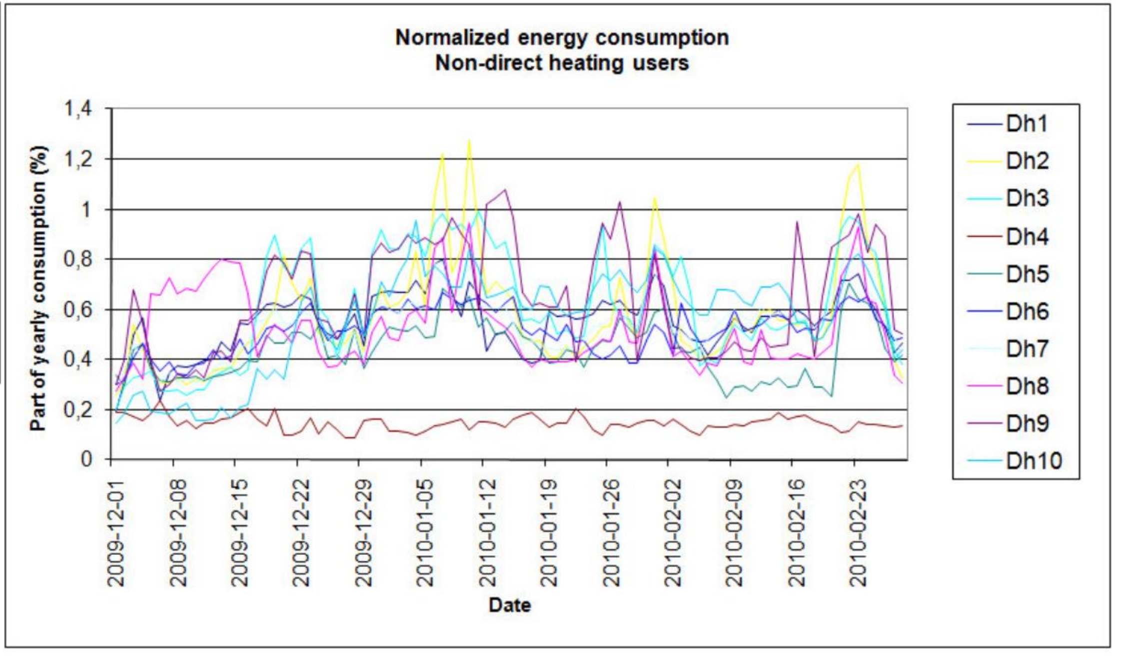
Max A L1: 194A
Max A L2: 138A
Max A L3: 118A

The fuse is rated 250 A.
63 apartments times 16 A = 1008 A

3 x 230V x 16 A= 11 kW; 3 x 230V x 250A= 175,5 kW;

Velander's equation





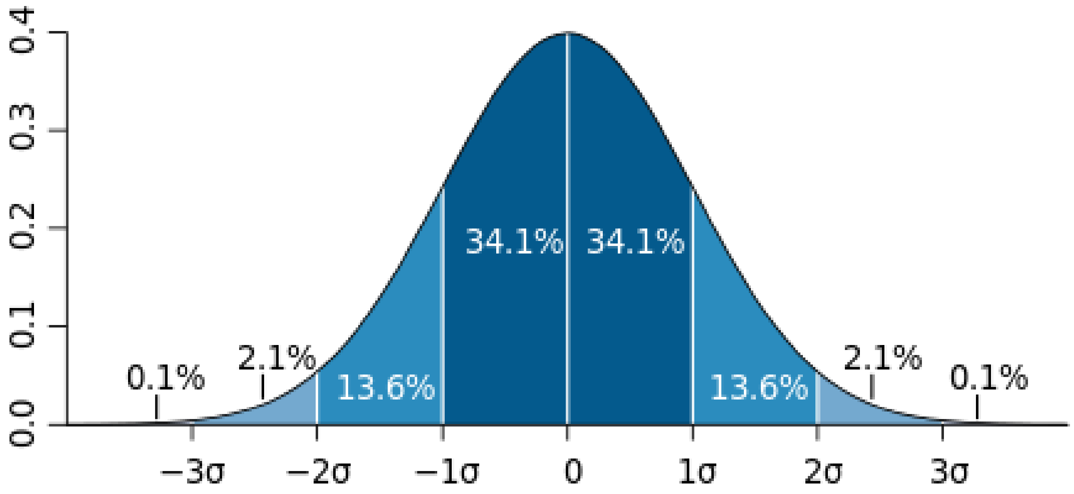
Not all loads are active at the same time. There is a "Load Coincidence factor". The Valander's formula takes this into consideration:

Pmax = aW + b sqrt(W)

W = annual energy consumption kWh

Velander's equation

Where is this formula coming from?
Remember the equation for the Standard deviation?
Empirical equation



Pmax = aW + b sqrt(W)

W = annual energy consumption kWh

Velander's equation

Velander constants		Category
a	b	
0,0003	0,025	Small house/Direct heating (older than ELAK)
0,0003	0,025	Small house /Electric boiler
0,0003	0,025	Small house/Combination oil-electricity
0,0003	0,025	Small house/Heat pump (outdoor air-with additional heating)
0,00033	0,05	Small house/Household electricity

Table 3.1; Selected Velander constants

Greta Brännlund, Evaluation of two peak load forecastingmethods used at Fortum, Degree project in Electric Power Systems, Second Level, KTH Stockholm, Sweden 2011.

Persson, Erik; Jonsson, Patrik , Utvärdering av Velanders formel för toppeffektberäkning i eldistributionsnät: Regressionsanalys av timvis historiska kunddata för framtagning av Velanderkonstanter, Examensarbete Energiteknik, Mälardalen University, School of Business, Society and Engineering, 2018.

For your project

Suggestions?

For your project

E.On has different ratings for different equipment

We want to make one simulation, so we want to estimate only one load for each customer.

We size our components (lines and transformers) based on this load.

For your project

Example of E.On sizing equipment:

1.2.6.1 Voltage Regulation - Flats

Voltage regulation from LV bus-bars of the HV/LV transformer to any cut-out at the central metering position shall not exceed:

• 6% of 230 volts when supplied from “Standard 11kV Feeders”.

• 4% of 230 volts when supplied from “Long 11kV Feeders”.

The overall loop resistance is no greater than 0.24 ohms at the service position

1.2.6 Supplies to Flats

1.2.6.1 Voltage Regulation - Flats

Section 6 of this Manual, Low Voltage Network Design Calculations, detailes the method to be used to calculate voltage regulation on LV mains and services.

Voltage regulation from LV bus-bars of the HV/LV transformer to any cut-out at the central metering position shall not exceed:

- 6% of 230 volts when supplied from "Standard 11kV Feeders".
- 4% of 230 volts when supplied from "Long 11kV Feeders".

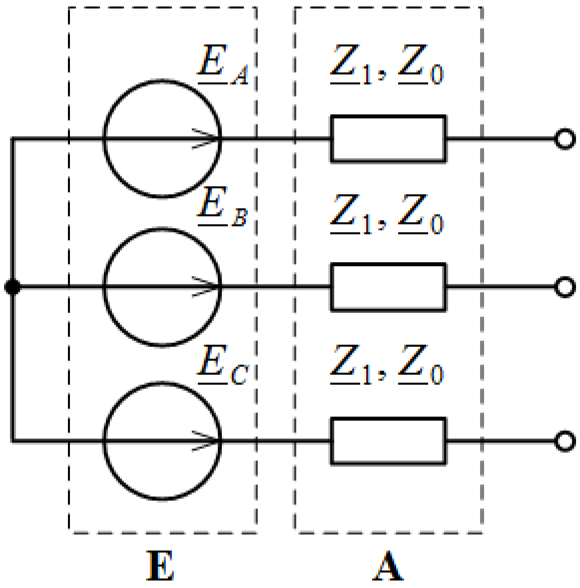
A 'Long 11kV Feeder' is defined as extending beyond the 15km radius of a Bulk Supply Point or Primary Substation. See Section 4 Network Voltage Policy 6% of 230 volts

provided that:

- The overall loop resistance is no greater than 0.24 ohms at the service position at the head of the most remote rising main (comprising the sum of transformer, main and service cable go/return impedances).
- On electrical storage heated properties the total space and water heating load must not cause a step voltage change greater than 3% when switched by the metering time/tele switch.

	Maximum Loop Resistance for simultaneously switched heating devices								
Nameplate kW rating @230v	6	7	8	9	10	11	12	13	14
Max Loop Resistance for 3% step voltage change	0.24	0.21	0.18	0.16	0.14	0.13	0.12	0.11	0.10

Out of scope from the course, but steps in voltage is a quality parameter! It is regulated in Sweden and in UK.



3% of 230 V = 6,9 V

V = I · Z
6.9 / 0.24 Ω = 28.75 A

3 · 230 · 28.75 = 20 kW

- On electrical storage heated properties the total space and water heating load must not cause a step voltage change greater than 3% when switched by the metering time/tele switch.

	Maximum Loop Resistance for simultaneously switched heating devices								
Nameplate kW rating @230v	6	7	8	9	10	11	12	13	14
Max Loop Resistance for 3% step voltage change	0.24	0.21	0.18	0.16	0.14	0.13	0.12	0.11	0.10

1.2.6.2 Service Cable Loading for Flats

The service cable design load shall be calculated according to the type of heating to be used. The formulae for "Non-electric heating" and "No central heating installed" make allowance for the future installation up to 6kW of storage heating and electric water heating.

The minimum design load for any service shall be 12kW

Non electric heating (i.e. gas, oil, solid fuel)

ADMD shall be 2 kW

Service cable design load = (ADMD x number of flats) +8 kW

e.g.

