Modelling of an electrical load

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Contents

1 INTRODUCTION

This paper describes the development of a mathematical model to be used for statistical evaluation of power consumption from a region consisting of different companies with workshop activities as well as office activities. The model proposed, is based on the results of a measurement campaign. The measurements are related to power consumption from an area consisting of different companies with a mixture of workshop and office activities. The companies and their yearly power consumption are presented in Table I.

Table I. Name and power consumption for the companies that were involved in the measurement campaign.

Company	Power consumption (kWh/year)	Fuse (A)	Voltage (kV)
HB LINDOME	220929	315	10
HB LINDOME	266298	200	10
MÖLNDAL KOMMUN	22900	35	0.4
MÖLNDAL KOMMUN	111900	100	0.4
SVENSK VÅTRUMSTEKNIK I GÖTEBORG	19400	63	0.4
BILHUSET I LINDOME AB	121600	63	0.4
BILHUSET I LINDOME AB	13100	25	0.4
BILHUSET I LINDOME AB	3000	16	0.4
BILHUSET I LINDOME AB	15300	16	0.4
GISSLÉNS ENTREPRENAD AB	41400	35	0.4
TRIAGON SNICKERI AB	45700	63	0.4
R SEGERS FASTIGHETSKONTOR	67500	80	0.4
STÅLMARIN AB	45600	35	0.4
HULTHÉNS FASTIGHET O FÖRSÄLJNING	102000	35	0.4
STIGS RÖRLÄGGERI AB	9300	25	0.4
STURE JONSSONS PLÅTSLAGERI	11300	25	0.4
MKS INPLASTNING	6600	25	0.4
VAGOTT KB	150500	125	0.4
Total Consumption (kWh/year):	1274327		

2 SHORTLY ABOUT THE MEASUREMENTS

- Test location: Almås, Lindome, Sweden
- Test period: 2005-10-25 to 2005-11-29
- Test equipment : Electricity network analyzer “Unilyzer”, developed and delivered by company “Unipower”
- Used sample frequency: 30 minutes
- The presented test results are focused on the consumed active power

3 MEASUREMENT RESULTS

3.1 General

Fig. 1 summarizes the measurement results from the entire measurement period. Fig. 2 shows more in detail the results from the first 7 days. It is clear that the power consumption is significantly high during daytime relatively nighttime. It is also clear that the difference in power consumption differs significantly between normal working day and holiday. Days 4 and 5 are public holidays. A natural conclusion from this is to divide the upcoming analysis in different classes. The following breakdown is therefore:

- Power consumption during day time, working day
- Power consumption during night time, working day
- Power consumption during transition between daytime and nighttime, and vice versa, working day
- Power consumption during holiday

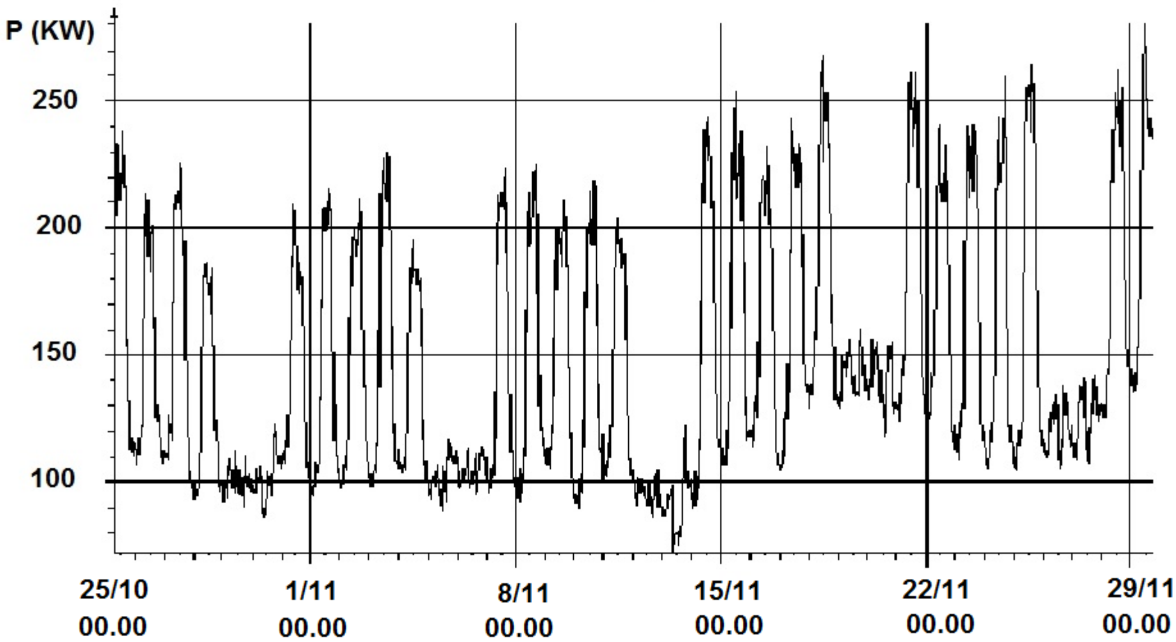

Fig. 1. Power consumption during entire measurement period.

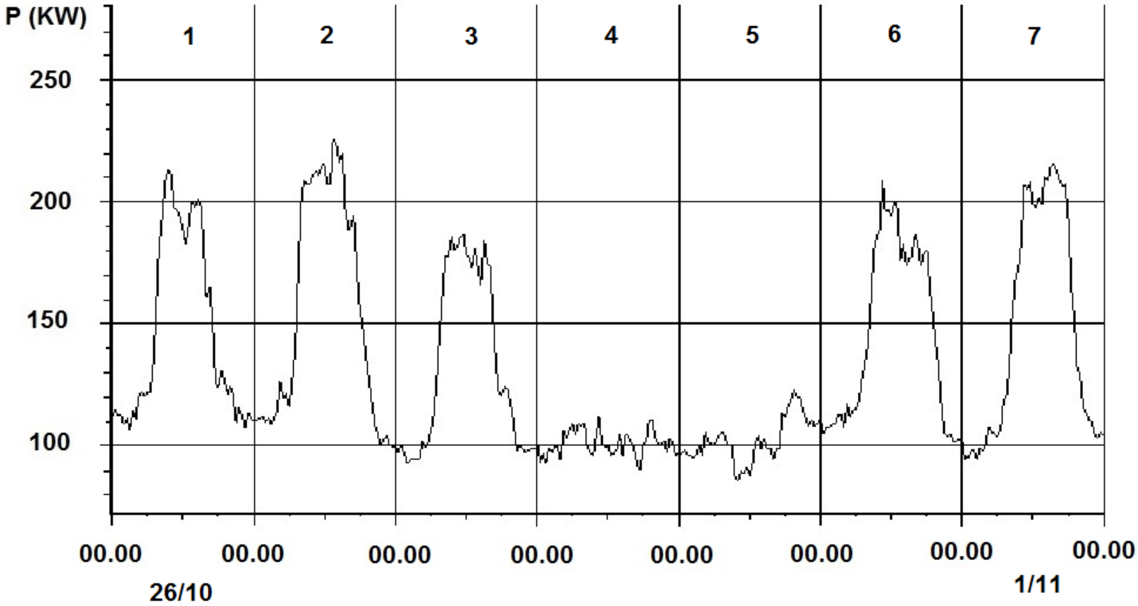

Fig. 2. Power consumption during the first 7 days.

3.2 Daily results

The measurement results follow according to Fig. 3 - Fig. 36. These figures illustrate the power consumption for every single day during the measurement period I question.

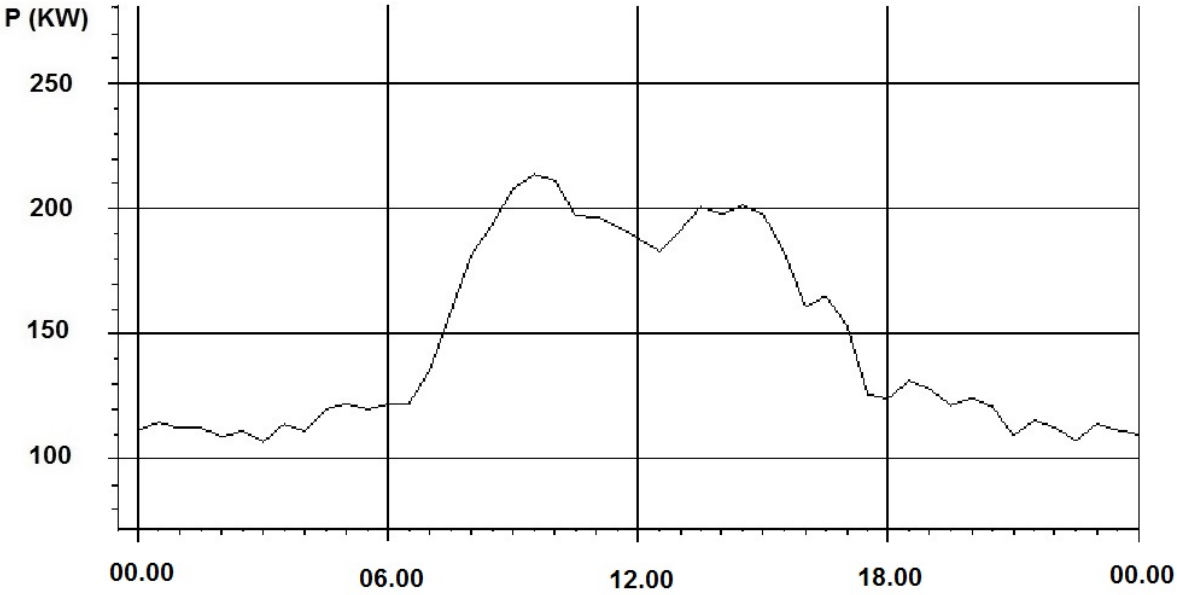

Fig. 3. Power consumption 26/10, 00.00 – 27/10, 00.00. Day 1.

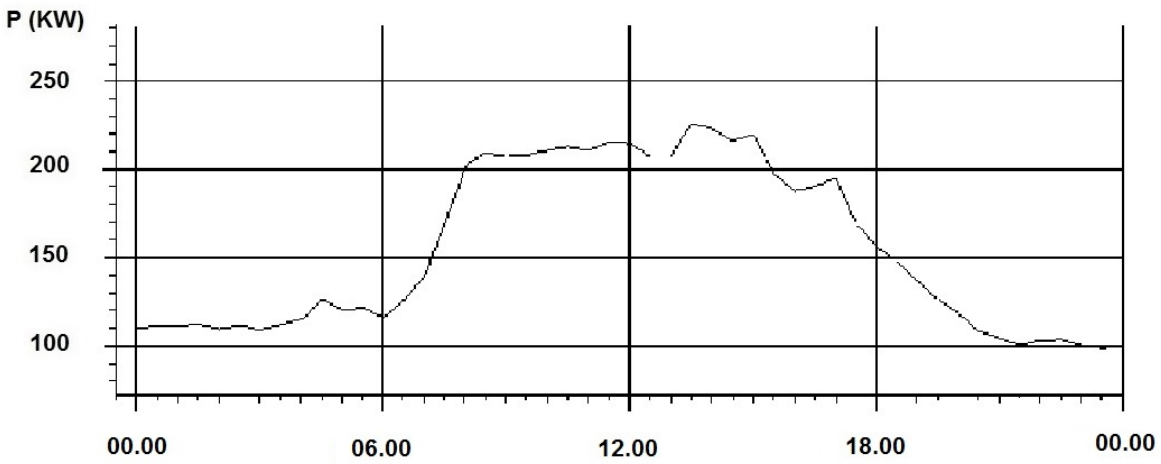

Fig. 4. Power consumption 27/10, 00.00 – 28/10, 00.00. Day 2.

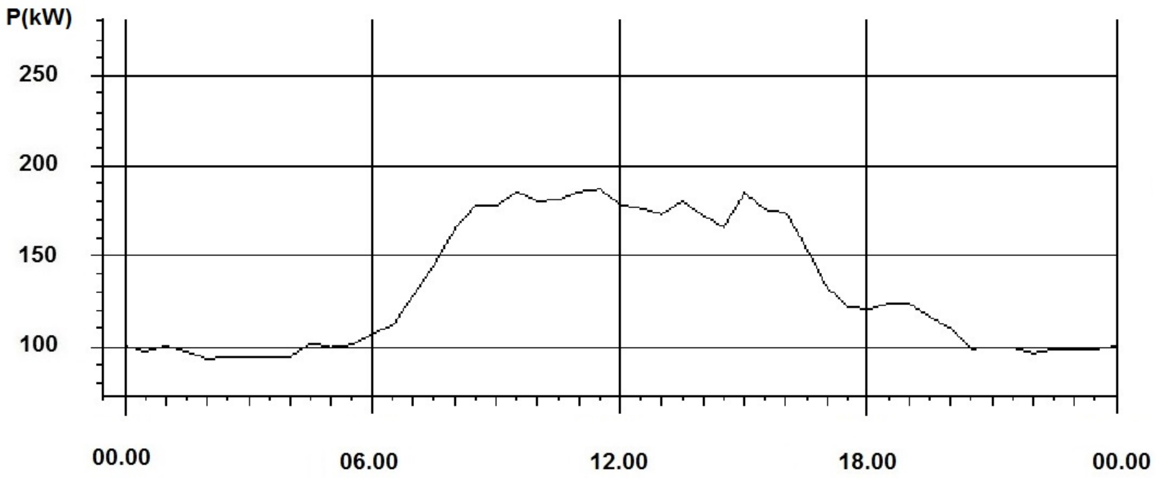

Fig. 5. Power consumption 28/10, 00.00 – 29/10, 00.00. Day 3.

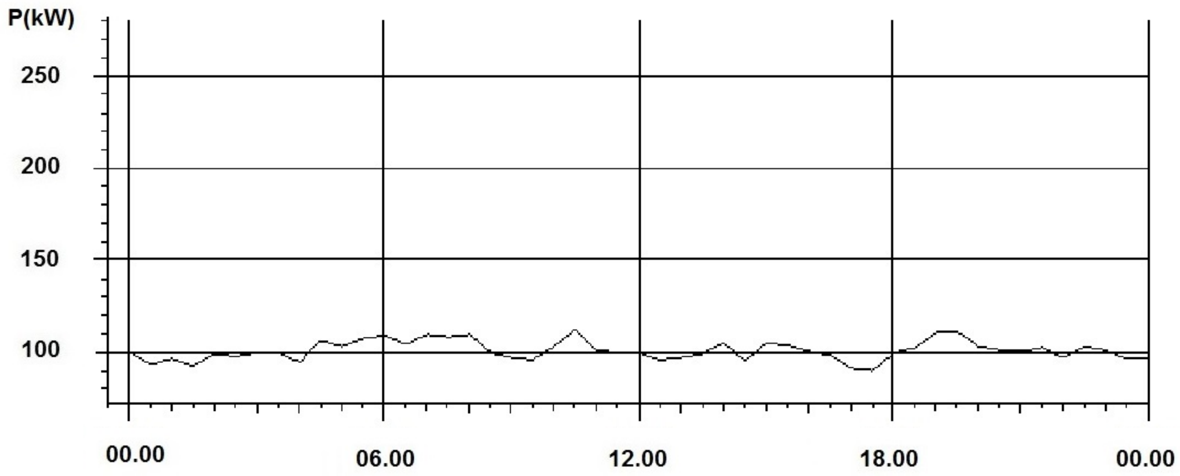

Fig. 6. Power consumption 29/10, 00.00 – 30/10, 00.00. Weekend. Day 4.