2 flats = 2kW x 2+ 8kW =12kW

26 flats = 2kW x 26 + 8kW =60kW

No central heating installed and gas not available

ADMD shall be 3 kW

Service cable design load = (ADMD x number of flats) +8 kW

e.g.

2 flats = (3kW x 2)+ 8kW =14kW

26 flats = (3kW x 26) + 8kW =86kW

Direct acting electric heating (i.e. panel, ceiling heaters)

ADMD shall be 2 kW + 50% of installed electric space heating load (ignore water heating)

Service cable design load = (ADMD x number of flats) +8 kW.

e.g.

2 flats with 8kW of panel heaters each = (2kW + 8kW/2) x 2) +8kW =20kW

26 flats with 10kW of panel heaters each = (2kW +10kW/2) x 26) + 8kW =190kW

1.2.4.1 Residential Loads

'Non-electric' and 'No Central Heating' values of After Diversity Maximum Demand (ADMD) assume small or average houses and flats up to 4 bedrooms. For larger properties increase the ADMD by 0.5kW per additional bedroom.

Heating Type	**ADMD kW (LV Mains)**
No central heating – gas available in the dwelling	2.0
No central heating – gas not available in the dwelling	3.0
Gas / Oil or Solid fuel central heating	2.0
Direct electric heating – ceiling / panel /convector	2.0 plus 50% of installed space heating load (ignore water heating)
Electric storage heating	100% of installed storage and 100% of water heating load
Electric storage heating plus direct heating	100% of installed storage and 50% of direct heating +100% of water heating load
Note that the above values are "after diversity" demands and apply directly to the design of mains cables. When designing individual services or sizing transformers, further formulae are applied to adjust the diversity element as defined in the appropriate sections of this manual.	

For houses over four bedrooms increase the ADMD by 0.5kW per additional bedroom.

The minimum design load for any service shall be 12kW

Service cable loading shall be based on the formulae:

Non-electric heating (i.e. gas, oil solid fuel)

Service design load = (2x ADMD x N) +8 kW

= 12kW single house

= 16kW if looped to second house

ADMD is normally 2kW

N = 1 for single house. 2 if loop service is installed.

I use this values for the example with 63 apartments:

63 apartments: (2x 2 x 63) + 8 = 260 kW

260 / 3 / 230V = 377 A

Example of E.On sizing equipment:

1.2.6.3 Service cable / cut-out maximum thermal loading - Flats

Continuous summer cable ratings in ducts shall be used for services to flats;

The nameplate kW ratings of electrical appliances are based on a nominal voltage of 230v but may operate at up to 253v. As explained in section 1.2.5.3, a 1kW appliance nameplate rating equates to 1.2kW of load at 253v. The following service loadings are based on a current of 4.8 amps per kW:

35mm2 Hybrid – 90* Amps ≈ 18 kW
35mm2 Wavecon - 90* Amps ≈ 54 kW
95mm2 Wavecon - 201 Amps ≈ 125 kW
185mm2 Wavecon - 292 Amps ≈ 183 kW
300mm2 Wavecon - 382 Amps ≈ 239 kW

Example of E.On sizing equipment:

They estimated a load and based on that they choose a cable. No simulation involved.

For your project

Example of E.On sizing equipment:

1.2.10.2 Transformer size calculation

On residential developments the total load on the transformer shall be calculated according to the following formula:

Load = N x A x Ft x F2

Where F2=1+12/AN A = ADMD in KW N = No of houses Ft = 70%

Compared to cable sizing, there is a Ft and a F2 reducing the power.

Non electric heating (i.e. gas, oil, solid fuel)

ADMD shall be 2 kW

Service cable design load = (ADMD x number of flats) +8 kW

Property Type	Typical ADMD
Small shop	Single ph 8 kW
Café/Restaurant	Three ph 15 kW
Take away	Three ph 20 kW
Church	Three Ph supply lots with infra-red direct heating up to 50 kW
Farm	Three Ph up to 100 kW
Farm with grain dryer	Three Ph 200 kW depending on fan motor/heater
Beauty salon/ Tanning shop	Three ph 10 kW
Hair dressers	single ph 5 kW
Pubs	Three ph 20 kW exceptionally up to 120 kW
Garages/workshops	Three Ph 30 kW Compressor Motors and Welders
Village stores/ small supermarkets	Three Ph 20 kW
Milking parlours	Three Ph 50 kW (normally Single Ph motors)
Sewage pumps	Three Ph 20 kW - 150Kw Compressor Motors?
Small hotels/guest houses	Three Ph 20 kW
Small businesses	Three ph 20 kW
Residential care/nursing homes	Three Ph most have lifts and all-day heating can be 100 kW.

Note that the above values are "after diversity" demands and apply directly to the design of mains cables. When designing individual services or sizing transformers, further formulae are applied to adjust the diversity element as defined in the appropriate sections of this manual.

Calculated values of Ft x F2 are shown below

	Values of Ft x F2 for ADMDs of:						
No of houses N	**2 kW**	**3 kW**	**4 kW**	**6 kW**	**10 kW**	**15 kW**	**20 kW**
1	4.90	3.50	2.80	2.10	1.54	1.26	1.12
2	2.80	2.10	1.75	1.40	1.12	0.98	0.91
3	2.10	1.63	1.40	1.17	0.98	0.89	0.84
4	1.75	1.40	1.23	1.05	0.91	0.84	0.81
5	1.54	1.26	1.12	0.98	0.87	0.81	0.78
6	1.40	1.17	1.05	0.93	0.84	0.79	0.77
7	1.30	1.10	1.00	0.90	0.82	0.78	0.76
8	1.23	1.05	0.96	0.88	0.81	0.77	0.75
9	1.17	1.01	0.93	0.86	0.79	0.76	0.75
10	1.12	0.98	0.91	0.84	0.78	0.76	0.74
15	0.98	0.89	0.84	0.79	0.76	0.74	0.73
20	0.91	0.84	0.81	0.77	0.74	0.73	0.72
25	0.87	0.81	0.78	0.76	0.73	0.72	0.72
30	0.84	0.79	0.77	0.75	0.73	0.72	0.71
40	0.81	0.77	0.75	0.74	0.72	0.71	0.71
50	0.78	0.76	0.74	0.73	0.72	0.71	0.71
60	0.77	0.75	0.74	0.72	0.71	0.71	0.71
70	0.76	0.74	0.73	0.72	0.71	0.71	0.71
100	0.74	0.73	0.72	0.71	0.71	0.71	0.70
150	0.73	0.72	0.71	0.71	0.71	0.70	0.70
200	0.72	0.71	0.71	0.71	0.70	0.70	0.70
250	0.72	0.71	0.71	0.71	0.70	0.70	0.70
300	0.71	0.71	0.71	0.70	0.70	0.70	0.70

Examples

1. 4 houses at 2 kW ADMD Trans load = 4 x 2kW x 1.75 = 14 kW
2. 70 houses at 6 kW ADMD Trans load = 70 x 6kW x 0.72 = 302 kW
3. 200 houses at 3 kW ADMD Trans load = 200 x 3kW x 0.71 = 426 kW

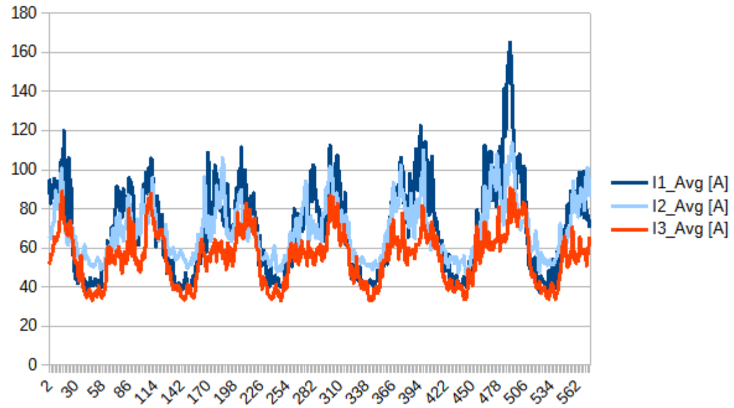
Back to the example with 63 apartments:

I use this values for the example with 63 apartments:

Contract = 63 x 16 A = 1008 A

Cable Load = (2x 2 x 63) + 8 = 260 kW = 377 A

Transformer Load = N x A x Ft x F2 = 63 x 4 x 0.74 = 252 x 0.74 = 186 A



Max A L1: 194A
Max A L2: 138A
Max A L3: 118A

For your project

1) Argue your solution.

2) Is the ADMD in the table in page 23? Use it.

3) Is the load apartments or houses? Use a reasonable ADMD (2 for small apartments, 4 for flats, for houses?) and use the table from page 51.

4) Street lights: Google the power of LED street lights, measure the distance between light posts in your street, measure the distance of posts in google maps…

5) Others: Check the area covered in Google maps and make an estimation per square metre. Make a list of the appliances that you imagine that there are in the facility (bottom-up method), google average power in a similar facility (top-down method). Visit the place and look around…

For your coming project

From here, the presentation goes through some common questions from Degree Projects and research topics.

The scope from here is a little over the content of the course.

Different types of loads

Loads change with voltage, frequency and temperature.
The power through a resistance changes with time.

20.5.1 Exponential Models

The exponential form for both real and reactive power is expressed in Eqs. (20.1) and (20.2) below as a function of voltage and frequency, relative to initial conditions or base values. Note that neither temperature nor torque appear in these forms. Assumptions must be made about temperature and/or torque values when synthesizing from component models to these exponential model forms.

$$P = P_o \left[\frac{V}{V_o}\right]^{\alpha_v} \left[\frac{f}{f_o}\right]^{\alpha_f} \tag{20.1}$$

$$Q = Q_o \left[\frac{V}{V_o}\right]^{\beta_v} \left[\frac{f}{f_o}\right]^{\beta_f} \tag{20.2}$$

Grigsby, L.L. ed., 2016. Electric power generation, transmission, and distribution. CRC press.