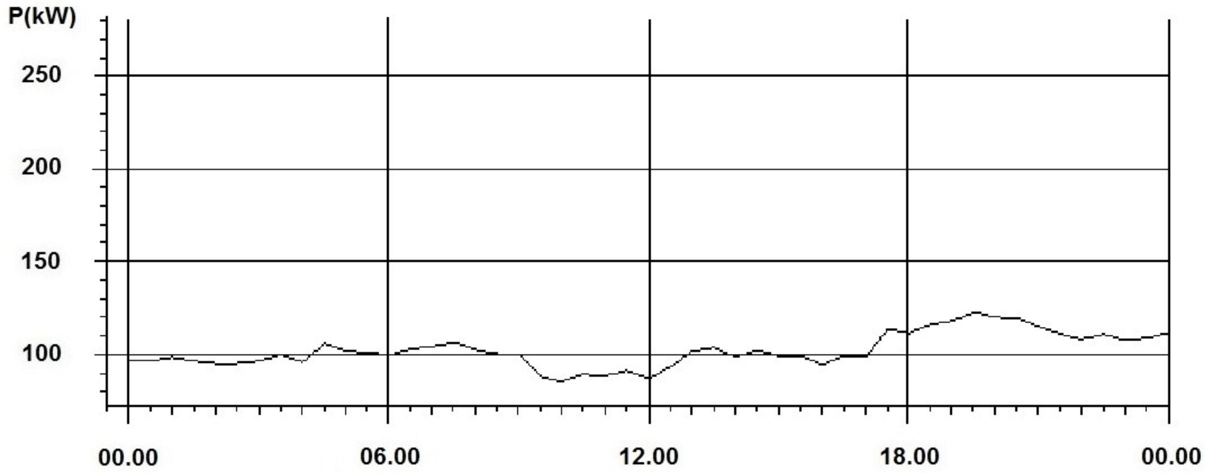

Fig. 7. Power consumption 30/10, 00.00 – 31/10, 00.00. Weekend. Day 5.

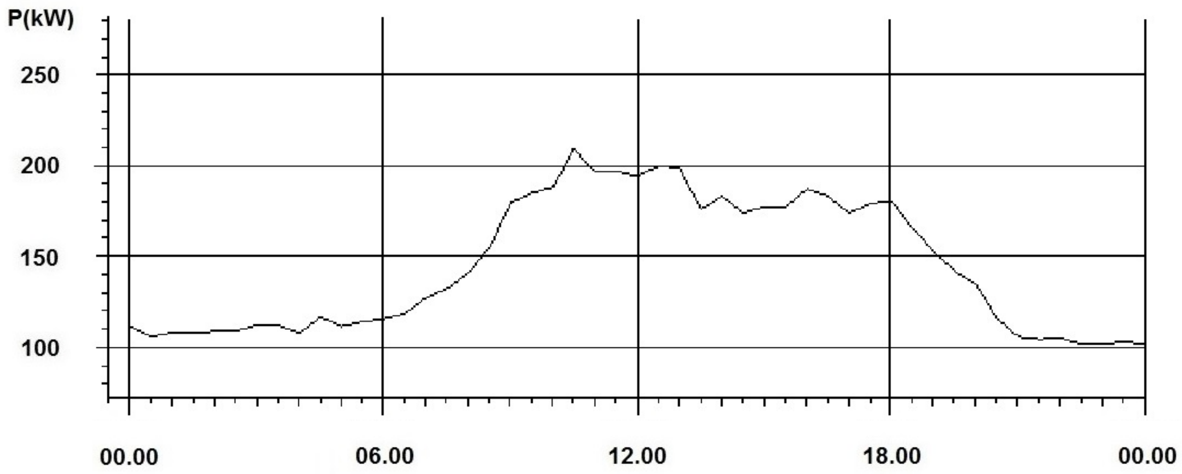

Fig. 8. Power consumption 31/10, 00.00 – 1/11, 00.00. Day 6.

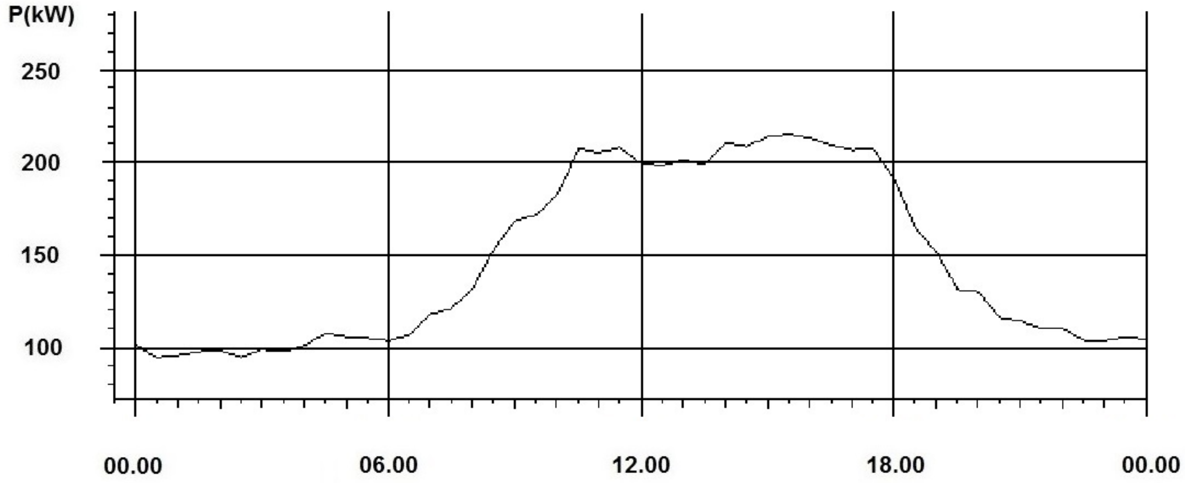

Fig. 9. Power consumption 1/11, 00.00 – 2/11, 00.00. Day 7.

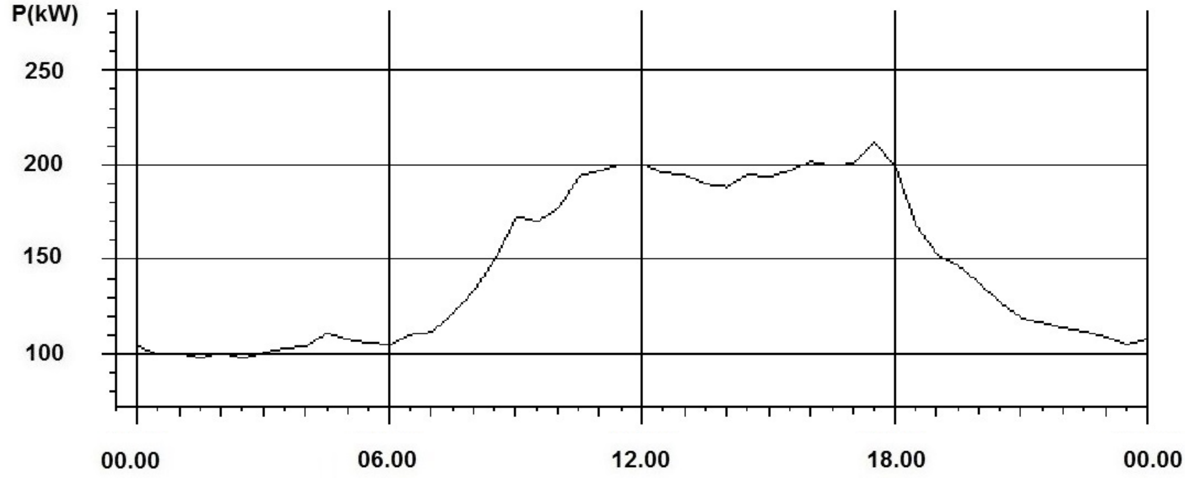

Fig. 10. Power consumption 2/11, 00.00 – 3/11, 00.00. Day 8.

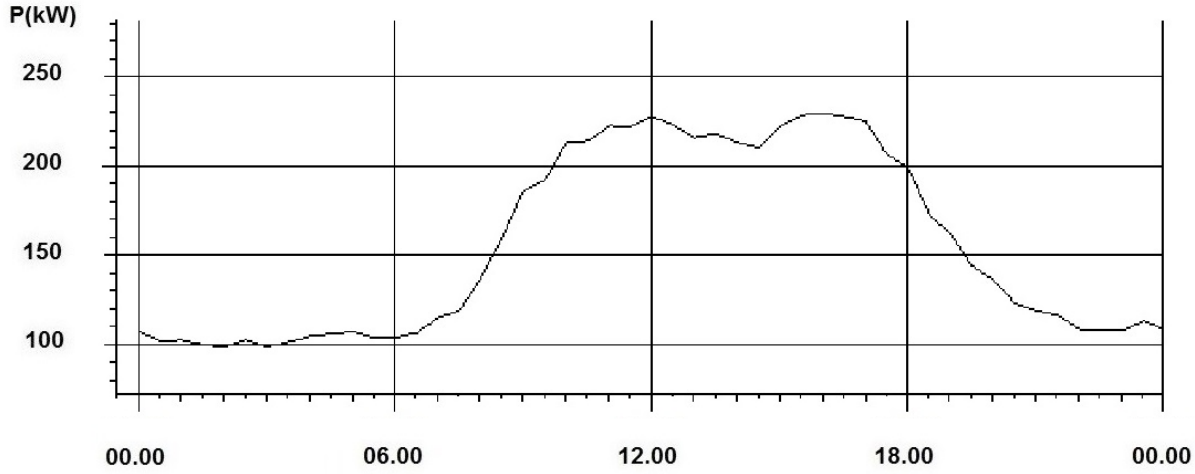

Fig. 11. Power consumption 3/11, 00.00 – 4/11, 00.00. Day 9.

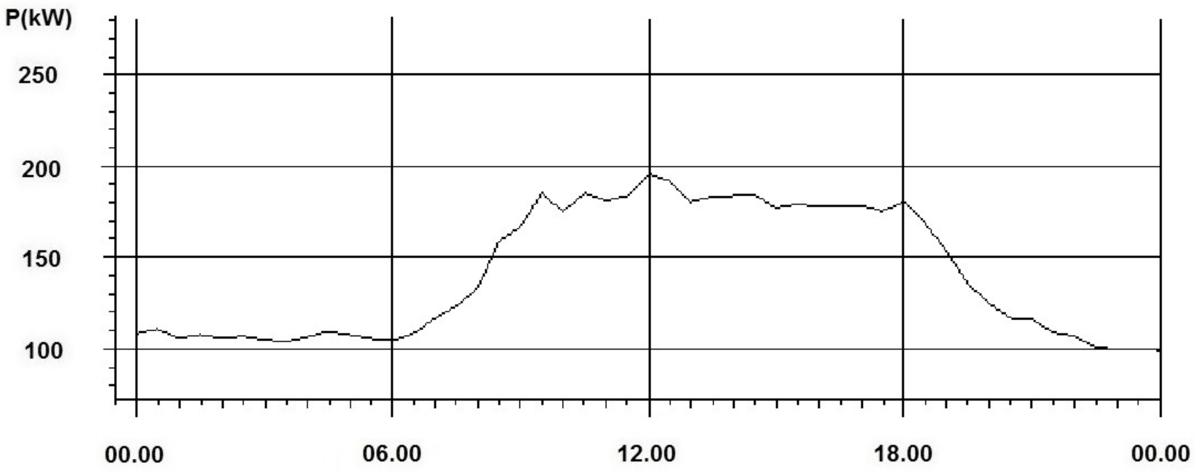

Fig. 12. Power consumption 4/11, 00.00 – 5/11, 00.00. Day 10.

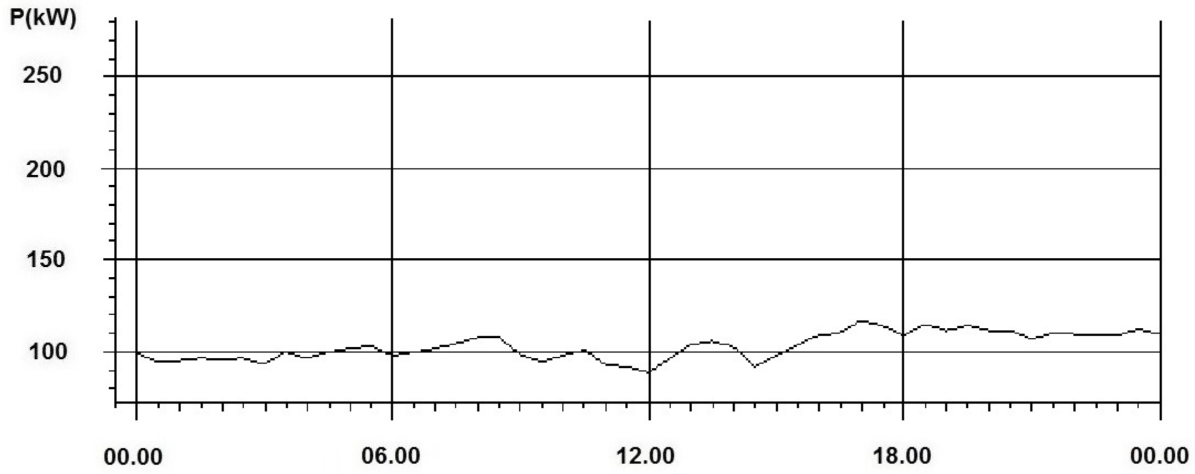

Fig. 13. Power consumption 5/11, 00.00 – 6/11, 00.00. Weekend. Day 11.

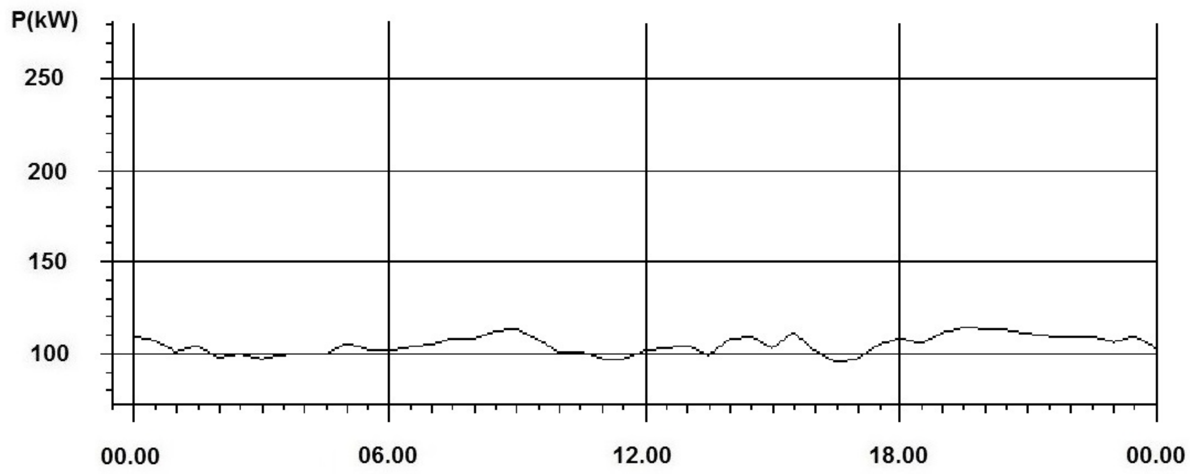

Fig. 14. Power consumption 6/11, 00.00 – 7/11, 00.00. Weekend. Day 12.

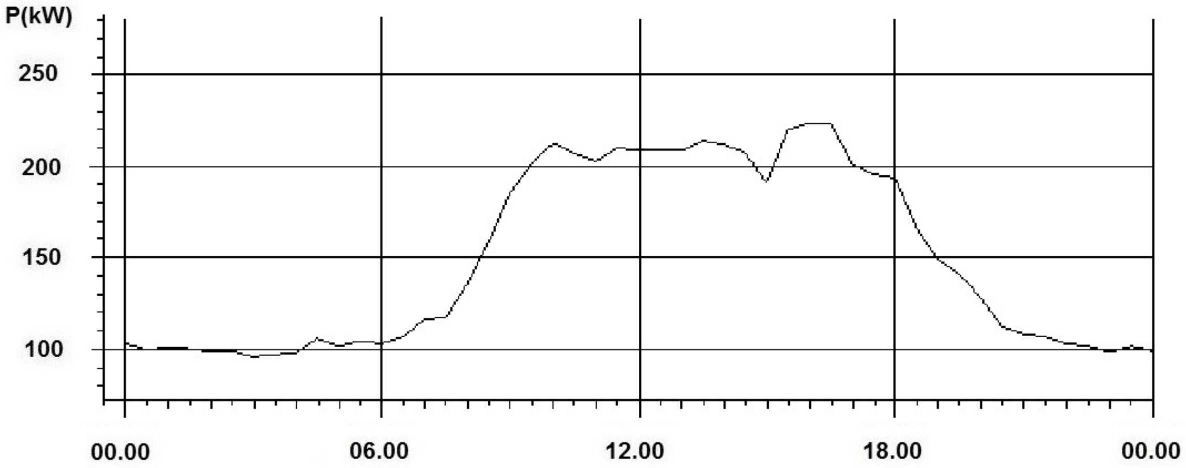

Fig. 15. Power consumption 7/11, 00.00 – 8/11, 00.00. Day 13.