Different types of loads

TABLE 20.1 Static Models of Typical Load Components—AC, Heat Pump, and Appliances

Load Component	Static Component Model
Refrigerator	$P = 1.0 + 1.3958*\Delta V + 9.881*\Delta V^2 + 84.72*\Delta V^3 + 293*\Delta V^4$
	$Q = 1.2507 + 4.387*\Delta V + 23.801*\Delta V^2 + 1540*\Delta V^3 + 555*\Delta V^4$
Freezer	$P = 1.0 + 1.3286*\Delta V + 12.616*\Delta V^2 + 133.6*\Delta V^3 + 380*\Delta V^4$
	$Q = 1.3810 + 4.6702*\Delta V + 27.276*\Delta V^2 + 293.0*\Delta V^3 + 995*\Delta V^4$
Washing Machine	$P = 1.0 + 1.2786*\Delta V + 3.099*\Delta V^2 + 5.939*\Delta V^3$
	$Q = 1.6388 + 4.5733*\Delta V + 12.948*\Delta V^2 + 55.677*\Delta V^3$
Clothes Dryer	$P = 1.0 - 0.1968*\Delta V - 3.6372*\Delta V^2 - 28.32*\Delta V^3$
	$Q = 0.209 + 0.5180*\Delta V + 0.363*\Delta V^2 - 4.7574*\Delta V^3$
Television	$P = 1.0 + 1.2471*\Delta V + 0.562*\Delta V^2$
	$Q = 0.243l + 0.9830*\Delta V + 1.647*\Delta V^2$
Fluorescent Lamp	$P = 1.0 + 0.6534*\Delta V - 1.65*\Delta V^2$
	$Q = -0.1535 - 0.0403*\Delta V + 2.734*\Delta V^2$
Mercury Vapor Lamp	$P = 1.0 + 0.1309*\Delta V + 0.504*\Delta V^2$
	$Q = -0.2524 + 2.3329*\Delta V + 7.811*\Delta V^2$
Sodium Vapor Lamp	$P = 1.0 + 0.3409*\Delta V - 2.389*\Delta V^2$
	$Q = 0.060 + 2.2173*\Delta V + 7.620*\Delta V^2$
Incandescent	$P = 1.0 + 1.5209*\Delta V + 0.223*\Delta V^2$
	$Q = 0.0$
Range with Oven	$P = 1.0 + 2.1018*\Delta V + 5.876*\Delta V^2 + 1.236*\Delta V^3$
	$Q = 0.0$
Microwave Oven	$P = 1.0 + 0.0974*\Delta V + 2.071*\Delta V^2$
	$Q = 0.2039 + 1.3130*\Delta V + 8.738*\Delta V^2$
Water Heater	$P = 1.0 + 0.3769*\Delta V + 2.003*\Delta V^2$
	$Q = 0.0$
Resistance Heating	$P = 1.0 + 2*\Delta V + \Delta V^2$
	$Q = 0.0$

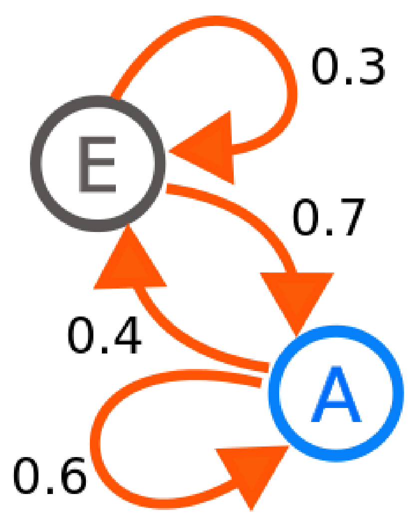
Load profile generation – Models

When are we using electrictricity?

Poisson distribution

$$f(k, \lambda) = \frac{e^{-\lambda} \lambda^k}{k!}$$

Markov chain



Bottom up - Load profile generation

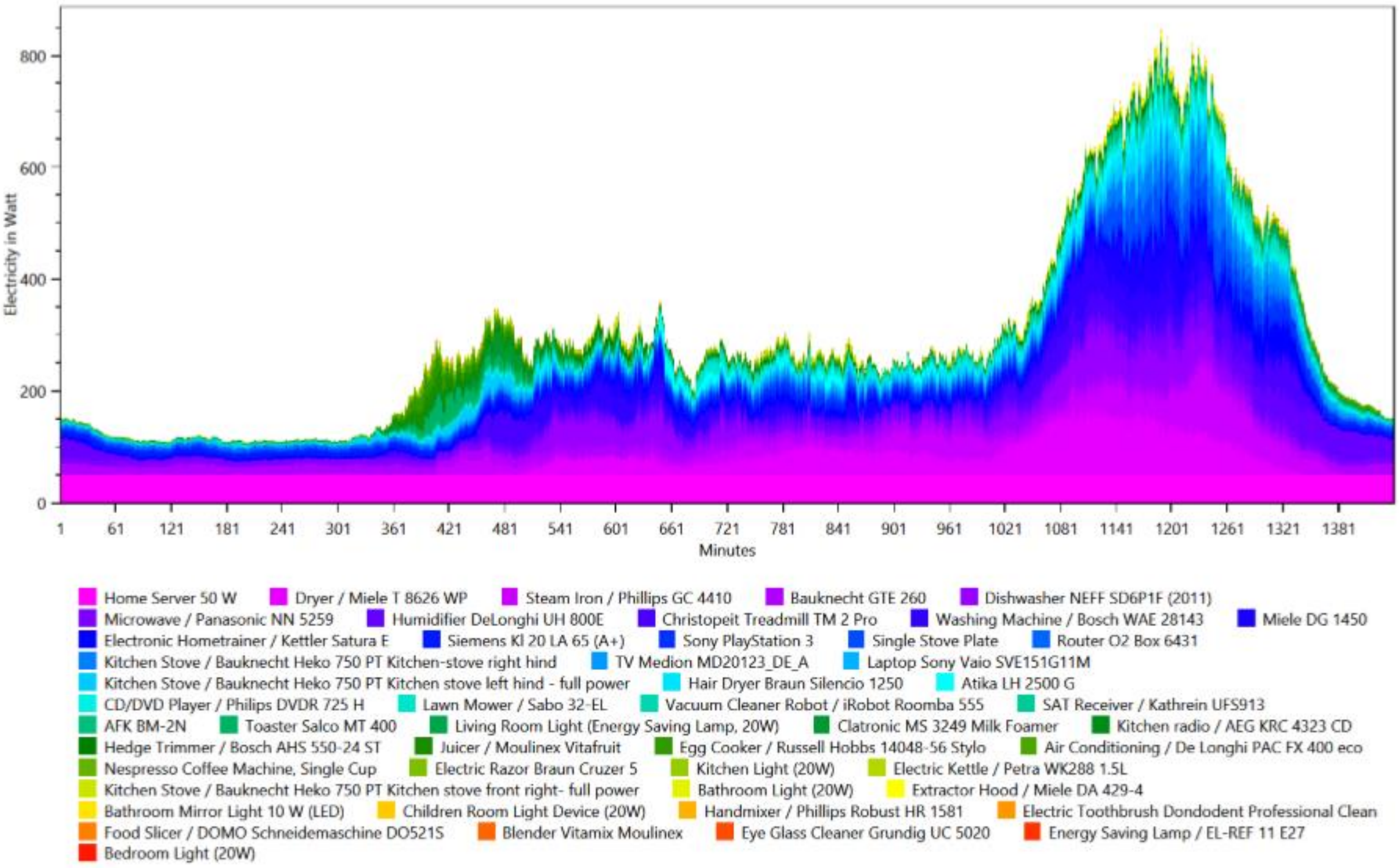
You can find a load generator here:
http://www.loadprofilegenerator.de/

Table I
CLASSIFICATION OF HOUSEHOLD APPLIANCES BY USAGE TYPE.

Type	Appliance
A	**cold app.:** refrigerator, fridge-freezer, upright freezer, chest freezer **computer:** fax/printer **others:** door bell, smoke detector
B	**audiovisual:** set top box, speakers **computer:** modem, router, multifunction printer
C	**audiovisual:** television (CRT, LCD, plasma), hi-fi, DVD recorder,home cinema, VCR, games consoles (PS3, Xbox 360, Wii, box), DVD player, radio, CD player, blu-ray player **computer:** desktop, monitor, laptop, printer, scanner
D	**washing:** washing machine, washer-dryer, clothes dryer, dish-washer **cooking:** bread maker, yoghurt maker **space heat.:** electric space heating, additional space heating **water heat.:** electric water heating, additional water heating **others:** iron, vacuum cleaner, trouser press, sewing machine
E	**cooking:** oven, cooker, hob, microwave, kettle, food steamer, fryer, coffee machine, bottle warmer, toaster, grill, extractor hood, food mixer **others:** steriliser
F	lighting
G	**others:** charger, cordless phone
H	**others:** dehumidifier, aquarium, pond pump, house alarm, vivarium, fan, clock radio, digital picture frame, baby monitor
I	**others:** organ, hair straightener, paper shredder, sun bed, electric blanket

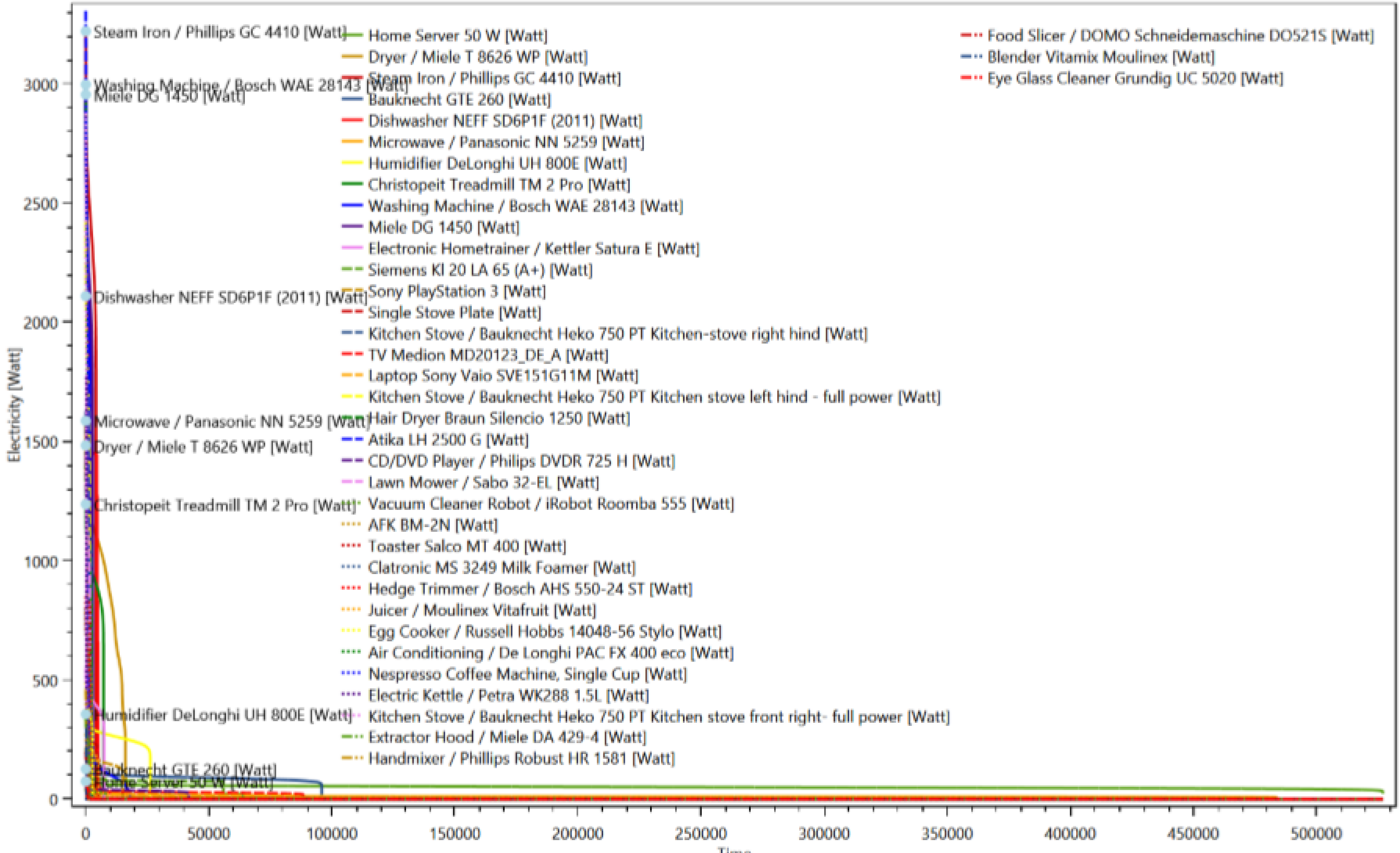
Load profile generation

You need a probability density function of all appliances



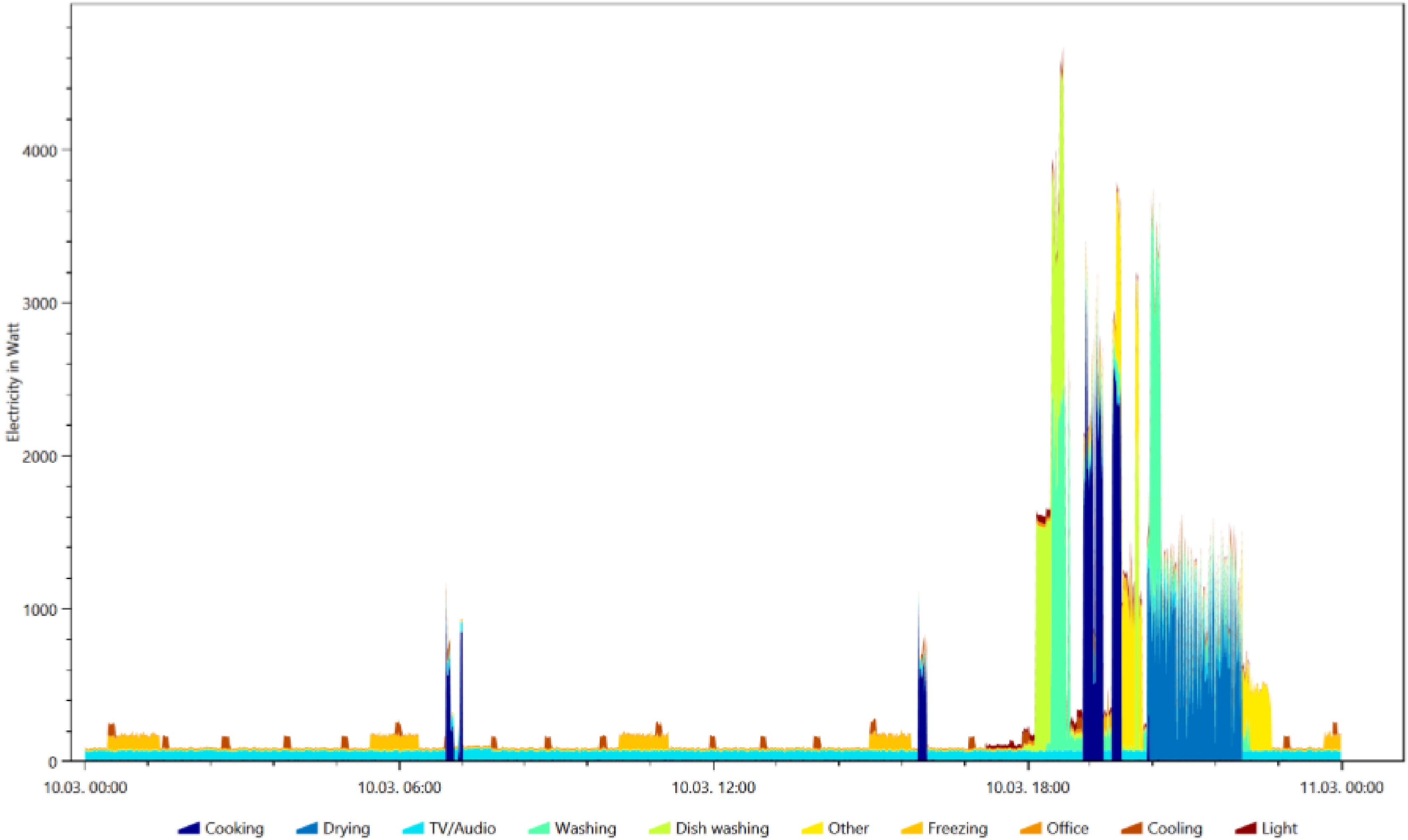
Load profile generation

How long is each appliance ON



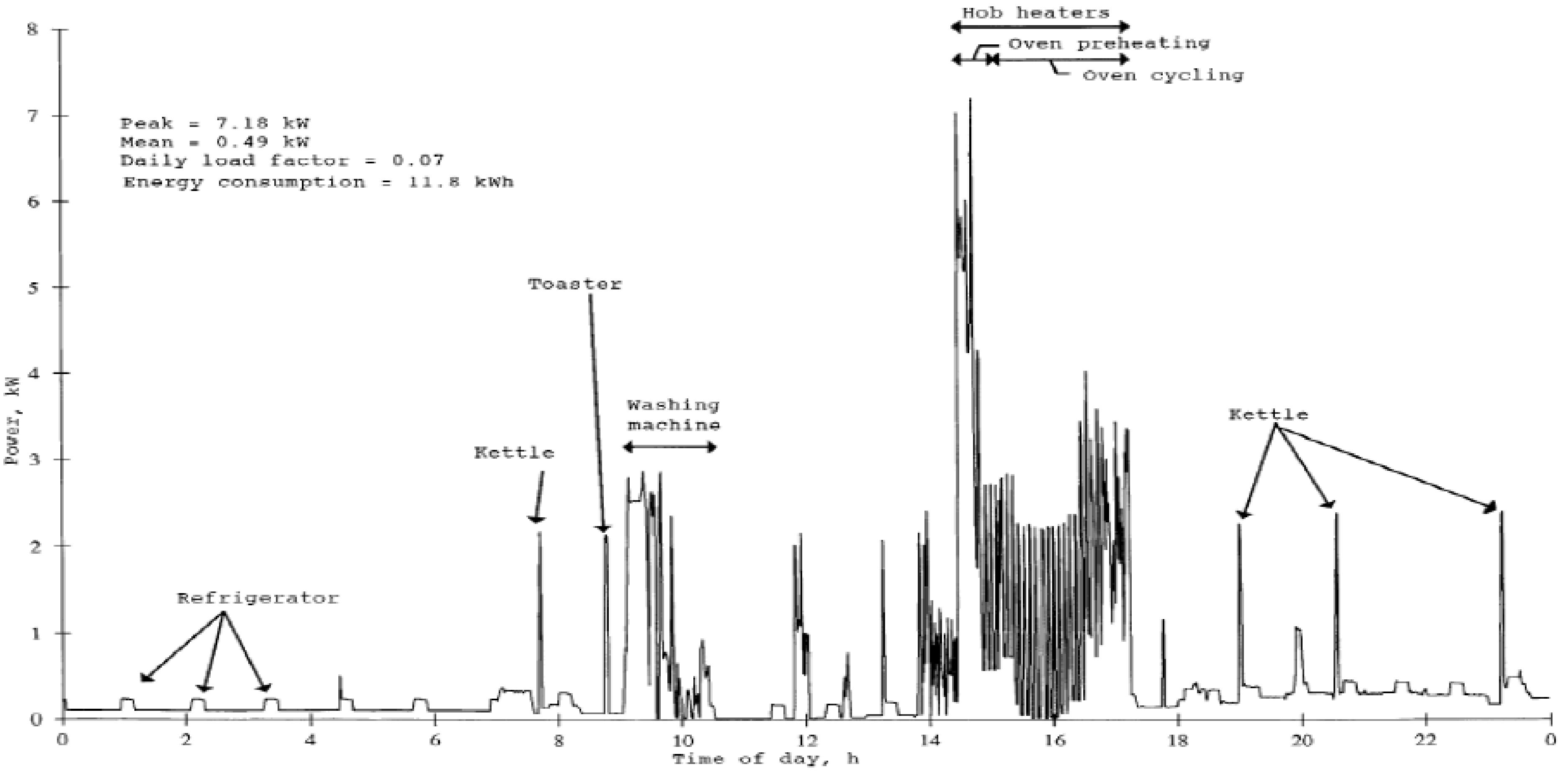
Load profile generation

And we add each contribution.
This is a very good tool if you need a load profile for your studies.



Load identification

The opposite problem, we have the load profile, can we find the functions that build the load profile?



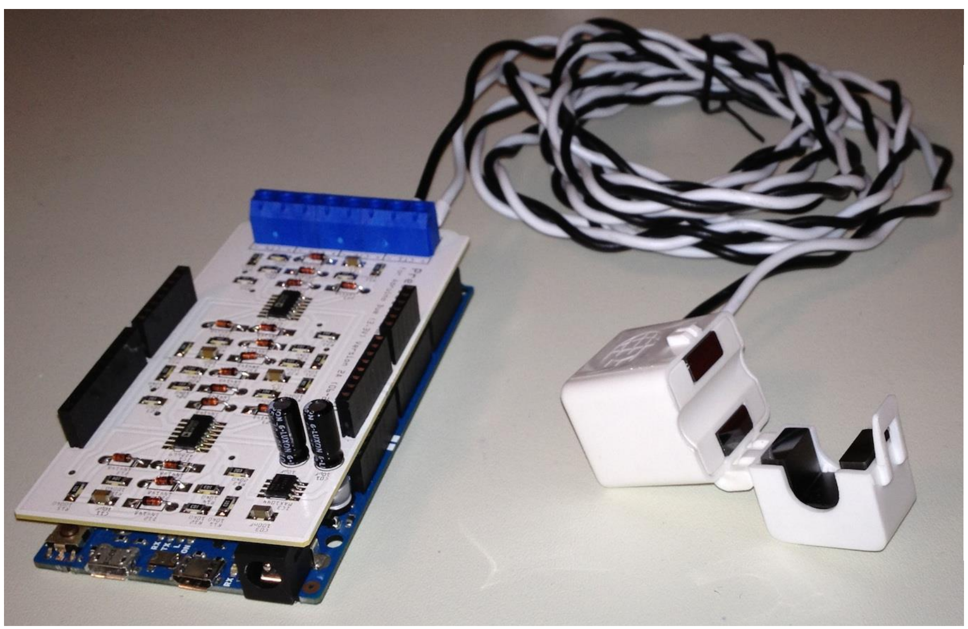
Pattern recognition

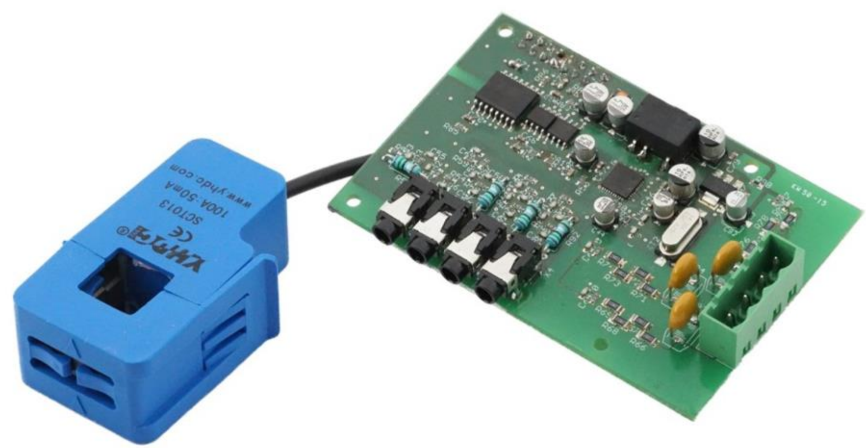
Check http://nilm.ca/ for Arduino and raspberry pi projects

Non-Intrusive Load Monitoring (NILM)

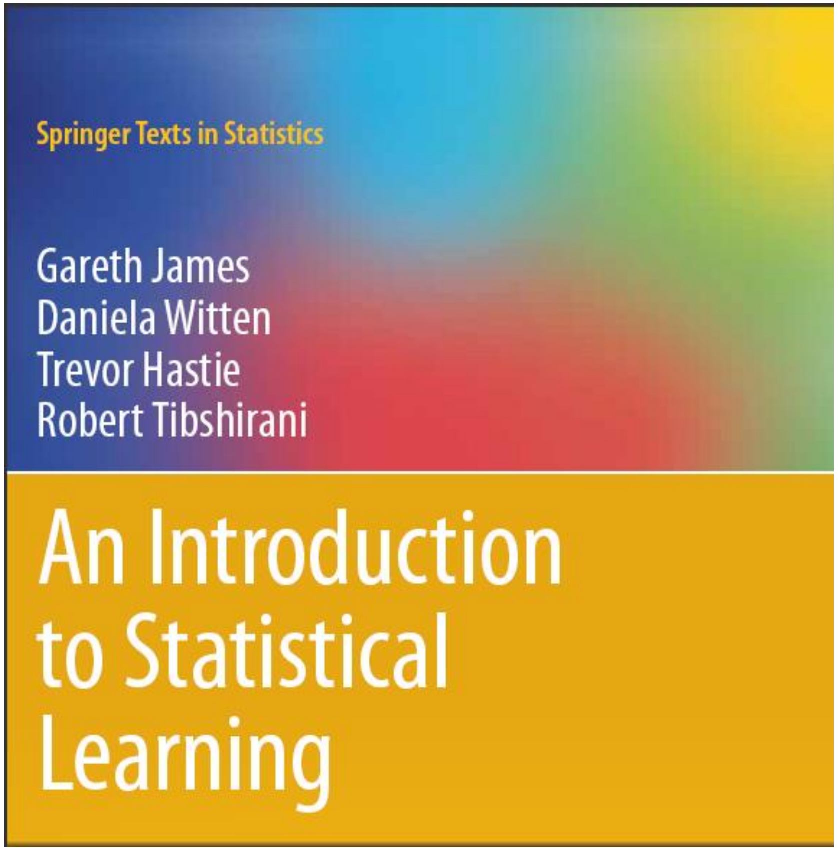
Disaggregation Research for Smart Grid, Smart Homes, and Smart Meters

This site is dedicated to NILM and disaggregation research done by Stephen Makonin.





Pattern recognition



Mohamed Elhafiz Hassan, Power Plant Operation Optimization: Unit Commitment of Combined Cycle Power Plants Using Machine Learning and MILP, 2019