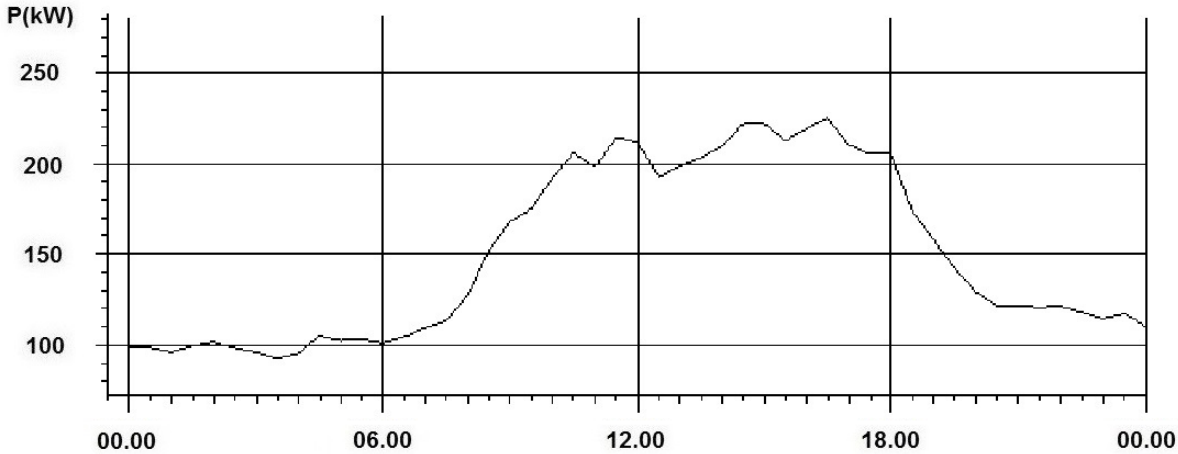

Fig. 16. Power consumption 8/11, 00.00 – 9/11, 00.00. Day 14.

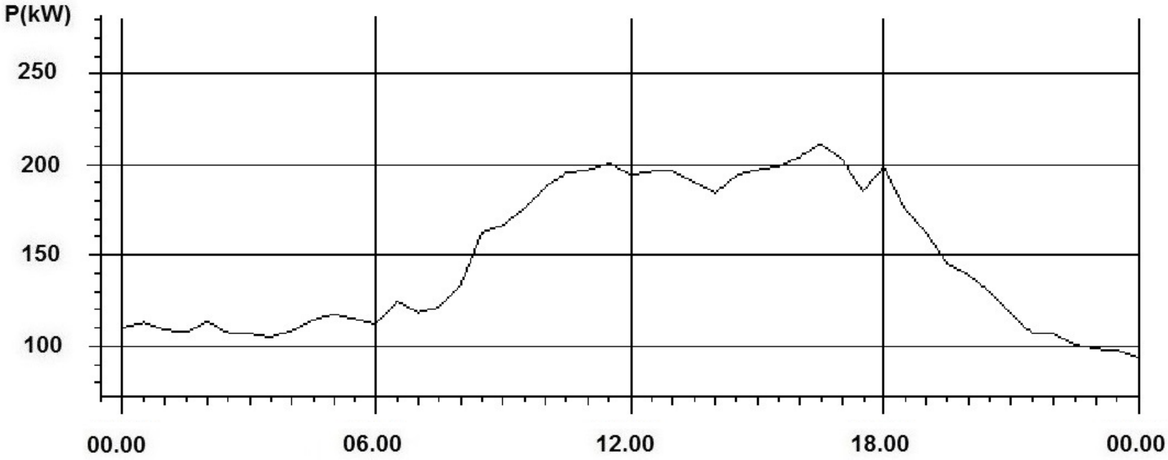

Fig. 17. Power consumption 9/11, 00.00 – 10/11, 00.00. Day 15.

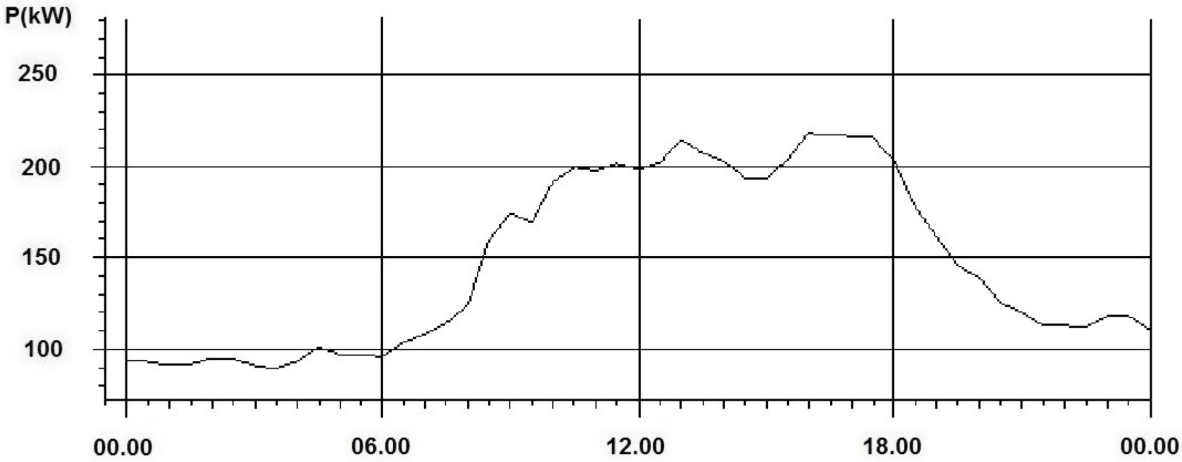

Fig. 18. Power consumption 10/11, 00.00 – 11/11, 00.00. Day 16.

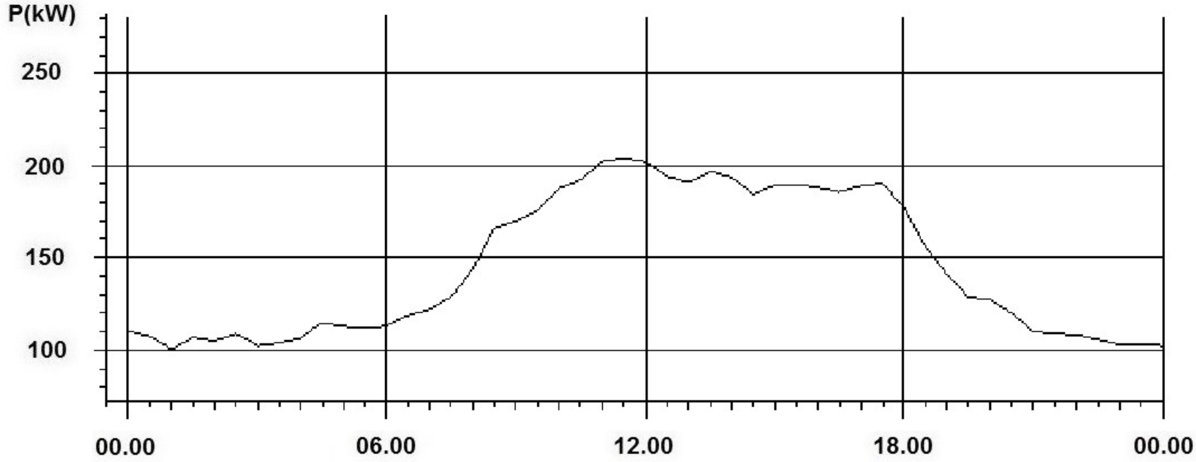

Fig. 19. Power consumption 11/11, 00.00 – 12/11, 00.00. Day 17.

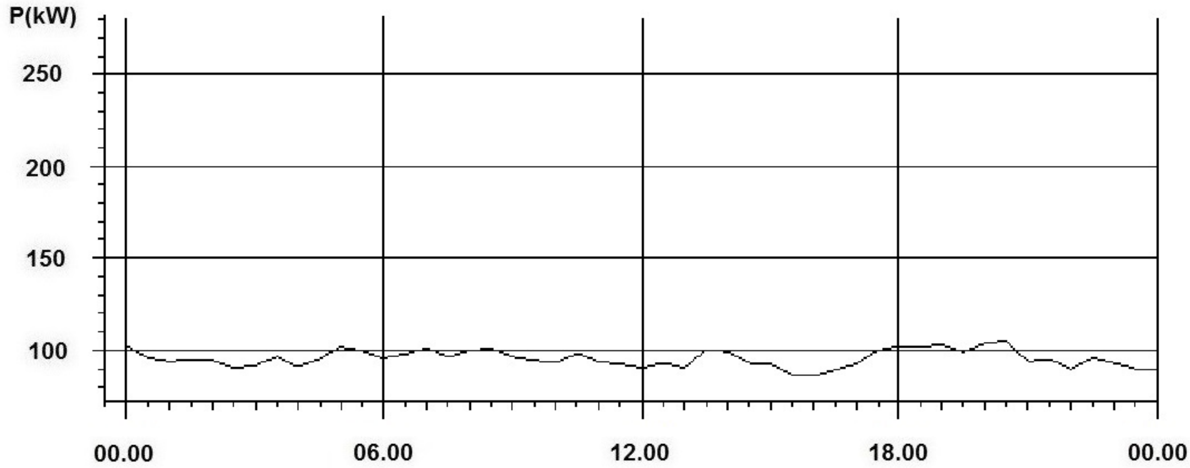

Fig. 20. Power consumption 12/11, 00.00 – 13/11, 00.00. Weekend. Day 18.

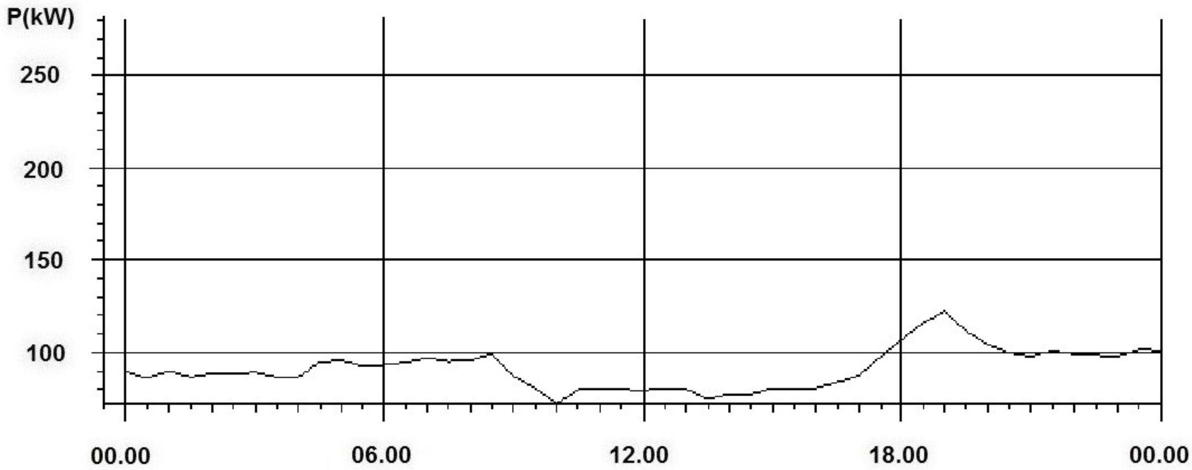

Fig. 21. Power consumption 13/11, 00.00 – 14/11, 00.00. Weekend. Day 19.

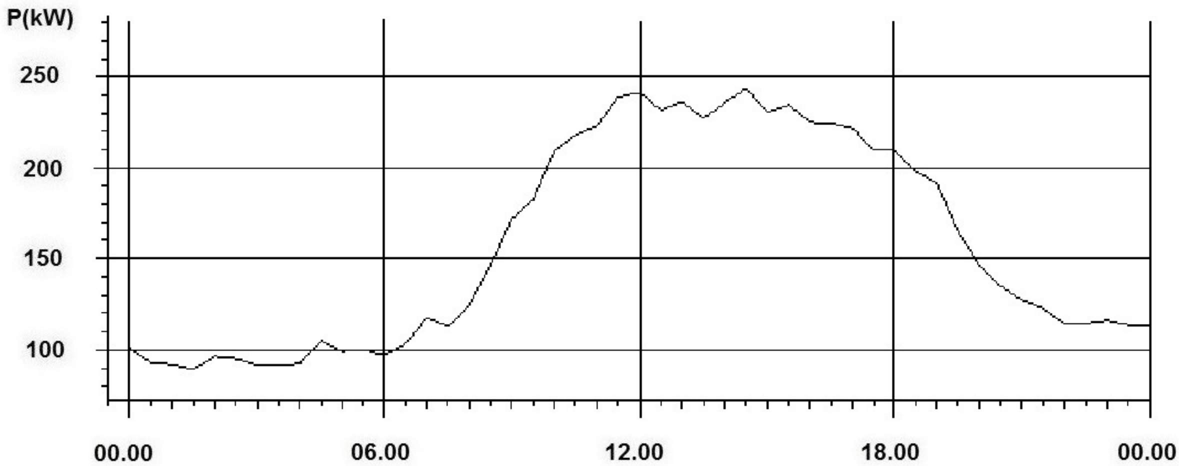

Fig. 22. Power consumption 14/11, 00.00 – 15/11, 00.00. Day 20.

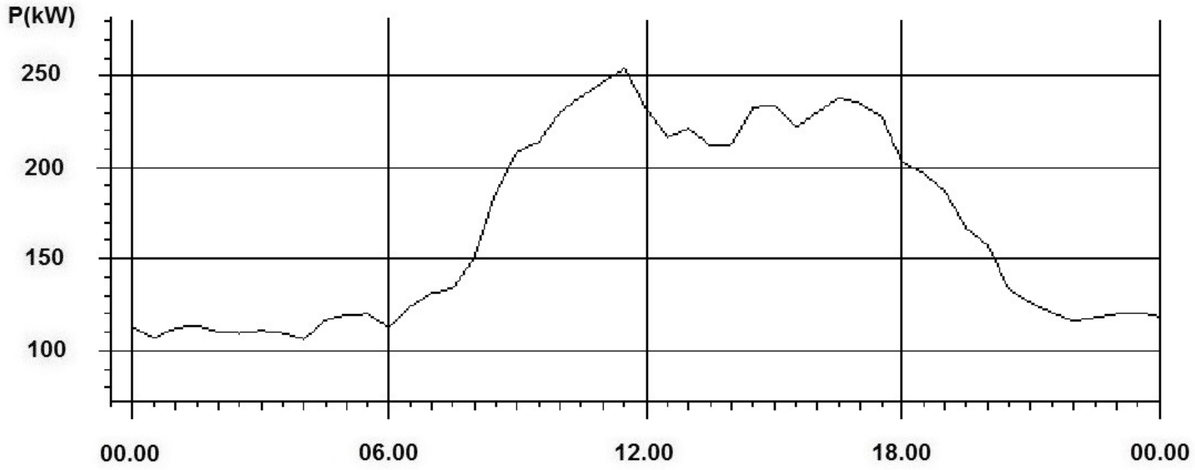

Fig. 23. Power consumption 15/11, 00.00 – 16/11, 00.00. Day 21.

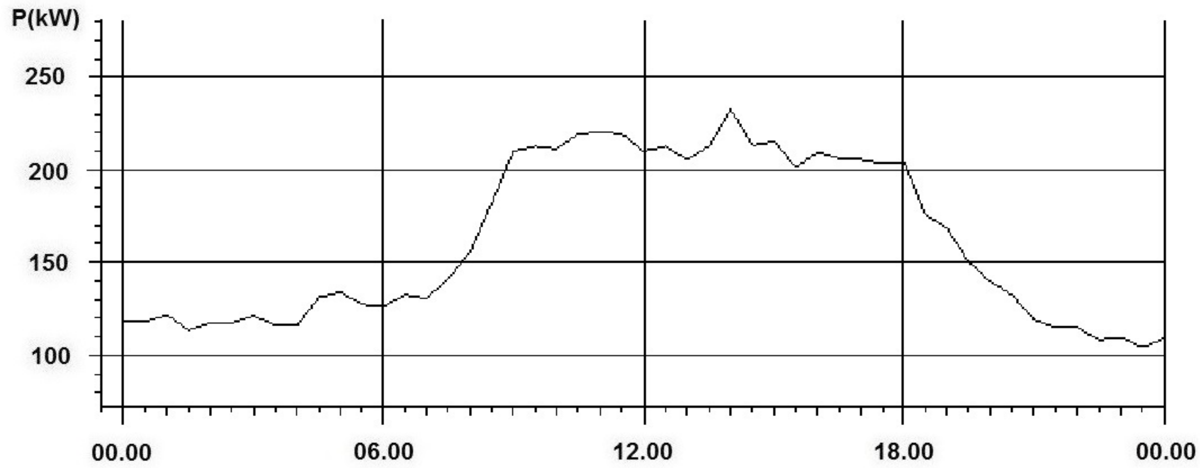

Fig. 24. Power consumption 16/11, 00.00 – 17/11, 00.00. Day 22.