http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1361827&dswid=-4330

Pattern recognition

Data from a smart meter: http://ampds.org/

NILMTK: An Open Source Toolkit for Non-intrusive Load Monitoring

Nipun Batra[1], Jack Kelly[2], Oliver Parson[3], Haimonti Dutta[4], William Knottenbelt[2], Alex Rogers[3], Amarjeet Singh[1], Mani Srivastava[5]

[1] Indraprastha Institute of Information Technology Delhi, India {nipunb, amarjeet}@iiitd.ac.in

[2] Imperial College London {jack.kelly, w.knottenbelt}@imperial.ac.uk

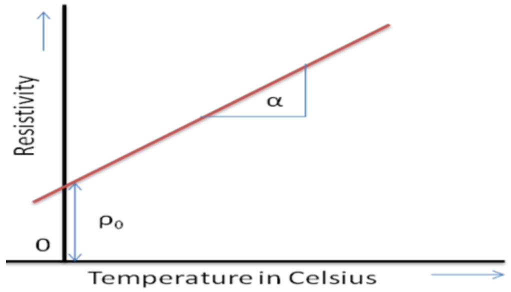
[3] University of Southampton {osp, acr}@ecs.soton.ac.uk

[4] CCLS Columbia {haimonti@ccls.columbia.edu}

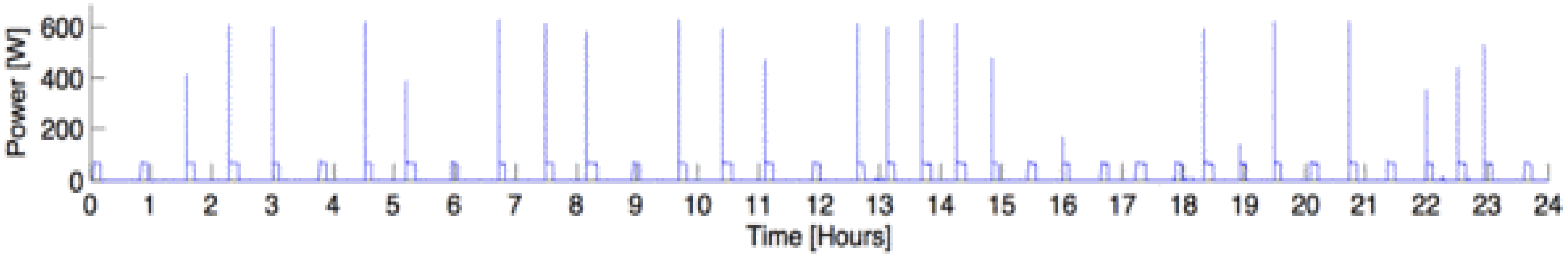
[5] UCLA {mbs@ucla.edu}

Different types of loads

Each load has its "fingerprint"



Loads change with voltage, frequency and temperature.
The power through a resistance changes with time.



fridge, data from www.tracebase.org

Ribeiro, P.F., Duque, C.A., Ribeiro, P.M. and Cerqueira, A.S., 2013. Power systems signal processing for smart grids. John Wiley & Sons

Loads change with voltage, frequency and temperature.

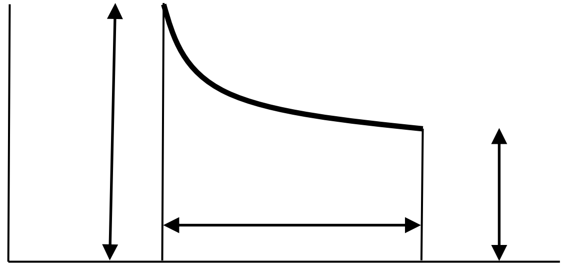
20.5.1 Exponential Models

The exponential form for both real and reactive power is expressed in Eqs. (20.1) and (20.2) below as a function of voltage and frequency, relative to initial conditions or base values. Note that neither temperature nor torque appear in these forms. Assumptions must be made about temperature and/or torque values when synthesizing from component models to these exponential model forms.

$$P = P_o \left[\frac{V}{V_o}\right]^{\alpha_v} \left[\frac{f}{f_o}\right]^{\alpha_f} \tag{20.1}$$

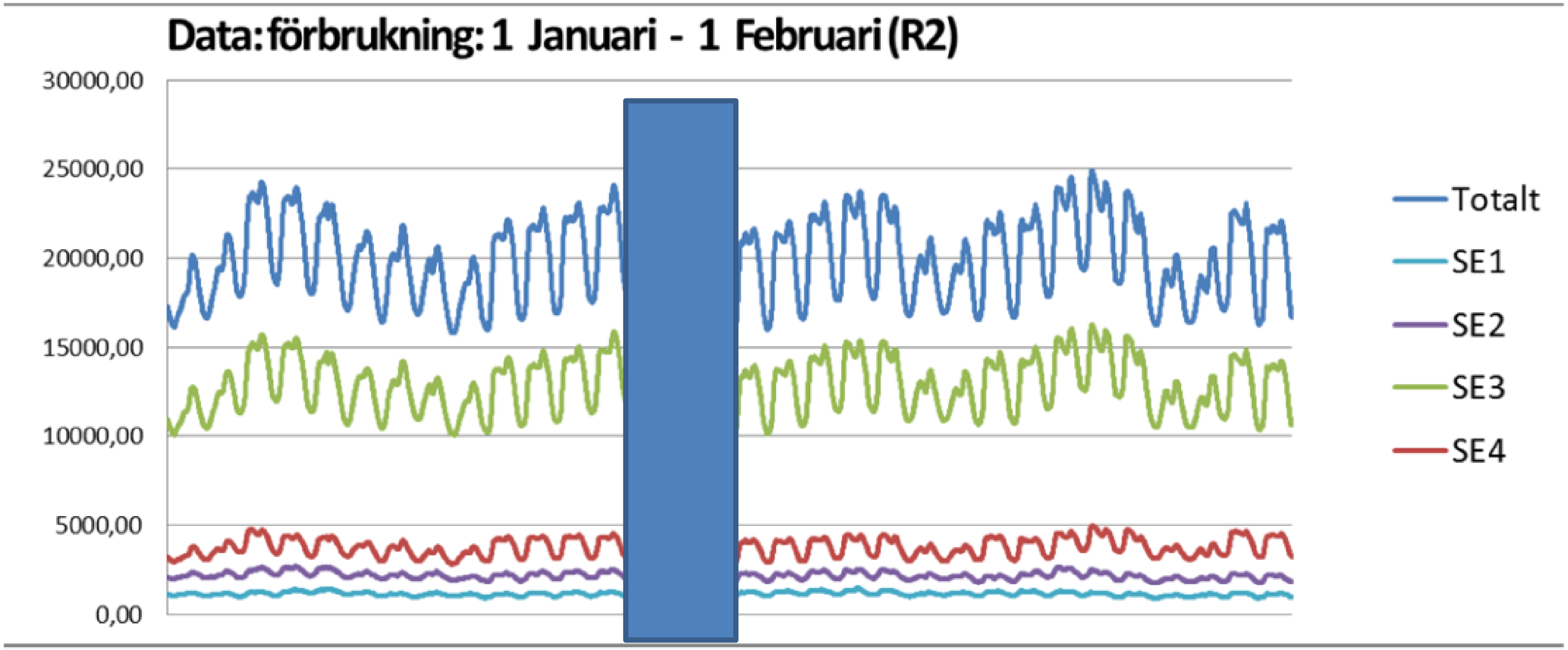
$$Q = Q_o \left[\frac{V}{V_o}\right]^{\beta_v} \left[\frac{f}{f_o}\right]^{\beta_f} \tag{20.2}$$

Loads change with time also. This could be a Power-Time graph of a water boiler. The R reduces when it gets warm. The time depends on how much water we boil.



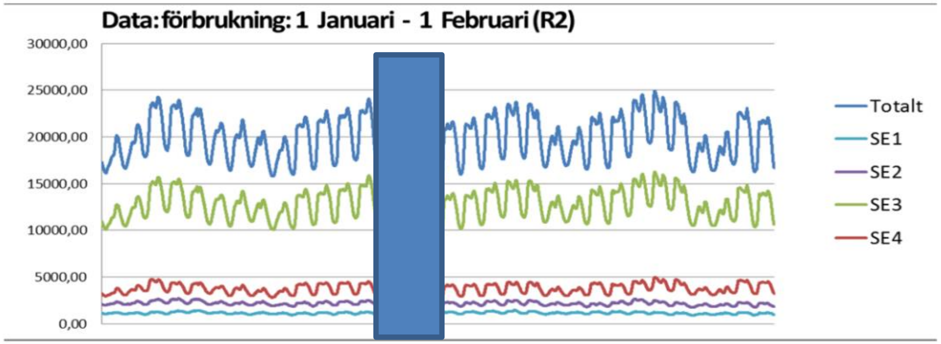
What is the power demand missing

Example from a job interview.



Figur 7 Elförbrukning för de 4 areorna i Sverige under januari 2011.

What is the power demand missing



Figur 7 Elförbrukning för de 4 areorna i Sverige under januari 2011.

- Ask for advise!
- Fourier?
- Top down methods: Find parameters, like weekend, temperature… average from week before and after...
- There are open source and available programs for machine learning.

Visit to HSLU – Lucerne – Switzerland

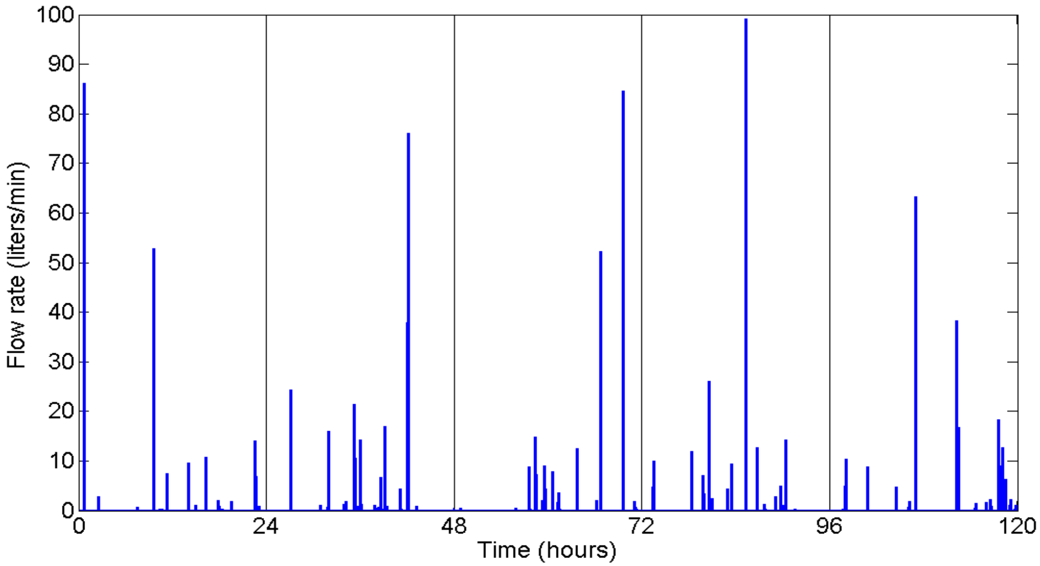
The problem

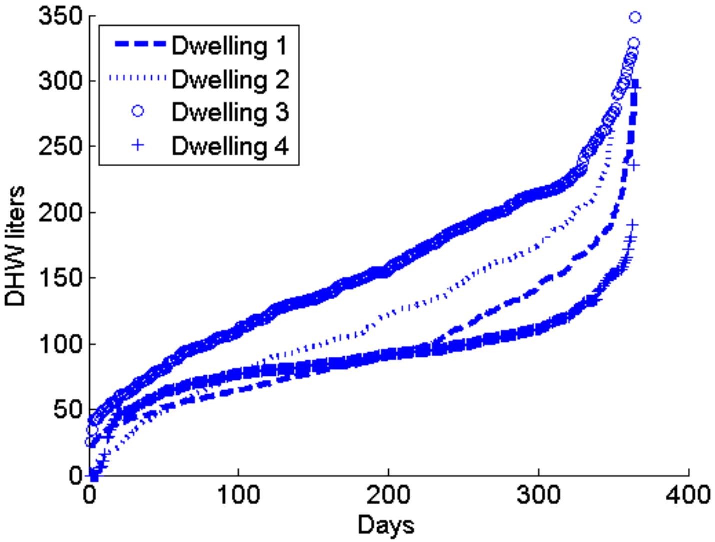
Load Profiles are used to predict demand and size systems.