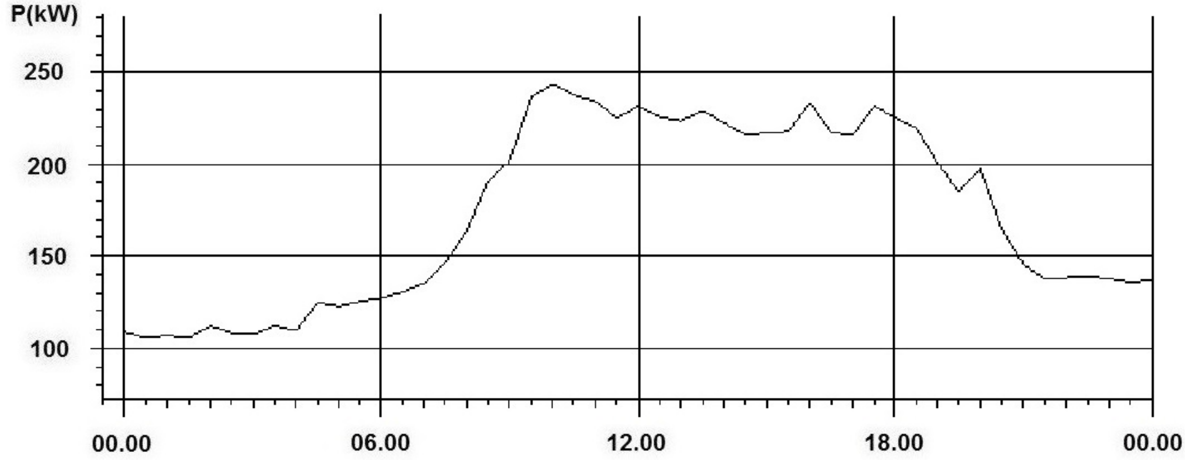

Fig. 25. Power consumption 17/11, 00.00 – 18/11, 00.00. Day 23.

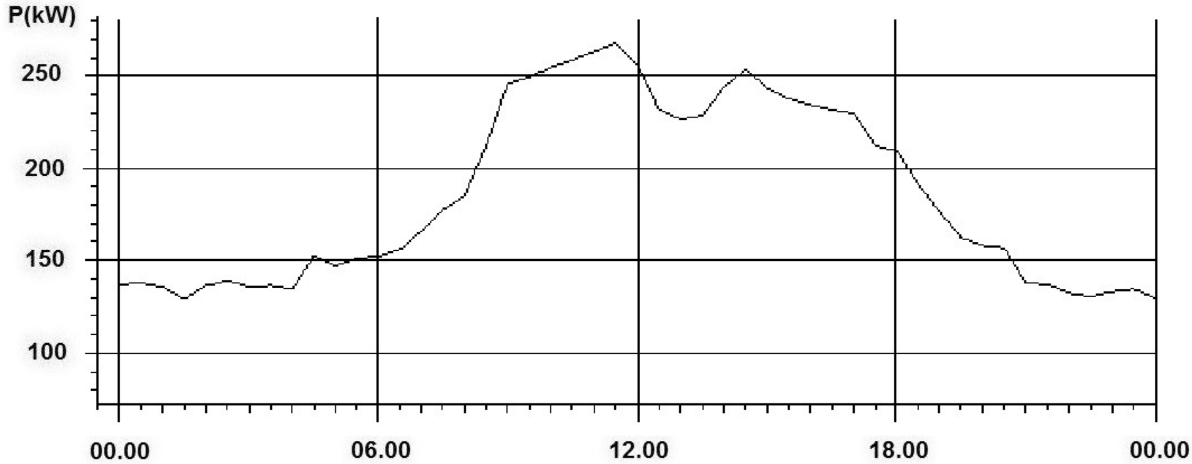

Fig. 26. Power consumption 18/11, 00.00 – 19/11, 00.00. Day 24.

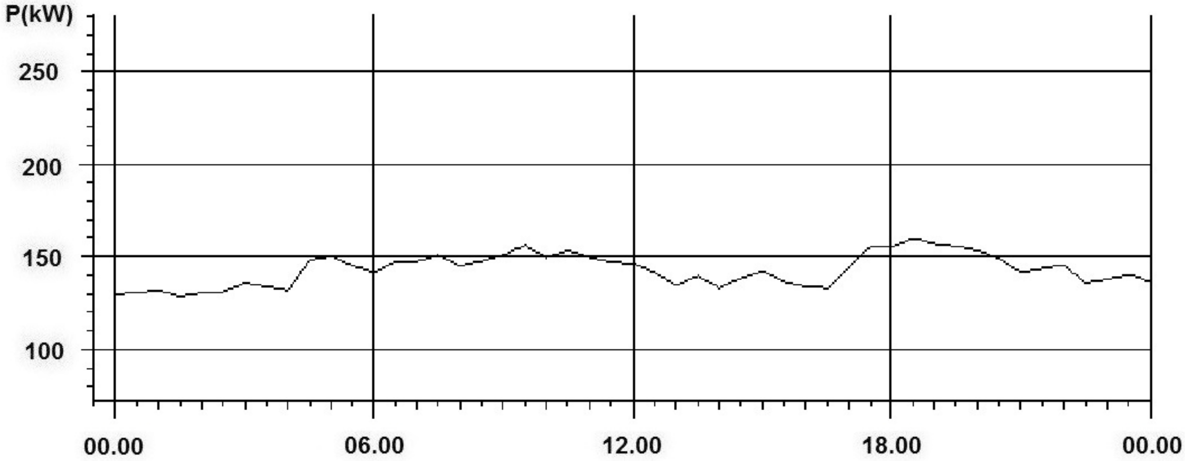

Fig. 27. Power consumption 19/11, 00.00 – 20/11, 00.00. Weekend. Day 25.

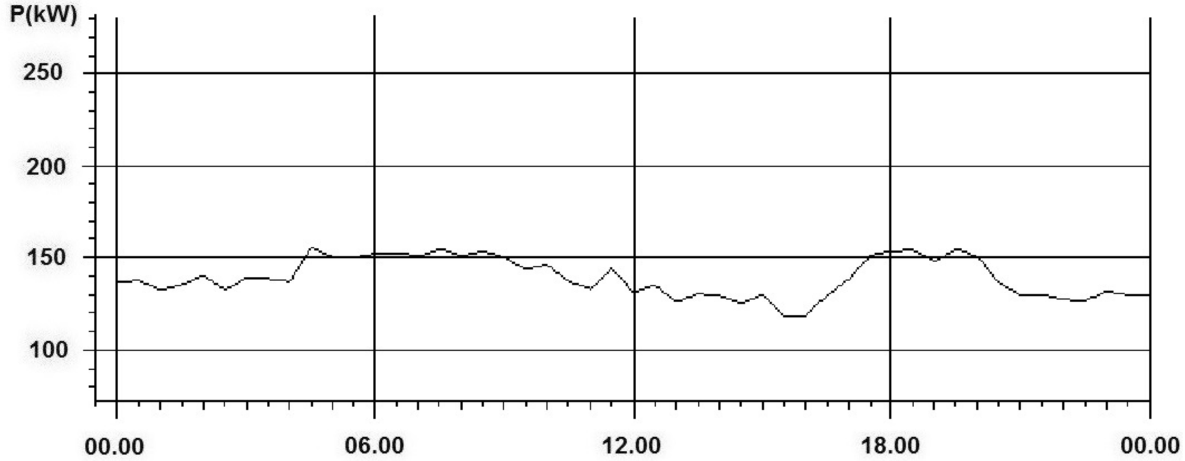

Fig. 28. Power consumption 20/11, 00.00 – 21/11, 00.00. Weekend. Day 26.

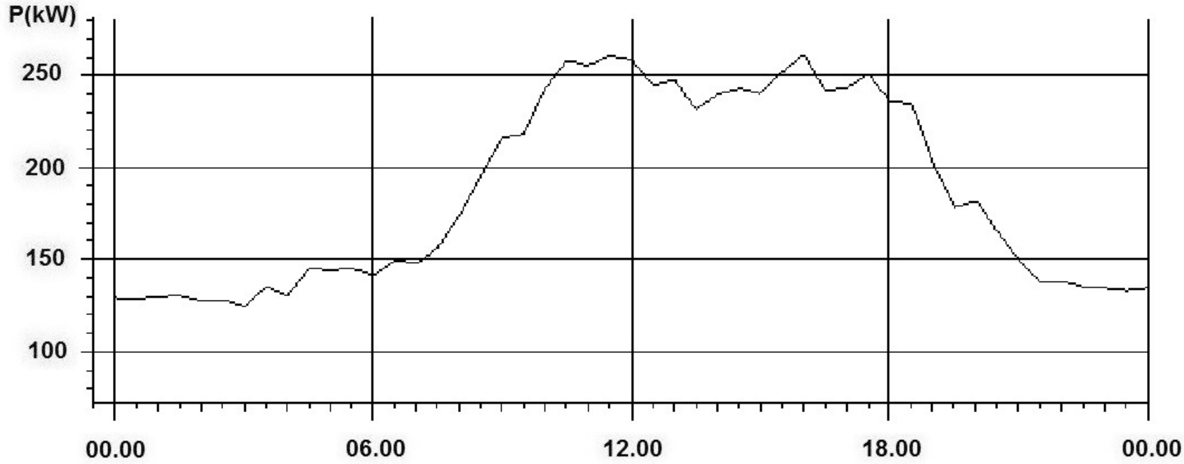

Fig. 29. Power consumption 21/11, 00.00 – 22/11, 00.00. Day 27.

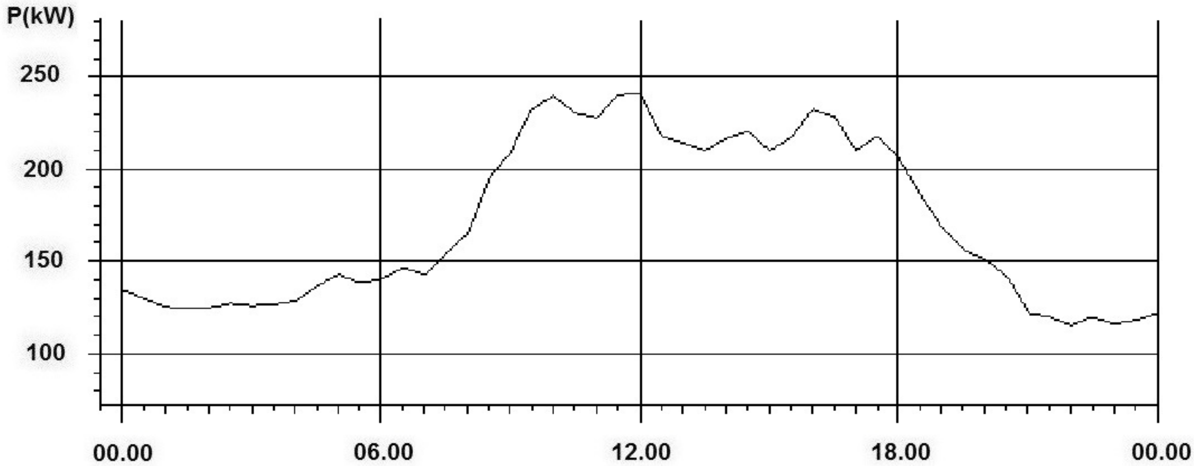

Fig. 30. Power consumption 22/11, 00.00 – 23/11, 00.00. Day 28.

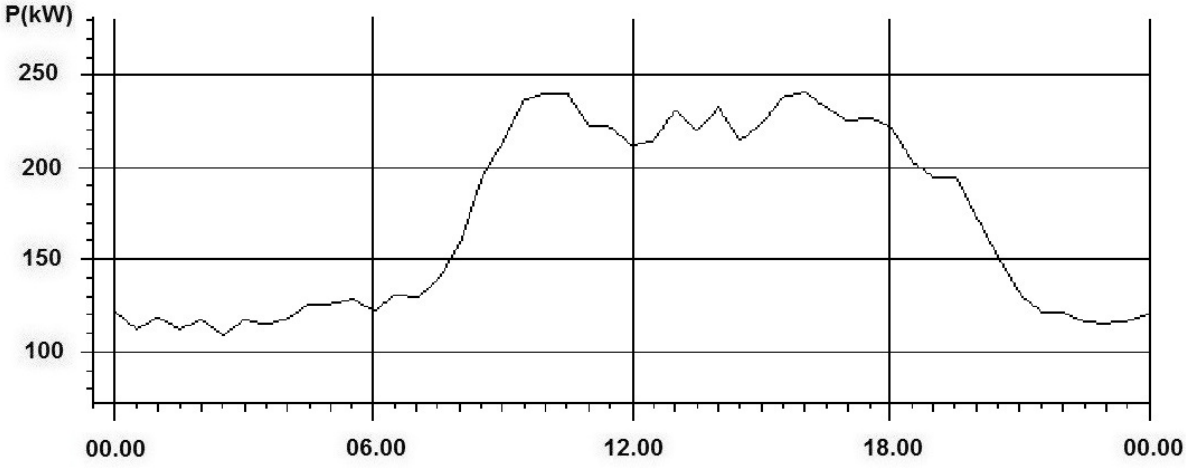

Fig. 31. Power consumption 23/11, 00.00 – 24/11, 00.00. Day 29.

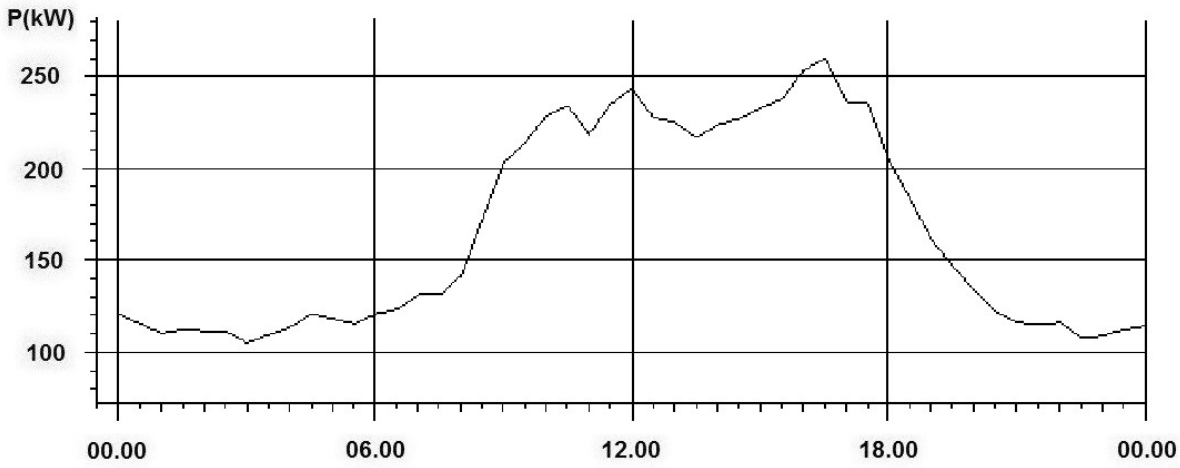

Fig. 32. Power consumption 24/11, 00.00 – 25/11, 00.00. Day 30.