HSLU wanted to create a representative load profile to test equipment.

Load profiles are also important if you have solar thermal panels in small systems.

The problem





The recorded all loads in 4 hours for one year.

In the figure: The average amount of hot water is presented.

The Generation of Domestic Hot Water Load Profiles in Swiss Domestic Buildings through Statistical Predictions, Energy and Buildings, Vol. 141, April 2017

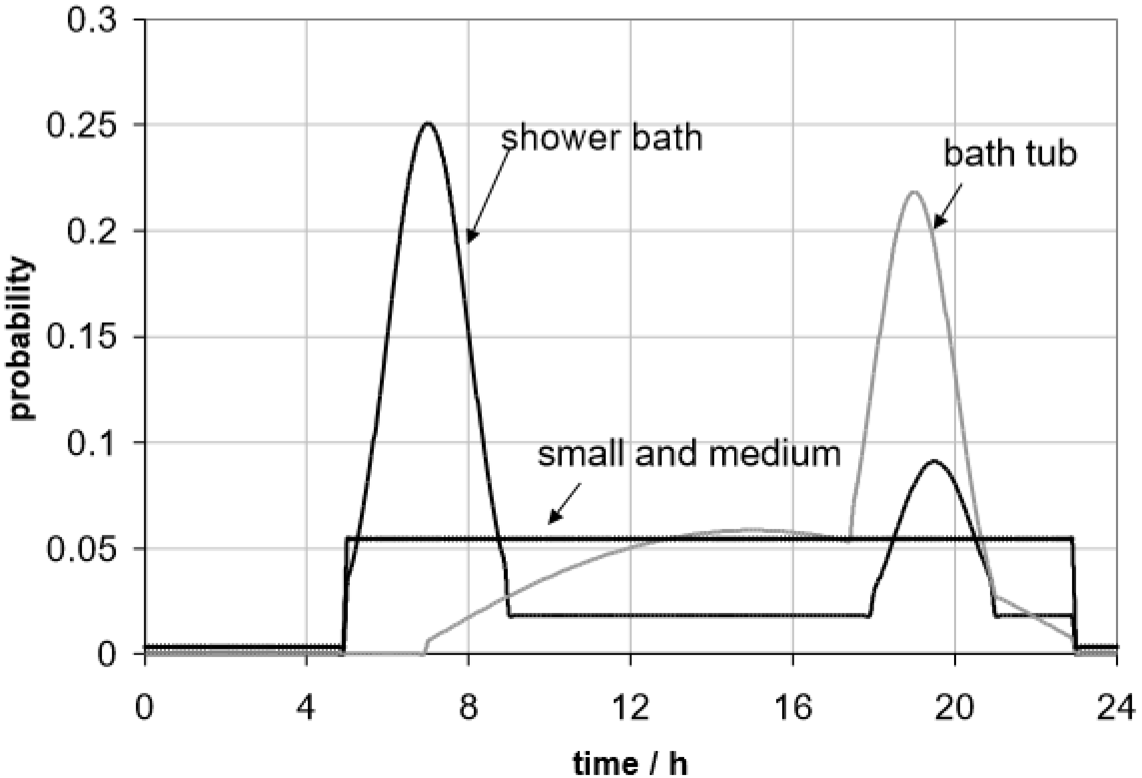
Load profile generation – hot water

	cat A: short load	cat B: medium load	cat C: bath	cat D: shower	Sum
Vdot in l/min	1	6	14	8	
duration in min	1	1	10	5	
inc/day	28	12	0.143 (once a week)	2	
sigma	2	2	2	2	
vol/load in l	1	6	140	40	
vol/day in l	28	72	20	80	200
portion	0.14	0.36	0.10	0.40	1

Table 1: Assumptions and derived quantities for the load profile.

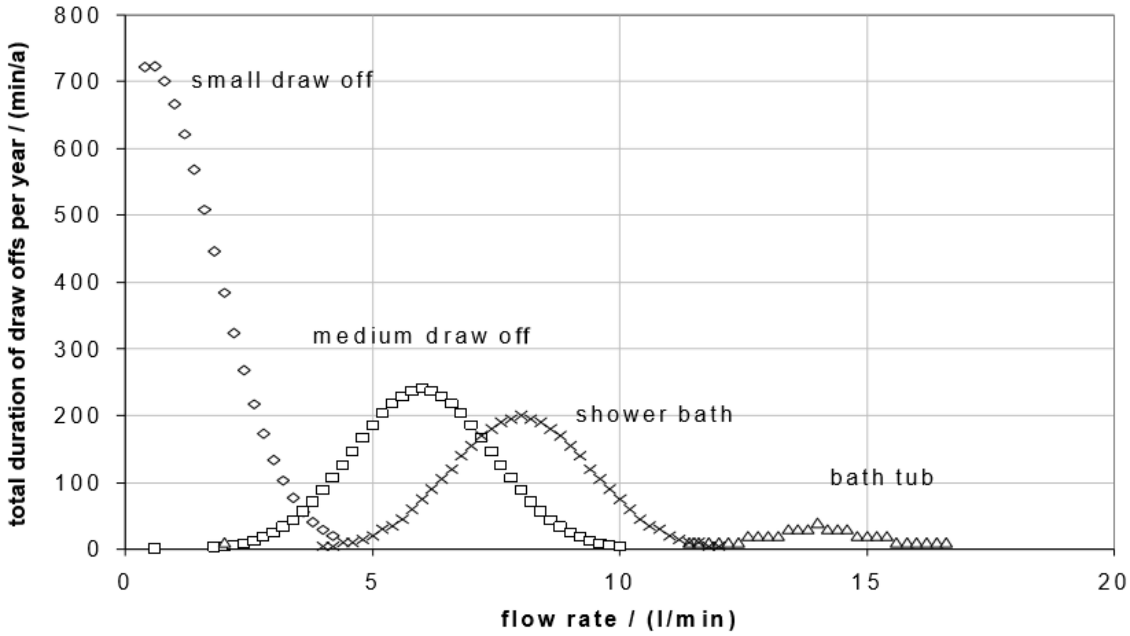
We assume a Poisson distribution for each category. The amount of water for each event follow a normal distribution.

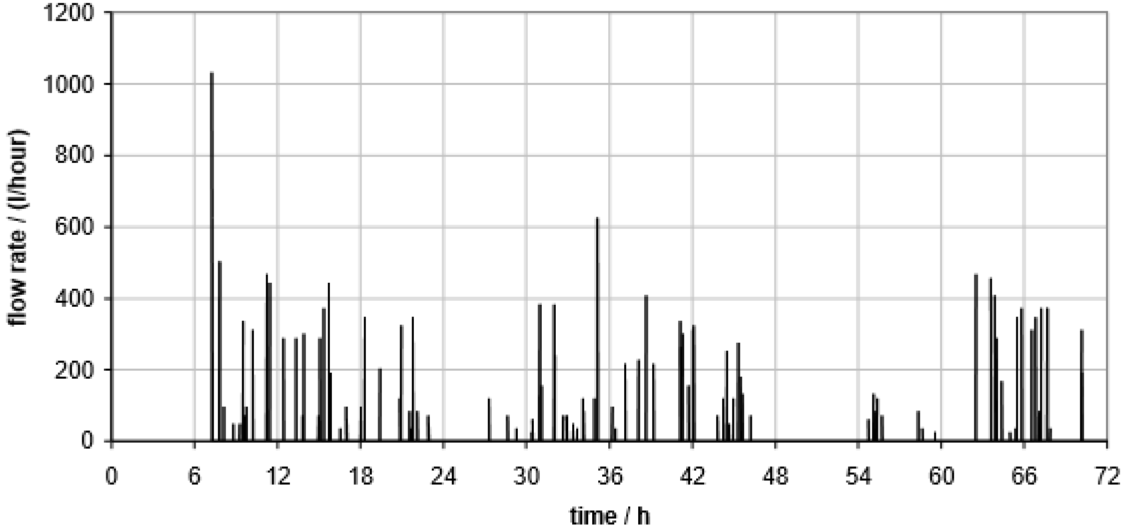
Load profile generation – hot water



Probability distribution of the DHW-load in the course of the day.

Load profile generation – hot water





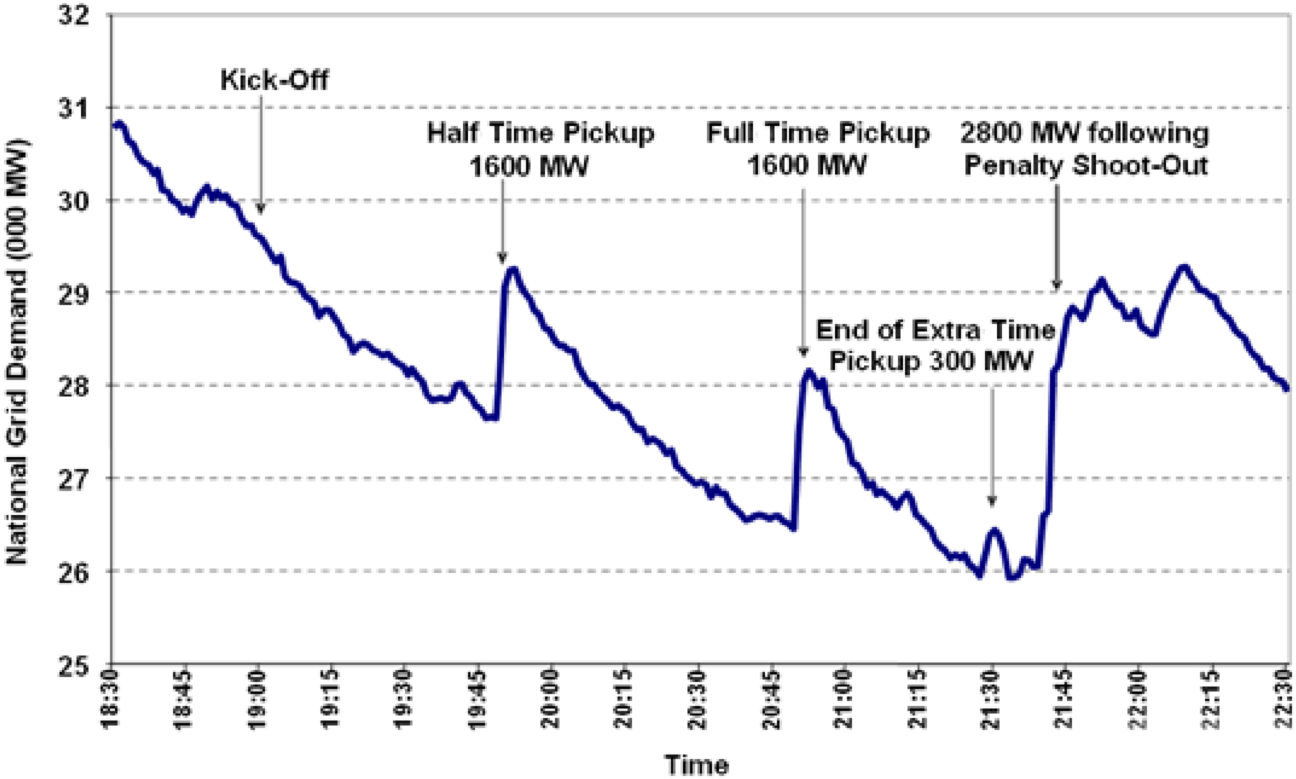
Demand response

It is to influence the users to reduce the demand when the grid is overloaded.

It has a lot of potential, but notice the economic incentive. Each user might reduce some small power, so the payment for the regulation will be too low to be interesting.

Risk example of demand regulation

Electricity consumption during the match England- Germany final 1990

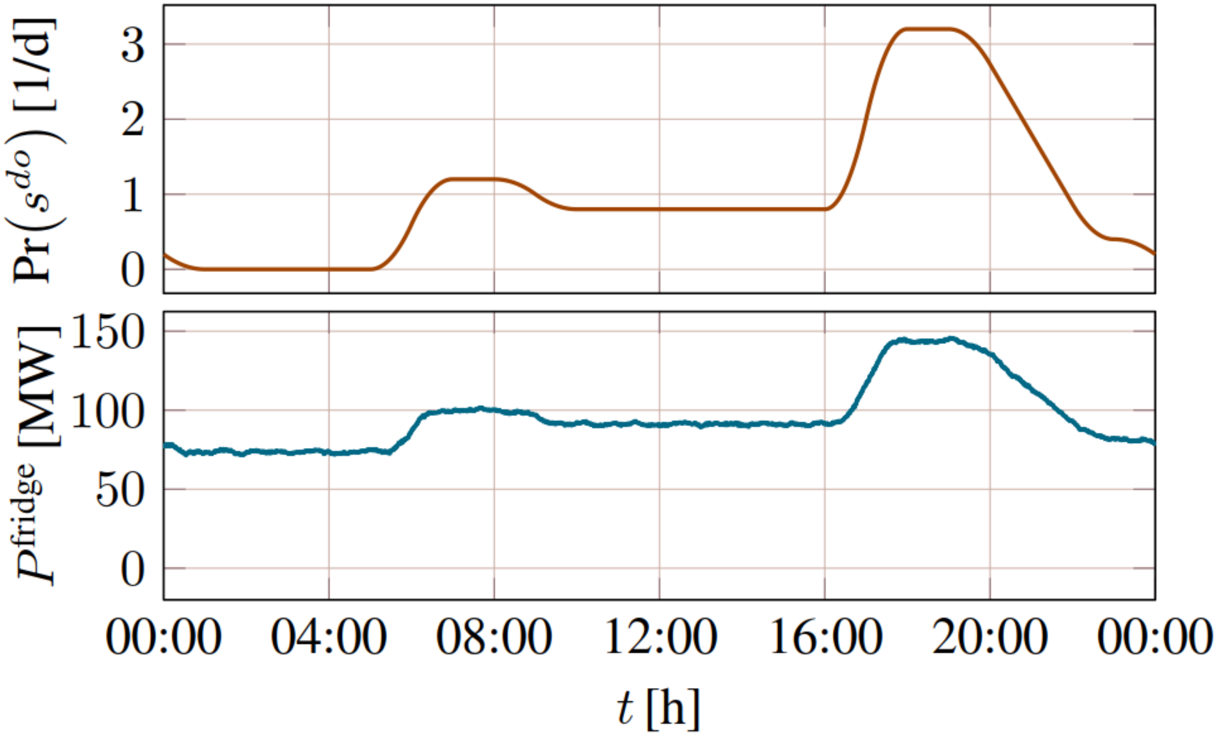


Example of demand response… we can change the TV programs to influence electricity consumption!

Demand response of refrigerators ETH

Demand response of refrigerators

Stochastic control of cooling appliances under disturbances for primary frequency reserves

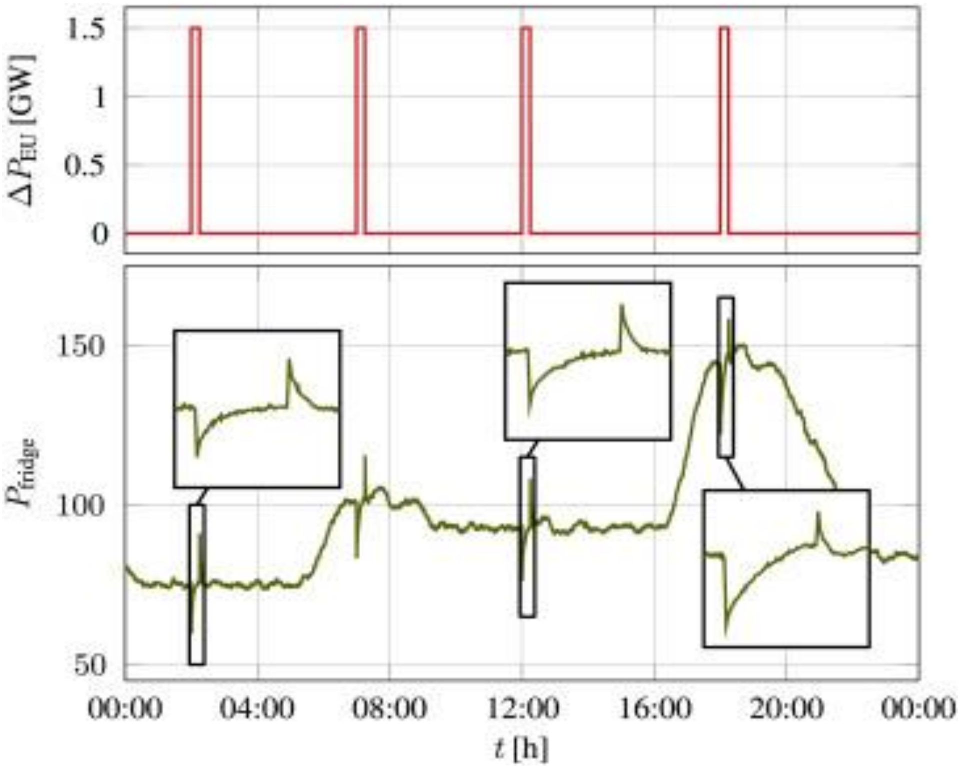


In the figure: Probability of opening the fridge and the power demand for fridges during the day

Sustainable Energy, Grids and Networks, vol 7, pp. 70-79, 2016

Demand response of refrigerators

We simulated the power that refrigerators use and how much they can contribute to the regulation



Notice that there is a peak in consumption some time after the fault, but not an oscillation

Incentives

Examples of test program in USA to reduce peak demands by disconnecting air conditioning units

Entergy, AR
50% cycling: $25/year
75% cycling: $40/year

San Diego Gas & Electric, CA
$0.75-$1.25/kwh saved

https://www.clearlyenergy.com/residential-demand-response-programs

Summary

- How to create load profiles
- How the loads behave in time
- Frequancy regulation
- Demand response:
  - Price
  - Refrigerator’s example
- What information you can obtain from a Smart meter and what is it useful for