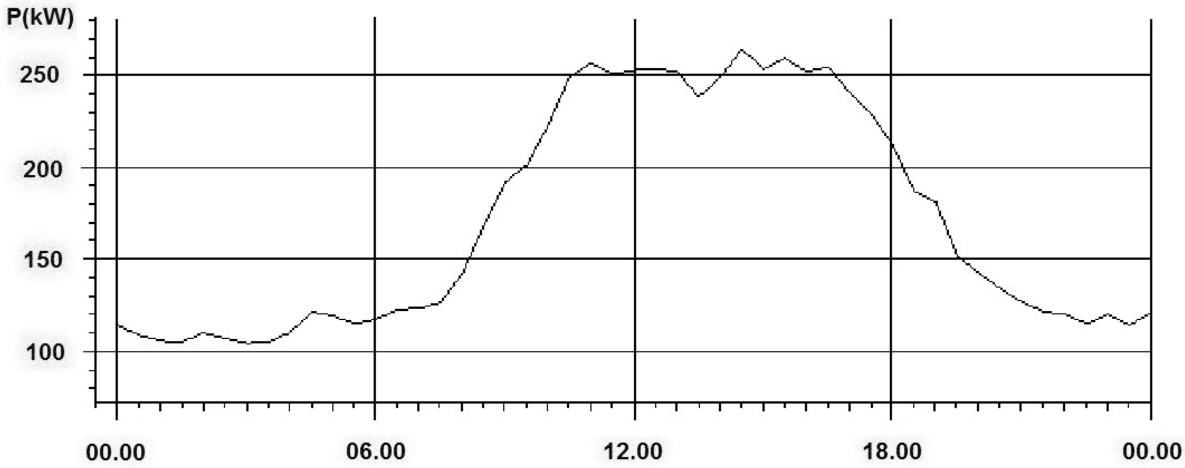

Fig. 33. Power consumption 25/11, 00.00 – 26/11, 00.00. Day 31.

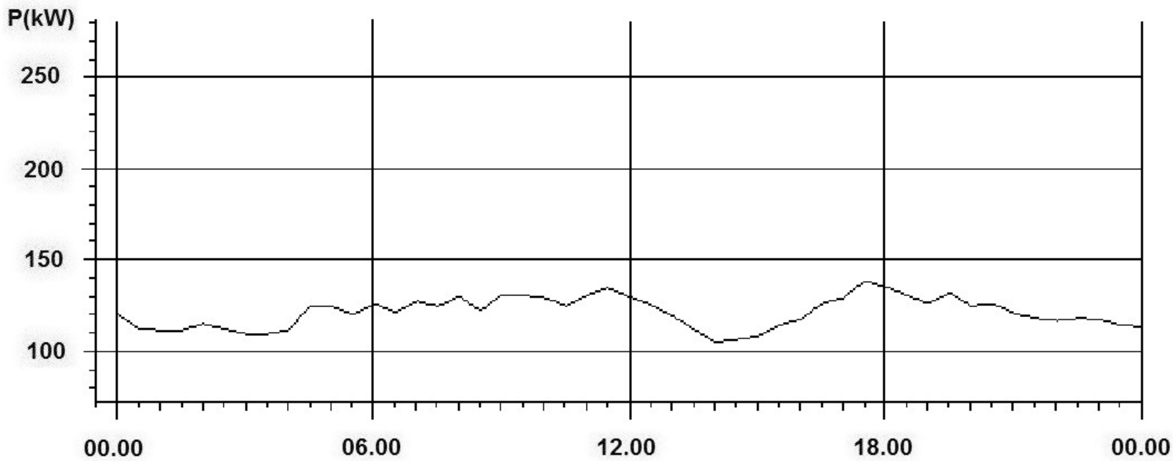

Fig. 34. Power consumption 26/11, 00.00 – 27/11, 00.00. Weekend. Day 32.

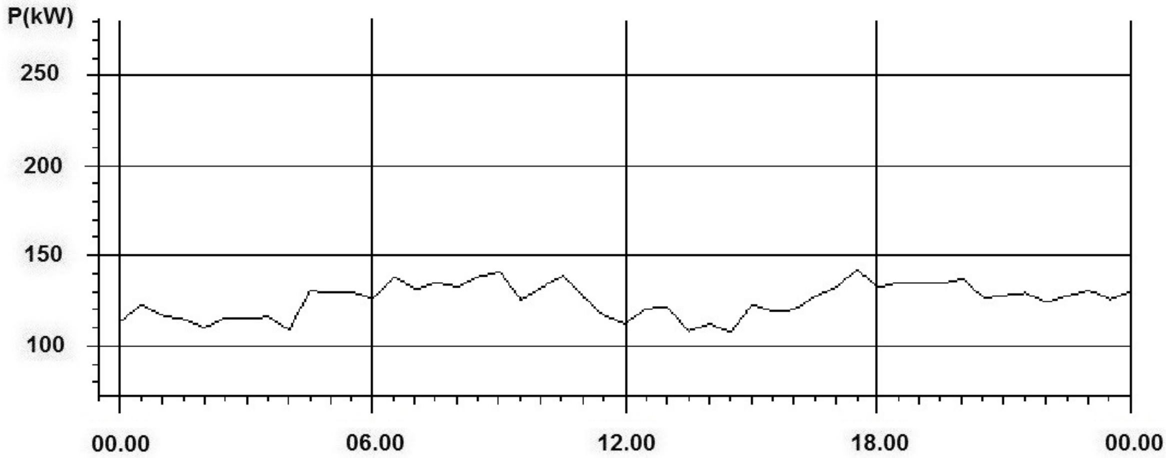

Fig. 35. Power consumption 27/11, 00.00 – 28/11, 00.00. Weekend. Day 33.

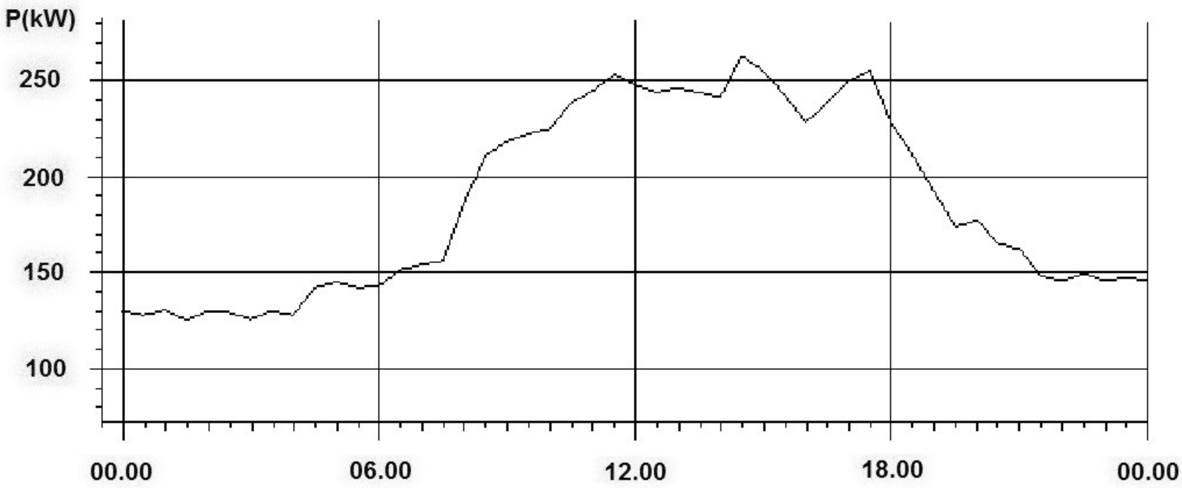

Fig. 36. Power consumption 28/11, 00.00 – 29/11, 00.00. Day 34.

4 STATISTICAL MODELL FOR AN INDUSTRIAL AREA

4.1 Basic principle

Fig. 37 shows the mean consumption for all working days. The values represent the mean of consumption for all time points. The corresponding mean values for the weekends is shown in Fig. 38.

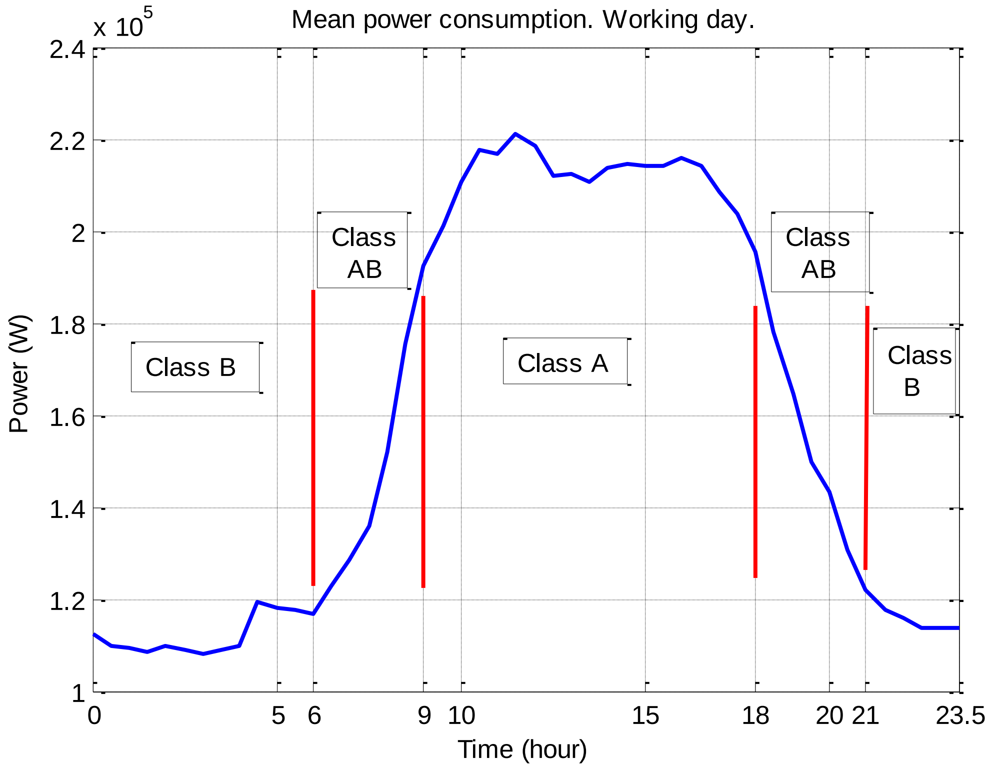

Fig. 37. Power consumption. Mean value for working days.

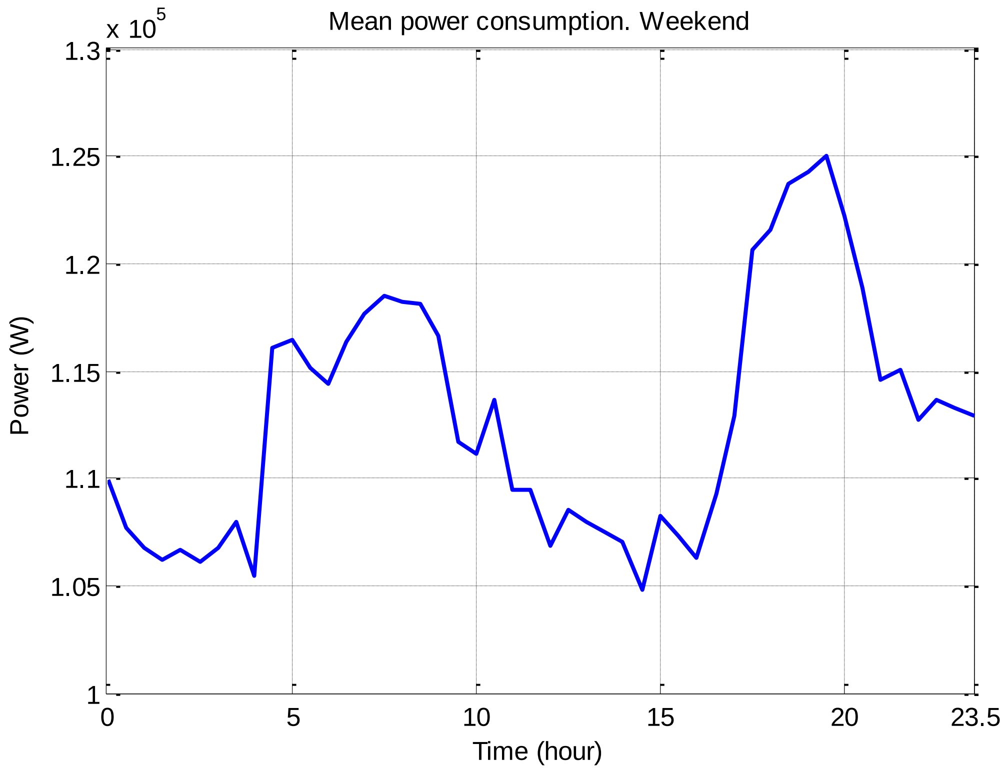

Fig. 38. Power consumption. Mean value for weekend days.

The results presented according to Fig. 37 and Fig. 38 make it reasonable to subdivide the days into different classes depending on what time points that are in question.

The following classification is done:

- Class A: Power consumption during day time. Working day.
- Class B: Power consumption during evening/night time. Working day.
- Class AB: Power consumption during transition between daytime to evening time and nighttime to day time. Working day.
- Class C: Power consumption during weekend

The following time intervals for the working day classes are defined:

- Time interval class A: 09.00 - 18.00
- Time interval class B: 00.00 – 06.00 and 21.00 – 00.00
- Time interval class AB: 06.00 – 09.00 and 18-00- 21.00

As shown in Fig. 3 - Fig. 36, one can consider the power consumption divided into different frequency components. In the following analysis, we choose to divide the same in two frequency components:

- Low frequency component
- High frequency component

Equ. 1 to Equ. 6 clarify certain details for the continued consideration of this topic:

Equ. 1:

$S = P + jQ$

Where: S: Apparent power
P: Active power
Q: Reactive power

Equ. 2:

$P = |S| \times \cos \varphi$

Equ. 3:

$Q = |S| \times \sin \varphi$

Where: φ: Phase angle

$|S|$ is divided into two components:

Equ. 4:

$|S| = S_L + S_H$

S_L: Low frequency power component
S_H: High frequency power component

Equ. 5:

$S_L = F1$

Equ. 6:

$S_H = F2 \times S_L$

Where: F1 and F2 are statistical functions.

4.2 Principle for the model

The model shall simulate the statistical distribution of power consumption over a defined time period. This is done by using Equ. 4 Equ. 5 and Equ. 6 in combination with the defined classes A, B, AB and C. According to Equ. 5, the statistical function, F1, gives the low frequency component. F1, depends on the class in question, resulting in F1(A), F1(B), F1(AB) and F1(C) according to:

F1(A): Defines low frequency component, day time, working day.

F1(B): Defines low frequency component, evening/night time, working day.

F1(AB): Defines low frequency component, transition between night time to day time resp. day time to evening time.

F1(C): Defines low frequency component, weekend.

Fig. 39 illustrates how the low frequency components are functions of time point during a working day. F1(B)” in the figure defines the low frequency component, evening/night time, for a new 24 hour cycle. This will indicate that all functions F1 are updated every new 24 hour cycle.

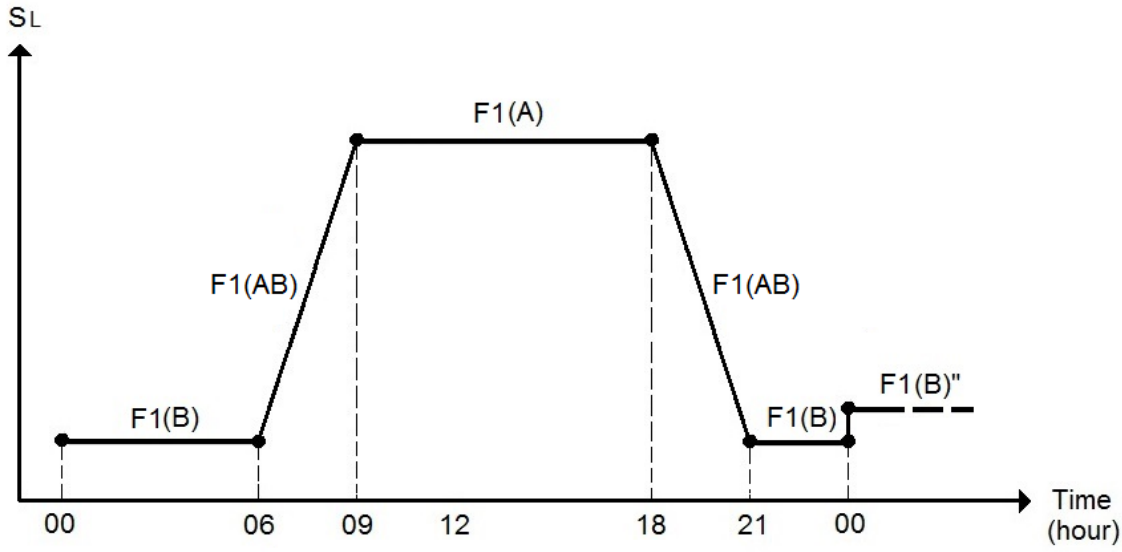

Fig. 39. Low frequency component as a function of time.

According to Equ. 6, the statistical function, F2, results in the high frequency component. Like function F1, also function F2 depends on the class in question, resulting in F2(A), F2(B), F2(AB) and F2(C) according to:

F2(A): Defines high frequency component, day time, working day.

F2(B): Defines high frequency component, evening/night time, working day.

F2(AB): Defines high frequency component, transition between night time to day time resp. day time to evening time, working day.

F2(C): Defines high frequency component, weekend.

The definitions of F1 and F2 will be treated in section 4.3 – section 4.3.5.

4.3 Statistical analysis

4.3.1 Measurement vectors and analysis of low/high frequency components

Fig. 40 - Fig. 43 show the measurements for class A, B, AB and C gathered in separated measurement vectors for respectively class. Each vector is analyzed regarding low frequency and high frequency component.

The frequency components are analyzed according to:

- Low frequency component: Measured values for all samples in respectively class are analyzed. Class AB is a special case and treated in a different way. See below.

- High frequency component: The gradient of adjacent samples are analyzed. Class AB is a special case and treated in a different way. See below. The gradient is defined according to Equ. 7.

Equ. 7:

$$\text{Grad (k)} = \frac{\mathrm{Vect(k+1)} - \mathrm{Vect(k)}}{\mathrm{Vect(k)}}$$

Where:

Grad(k): Gradient of sample k in measurement vector
Vect (k): Measurement value of sample k in measurement vector
Vect (k+1): Measurement value of adjacent sample in measurement vector

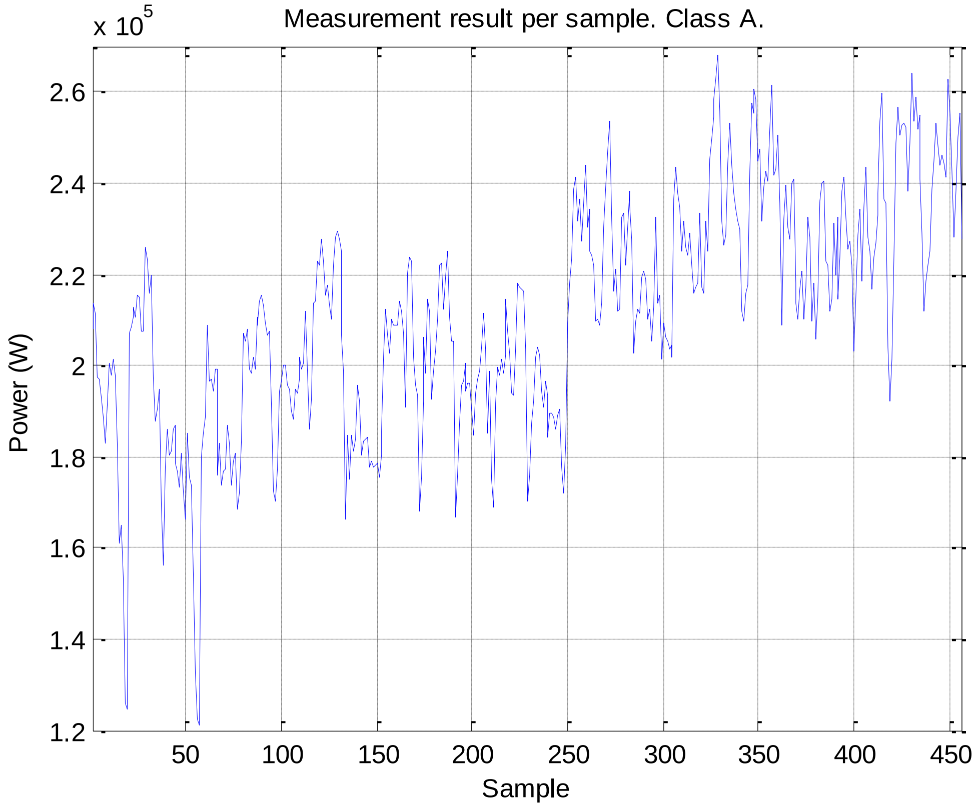

Fig. 40. Measurement result per sample. Class A. 456 samples. Min value = 120960 W. Max value = 267820 W.

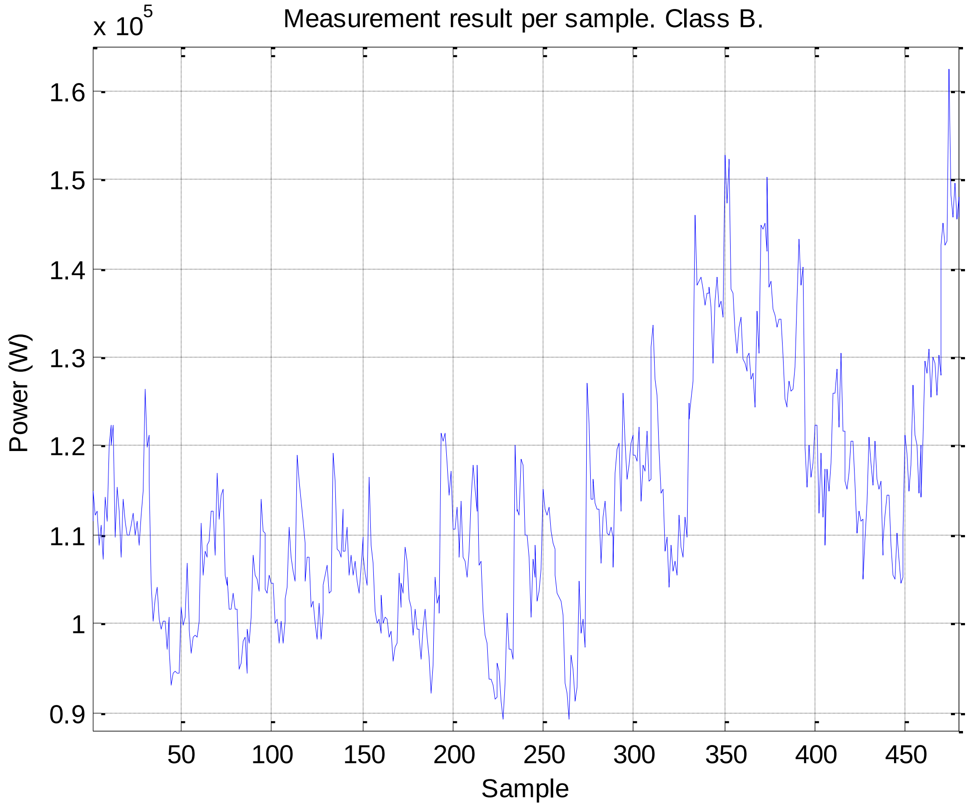

Fig. 41. Measurement result per sample. Class B. 480 samples. Min value = 89320 W. Max value = 162400 W.

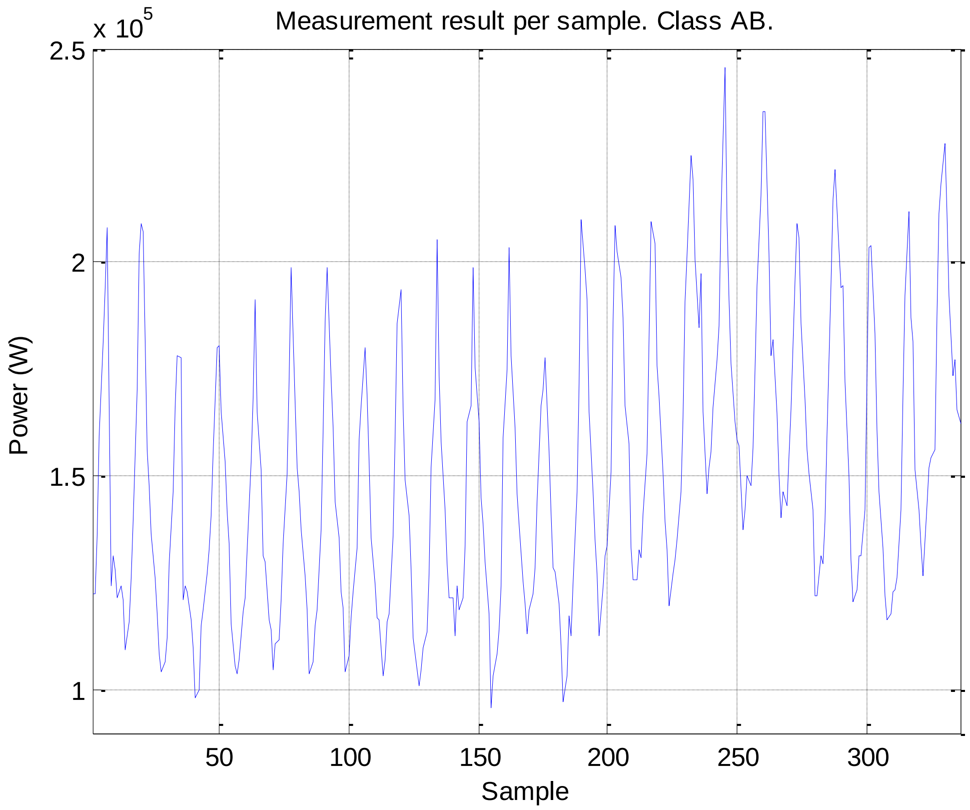

Fig. 42. Measurement result per sample. Class AB. 336 samples. Min value = 95900 W. Max value = 245420 W.

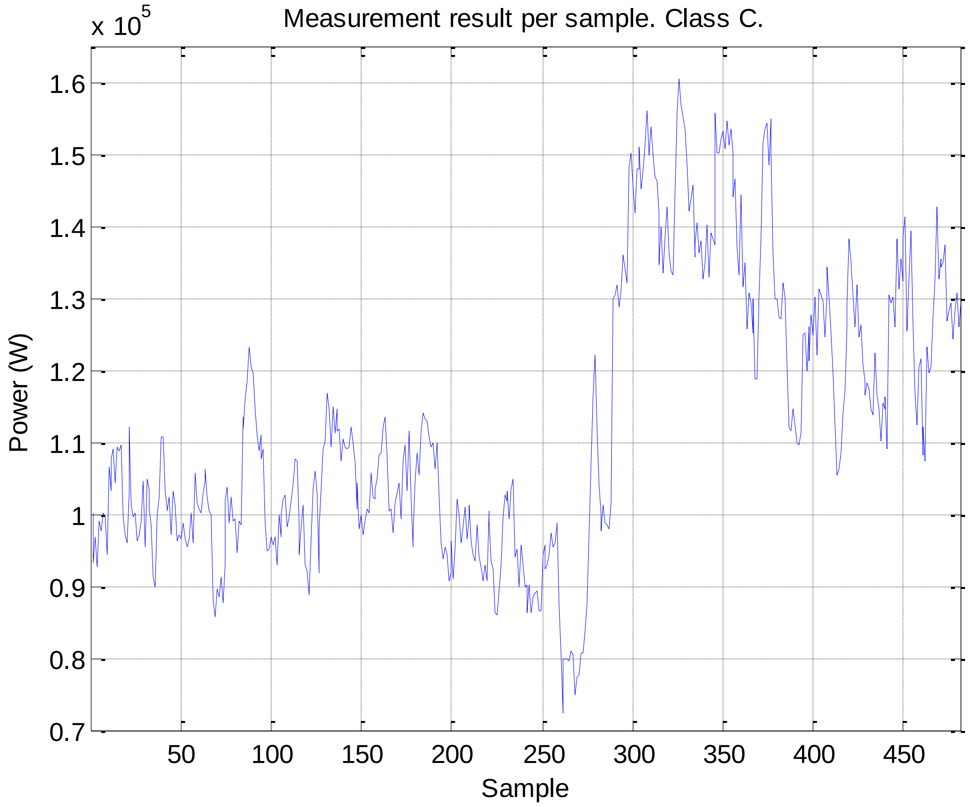

Fig. 43. Measurement result per sample. Class C. 481 samples. Min value = 72240 W. Max value = 160440 W.

4.3.2 Class A

4.3.2.1 Low frequency component

Fig. 44 shows the power distribution for measured values and for a Gauss distribution with corresponding mean value and standard deviation that are obtained from measurements.

Fig. 44. Class A. Power distribution per 5000 W. Blue curve: measured values. Red curve: Gauss distribution with $\mu = 2.1091 \times 10^5$ and $\sigma = 2.5107 \times 10^4$.

Outgoing from the comparison according to Fig. 44, Equ. 8 will be chosen for the modeling of F1(A).

Equ. 8:

$$F1(A) = N(\mu,\sigma)$$

Where:

N: Gauss distribution
μ: Mean value = 2.1091×10^5
σ: Standard deviation = 2.5107×10^4

4.3.2.2 High frequency component

Fig. 45 shows the gradient distribution for measured values and for a Gauss distribution. The mean value and standard deviation for the Gauss curve are not quite exactly the values that are obtained from measurements. They are slightly adjusted.

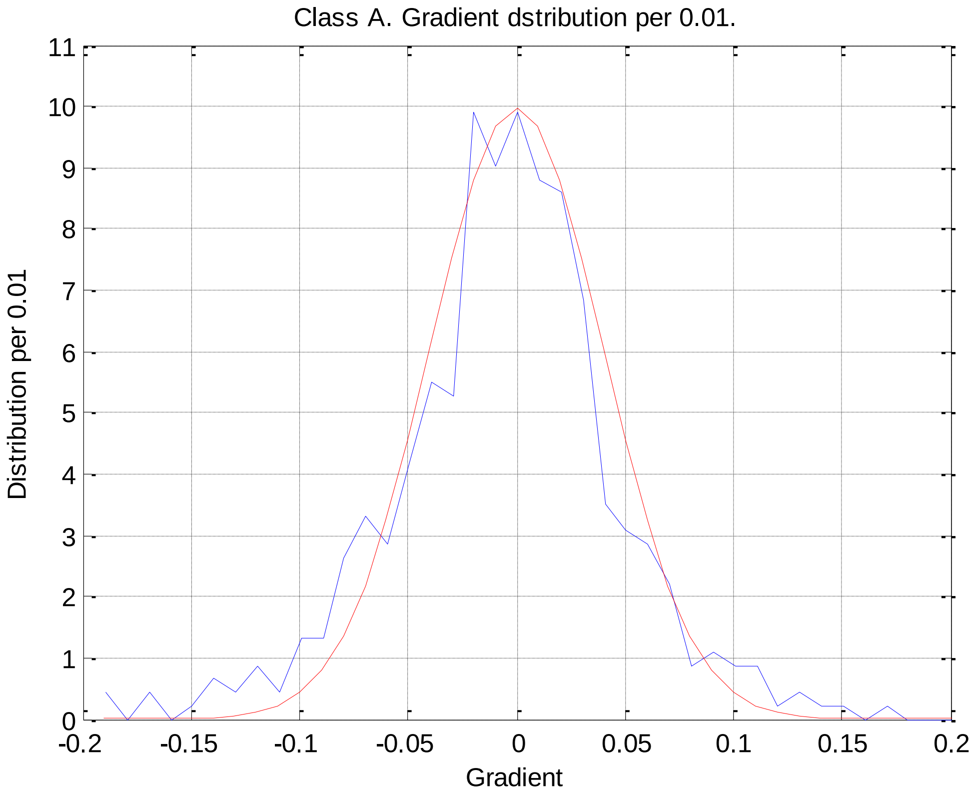

Fig. 45. Class A. Gradient distribution per 0.01. Blue curve: measured values. Red curve: Gauss distribution with $\mu = 0$ and $\sigma = 0.04$.

Outgoing from the comparison according to Fig. 45, Equ. 9 will be chosen for the modeling of F2(A).

Equ. 9:

$$F2(A) = N(\mu,\sigma)$$

Where:

N: Gauss distribution
μ: Mean value = 0
σ: Standard deviation = 0.04

4.3.3 Class B

4.3.3.1 Low frequency component

Fig. 46 shows the power distribution for measured values and for a Gauss distribution with corresponding mean value and standard deviation that are obtained from measurements.

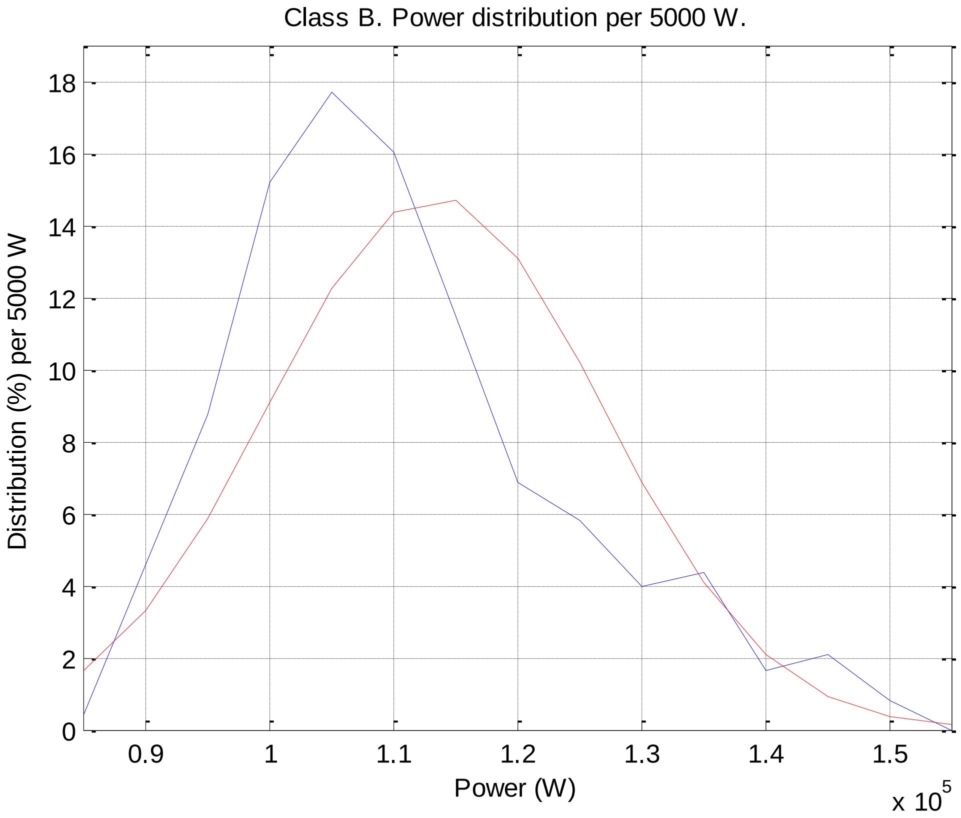

Fig. 46. Class B. Power distribution per 5000 W. Blue curve: measured values. Red curve: Gauss distribution with $\mu = 1.1333 \times 10^5$ and $\sigma = 1.3462 \times 10^4$.

Outgoing from the comparison according to Fig. 46, Equ. 10 will be chosen for the modeling of F1(B).

Equ. 10:

$$F1(B) = N(\mu,\sigma)$$

Where:

N: Gauss distribution
μ: Mean value = 1.1333×10^5
σ: Standard deviation = 1.3462×10^4

4.3.3.2 High frequency component

Fig. 47 shows the gradient distribution for measured values and for a Gauss distribution. The mean value and standard deviation for the Gauss curve are not quite exactly the values that are obtained from measurements. They are slightly adjusted.

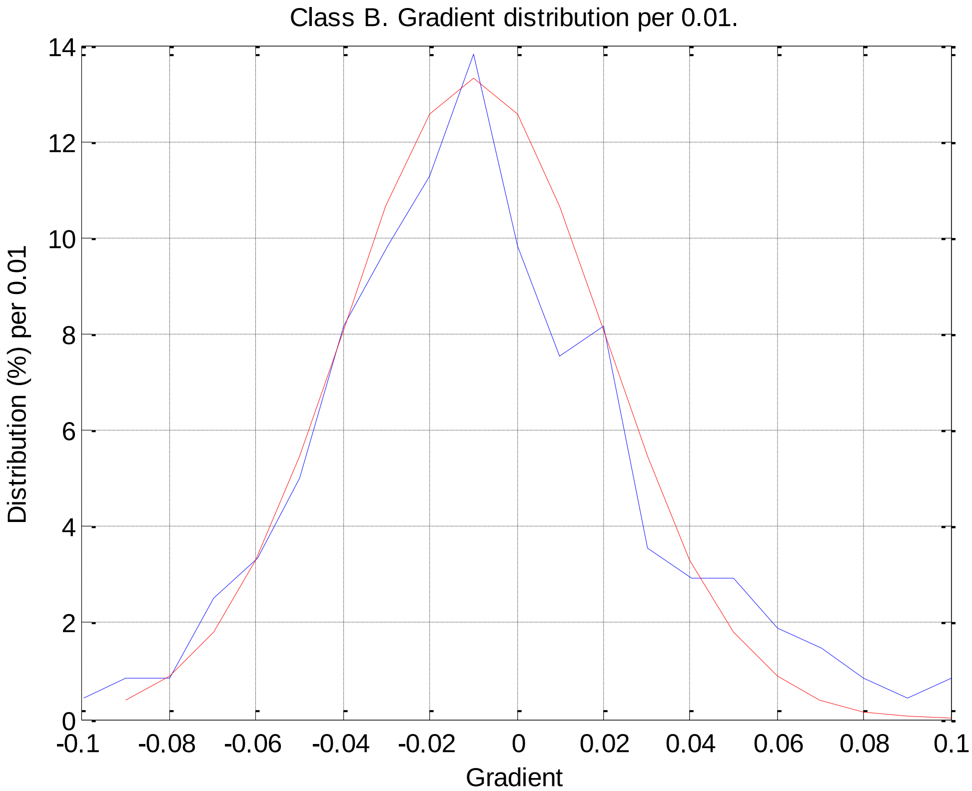

Fig. 47. Class B. Gradient distribution per 0.01. Blue curve: measured values. Red curve: Gauss distribution with μ = -0.01 and σ = 0.03.

Outgoing from the comparison according to Fig. 47, Equ. 11 will be chosen for the modeling of F2(B).

Equ. 11:

F2(B) = N(μ,σ)

Where:

N: Gauss distribution
μ: Mean value = - 0.01
σ: Standard deviation = 0.03

4.3.4 Class AB

4.3.4.1 Low frequency component

The low frequency component is calculated according the following:

Time region between 06 – 09:

Equ. 12:

$$F1(AB) = F1(B) + \frac{F1(A) - F1(B)}{N1} \times dN$$

Where:

N1: Number of simulation steps in time region 06 – 09
dN: Simulation step in time region (1 - N1)

Time region between 18 – 21:

Equ. 13:

$$F1(AB) = F1(A) + \frac{F1(B) - F1(A)}{N2} \times dN$$

Where:

N2: Number of simulation steps in time region 18 – 21
dN: Simulation step in time region (1 - N2)

4.3.4.2 High frequency component

The high frequency component is calculated according to:

Equ. 14:

$$F2(AB) = F2(A)$$

4.3.5 Class C

4.3.5.1 Low frequency component

Fig. 48 shows the power distribution for measured values and for a Gauss distribution with corresponding mean value and standard deviation that are obtained from measurements.

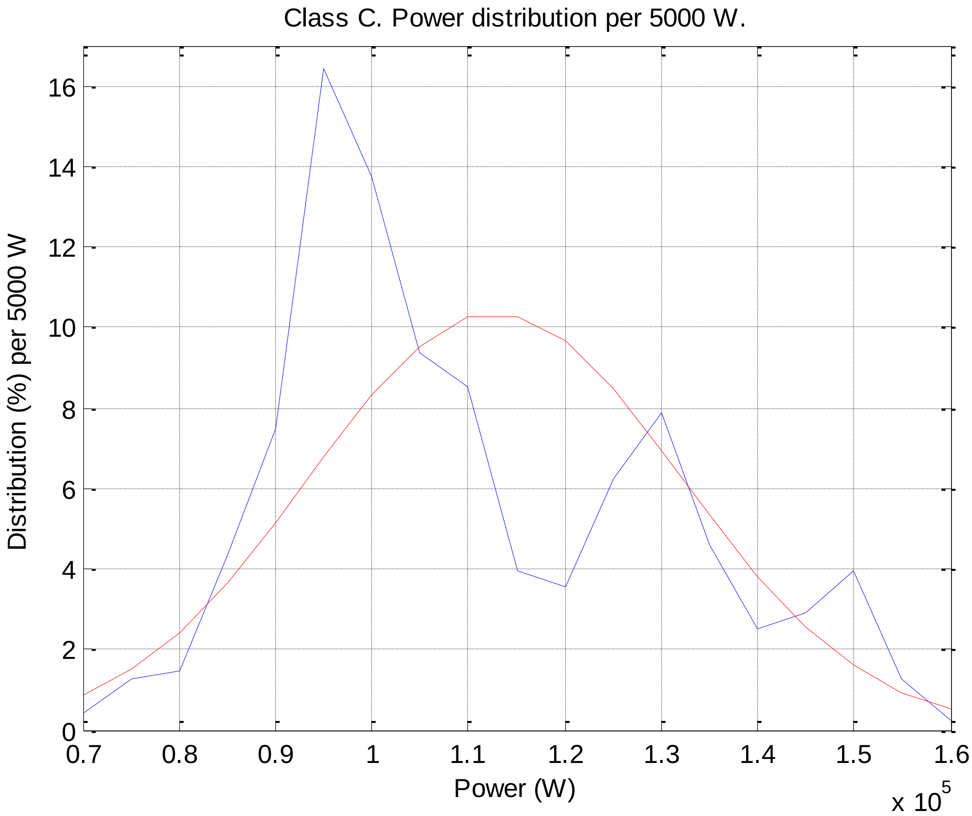

Fig. 48. Class C. Power distribution per 5000 W. Blue curve: measured values. Red curve: Gauss distribution with $\mu = 1.1278 \times 10^5$ and $\sigma = 1.9269 \times 10^4$.

Outgoing from the comparison according to Fig. 48, Equ. 15 will be chosen for the modeling of F1(C).

Equ. 15:

$F1(C) = N(\mu,\sigma)$

Where:

N: Gauss distribution
μ: Mean value = 1.1278×10^5
σ: Standard deviation = 1.9269×10^4

4.3.5.2 High frequency component

Fig. 49 shows the gradient distribution for measured values and for a Gauss distribution. The mean value and standard deviation for the Gauss curve are not quite exactly the values that are obtained from measurements. They are slightly adjusted.

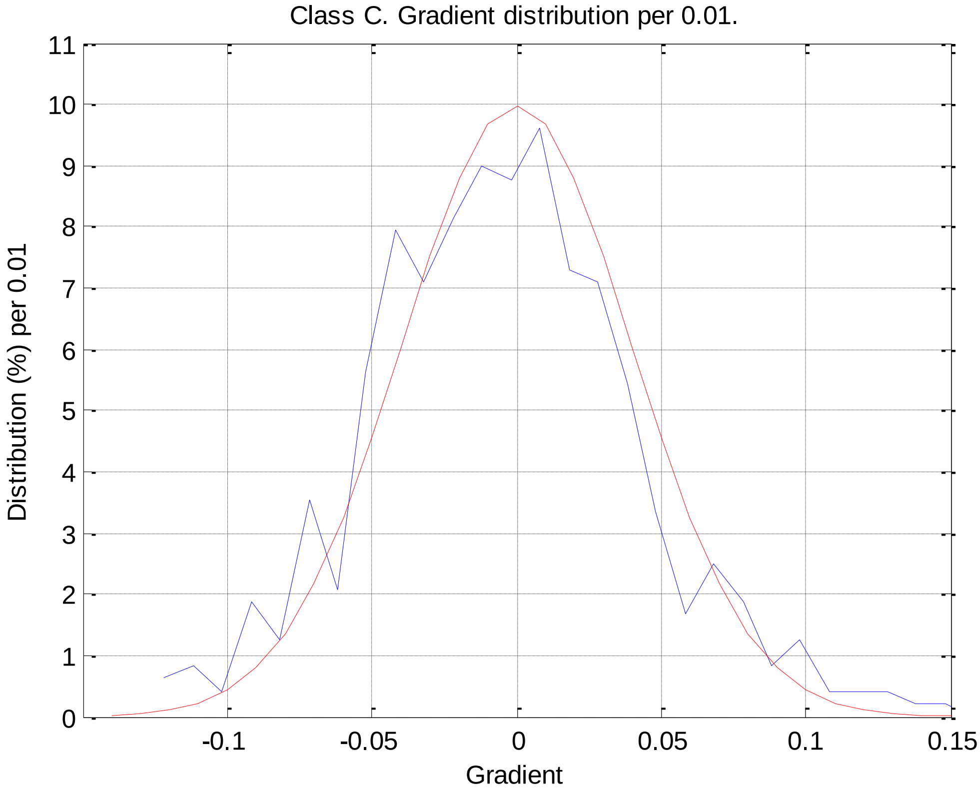

Fig. 49. Class C. . Gradient distribution per 0.01. Blue curve: measured values. Red curve: Gauss distribution with μ = 0 and σ = 0.04.

Outgoing from the comparison according to Fig. 49, Equ. 16 will be chosen for the modeling of F2(C).

Equ. 16:

$$F2(C) = N(\mu,\sigma)$$

Where:

N: Gauss distribution
μ: Mean value = 0
σ: Standard deviation = 0.04

4.3.6 Conclusion of the analysis

Table II gives a conclusion of the Gauss parameters for the classes.

Function F1 is updated each 24 hours cycle, giving the low frequency component. Function F2 is updated each 30 minute cycle, giving the high frequency component.

Table II. Statistical Gauss parameters for the classes.

Class	F1		F2	
	Mean value (W)	*Standard deviation (W)*	*Mean value*	*Standard deviation*
A	2.1091×10^5	2.5107×10^4	0	0.04
B	1.1333×10^5	1.3462×10^4	-0.01	0.03
AB	Lines between F1(A) and F1(B)		0	0.04
C	1.1278×10^5	1.9269×10^4	0	0.04

4.4 Validation

4.4.1 Total energy over a year

A comparison is done between real consumed energy during a year according to Table I and corresponding energy based on mean values for the classes according to Table II. The following assumption is done:

- Number of working days per year: 240
- Number of weekend/holidays per year: 125

Table III summarizes the calculation.

Table III. Calculation of daily energy consumption.

Class	Hours per day	Mean value (kW)	Energy per day (kWh) (Hours per day × Mean value)
A	9	210.91	1898.19
B	9	113.33	1019.97
AB	6	(210.91+ 113.33)/2	972.72
C	24	112.78	2706.72
Total energy per day, working day, all classes (kWh)			3890.88
Total energy per day, weekend/holiday (kWh)			2706.72

The calculated annual energy consumption is:

Equ. 17:

$$W_{annual} = N_{working\ day} \times W_{working\ day} + N_{weekend\ day} \times W_{weekend\ day}$$

Where:

W_{annual}: annual energy consumption
$W_{working\ day}$: Energy per day, working day = 3890.88 kWh
$W_{weekend\ day}$: Energy per day, weekend/holiday = 2706.72 kWh
$N_{working\ day}$: Number of working days per year = 240
$N_{weekend\ day}$: Number of weekend/holidays per year = 125

This results in:

$W_{annual} = 1.2722 \times 10^6$ kWh.

Measured annual energy according to Table I is 1.274327 kWh.

Measured and calculated values differs with about 1.7 %.

Thus it is a good agreement between measurement and calculation.

4.4.2 Mean power and standard deviation

A validation is performed by comparing the result from the 20 first measured working days with corresponding simulation. The following have been compared:

- Relation between mean power of measured working days and corresponding simulation.
- Relation between standard deviation of measured working days and corresponding simulation.

This has been performed for 1000 simulation cycles. The result follows according to Fig. 50 and Fig. 51.

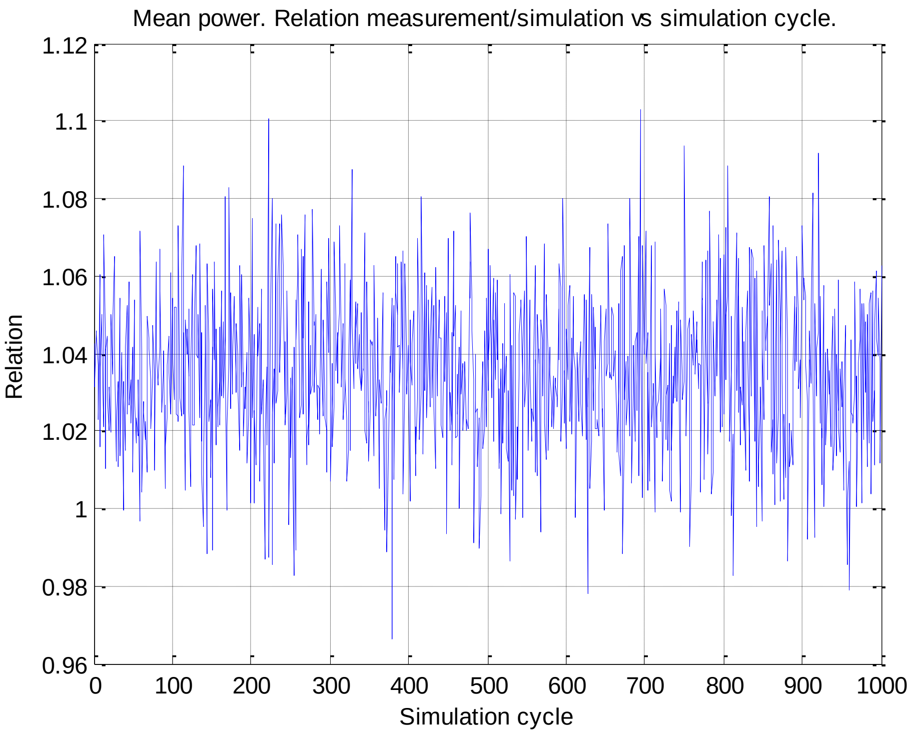

Fig. 50. Mean power. Relation measuremen/simulation vs simulation cycle.

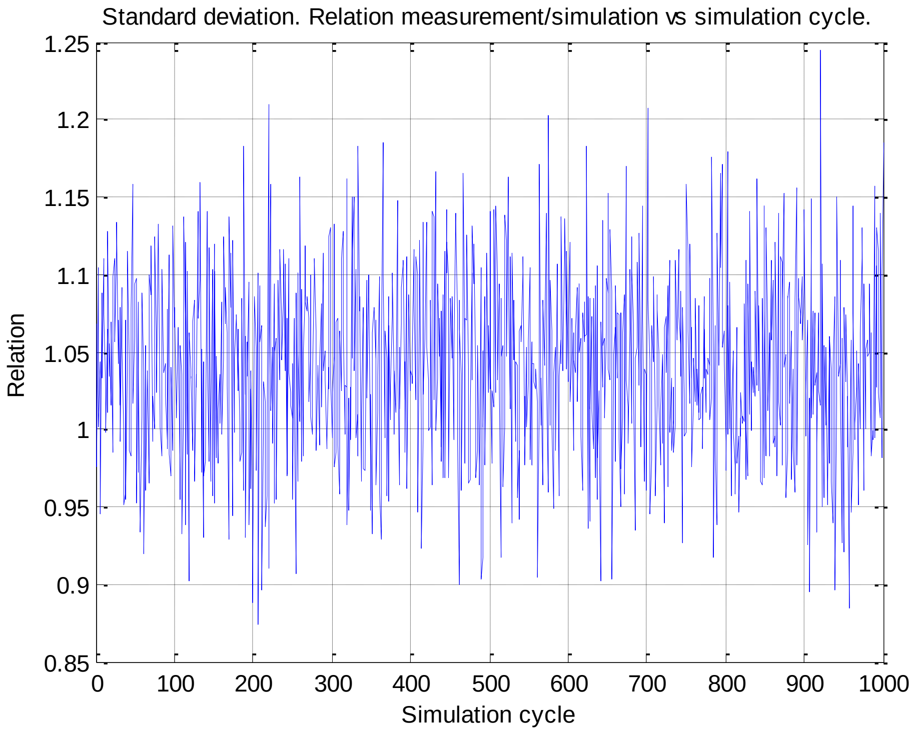

Fig. 51. Standard deviation of power. Relation measuremen/simulation vs simulation cycle.

Table IV gives the result of the comparison between measurement and simulation.

Table IV. Relation measurement / simulation.

Relation 1 (mean power)	**Relation 2 (standard deviation of power)**
Mean relation 1 = 1.0350	Mean relation 2 = 1.0407
Standard dev. relation 1= 0.0198	Standard dev. relation 2 = 0.0589

The comparison shows a perfectly acceptable consistency between measurements and simulations. The differences are:

- 3.5 % for mean power (with 2-σ limits +1.5 % to +5.5 %)
- 4 % for standard deviation (with 2-σ limits from -8 % to +16 %)

4.5 Simulation examples

Fig. 52 illustrates a simulation example based on the modelling according sections 4.1 - 4.3. The simulation covers 16 days with 12 working days and 4 weekend days.

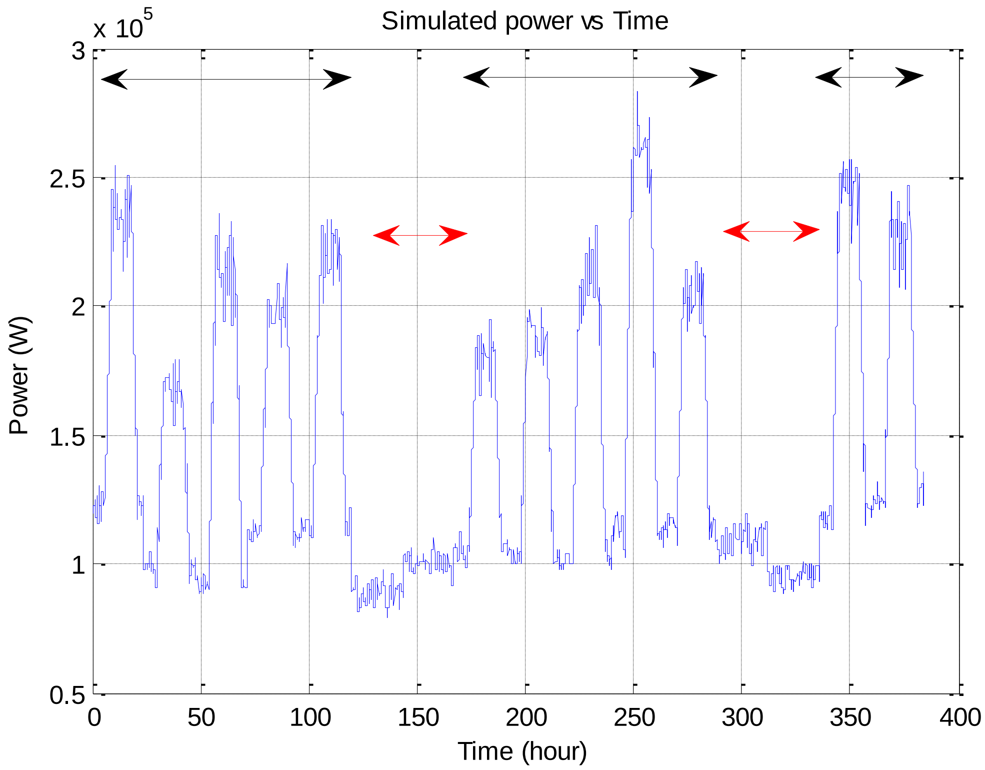

Fig. 52. Simulation example with 16 days, including 12 working days (black arrowed lines) and 4 weekend days (red arrowed lines).

The simulation according Fig. 52 is based on a phase angle of 0˚.

Fig. 53 - Fig. 55 illustrate a simulation example that covers 16 days with 12 working days and 4 weekend days. In addition there are different phase angles depending on time points, according to:

- 30˚ during working day between 06 – 21
- \- 10˚ during working day between 21 – 06 and during weekend days

The figures show apparent power, active power and reactive power.

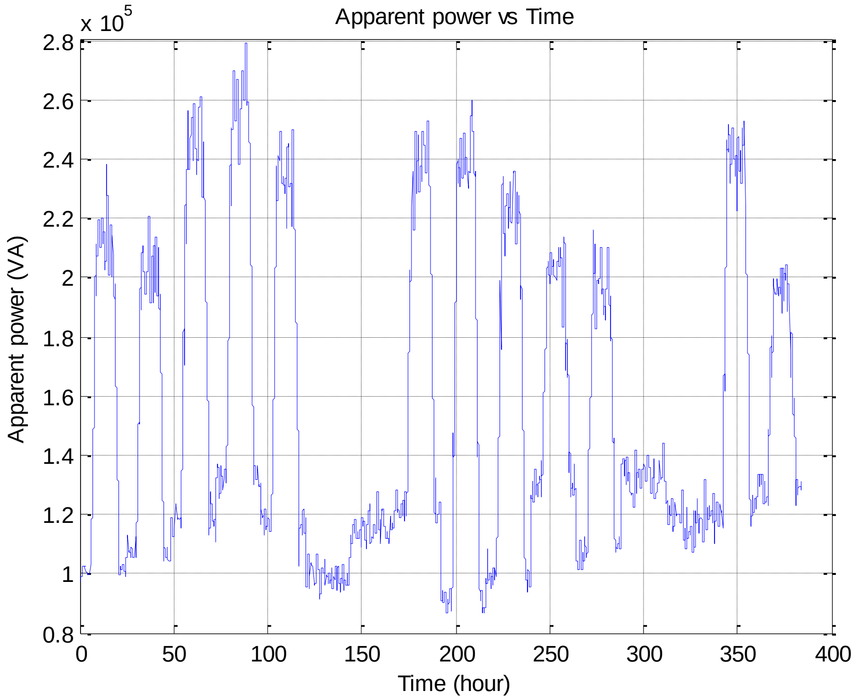

Fig. 53. Simulation example with 16 days, including 12 working days and 4 weekend days. Apparent power.

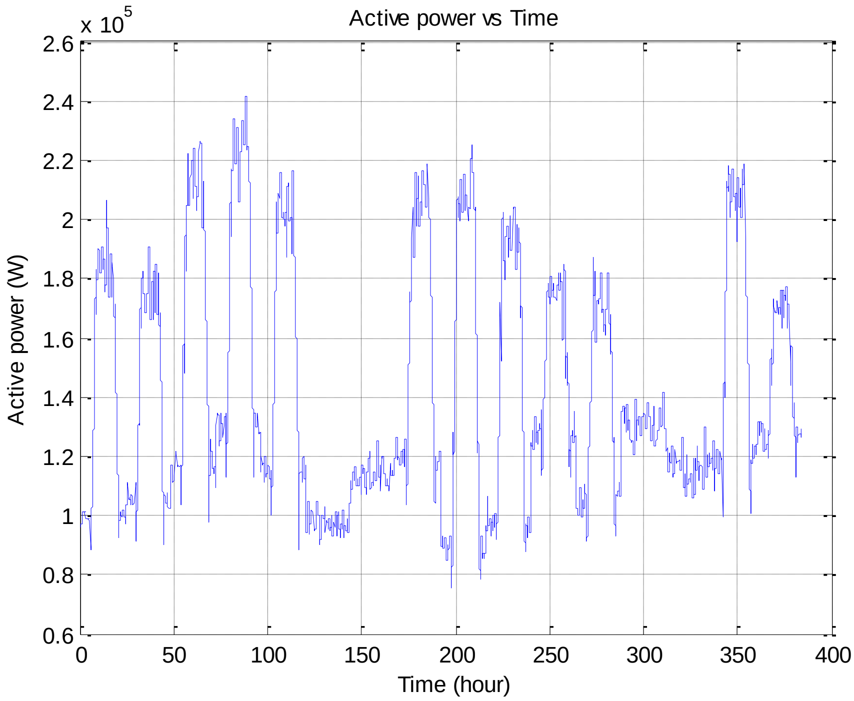

Fig. 54. Simulation example with 16 days, including 12 working days and 4 weekend days. Active power.

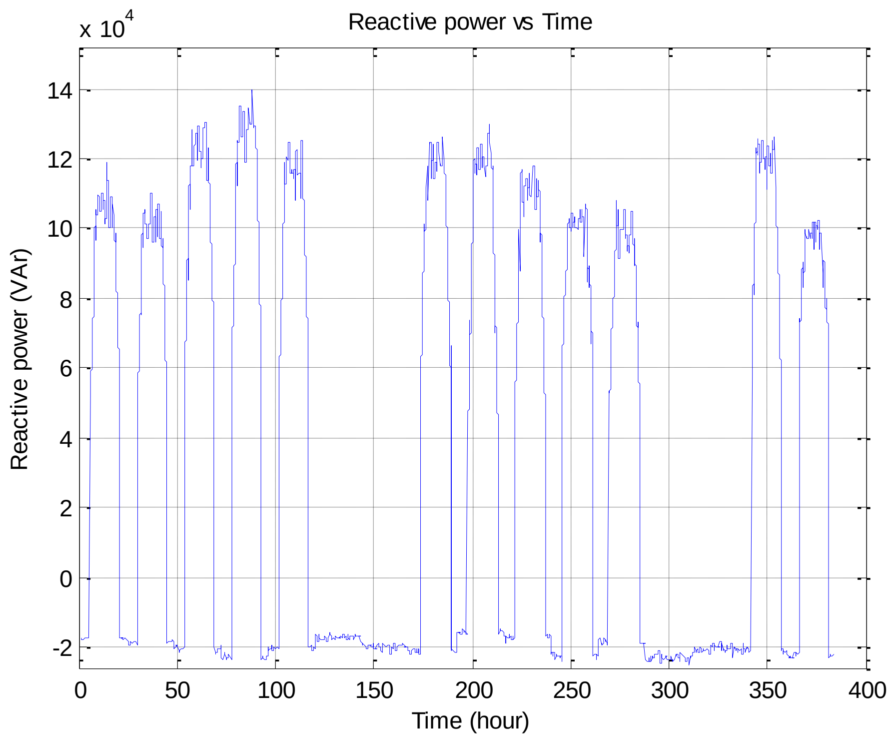

Fig. 55. Simulation example with 16 days, including 12 working days and 4 weekend days. Reactive power.

5 STATISTICAL MODEL FOR A GENERAL INDUSTRIAL AREA

Section 4 has treated circumstances in a specific industrial area. In order to model the power consumption in a general industrial area some parameters from Section 4 has to be modified. From Table II the following mean value of F1 can be found:

Class A: 210.91 kW
Class B: 113.33 kW
Class AB: 162.12 kW
Class C: 112.78 kW

By using Equ. 17 this results in an annual power consumption of 1.2722×10^6 kWh.

Suppose the mean values of F1 are changed to:

Class A: $W / 1.2722 \times 10^{6} \times 210.91$ kW
Class B: $W / 1.2722 \times 10^{6} \times 113.33$ kW
Class AB: $W / 1.2722 \times 10^{6} \times 162.12$ kW
Class C: $W / 1.2722 \times 10^{6} \times 112.78$ kW

The new values result in an annual power consumption of E kWh.

For a general annual power consumption the values according to Table V shall be used.

Table V. Statistical Gauss parameters for an industrial area.

Class	**F1**		**F2**	
	Mean value (W)	*Standard deviation (W)*	*Mean value*	*Standard deviation*
A	$K1 \times 2.1091 \times 10^{5}$	$K1 \times 2.5107 \times 10^{4}$	0	0.04
B	$K1 \times 1.1333 \times 10^{5}$	$K\ 1 \times 1.3462 \times 10^{4}$	-0.01	0.03
AB	Lines between F1(A) and F1(B)		0	0.04
C	$K1 \times 1.1278 \times 10^{5}$	$K1 \times 1.9269 \times 10^{4}$	0	0.04

Parameter K1 in Table V is defined according to:

Equ. 18:

$K1 = W / 1.2722 \times 10^{6}$

Where: W: Annual power consumption (kWh).

6 STATISTICAL MODELL FOR A COMMERCIALLY CENTER

For a commercially center, F1 and F2 are defined according to Table VI.

Table VI. Statistical Gauss parameters for a commercially center.

F1		**F2**	
Mean value (W)	*Standard deviation (W)*	*Mean value*	*Standard deviation*
$K2 \times 1.1278 \times 10^5$	$K2 \times 1.9269 \times 10^4$	0	0.04

Parameter K2 in Table VI is defined according to Equ. 18.

Equ. 19:

K2 = W / W_annual_ref

Equ. 20:

W_annual_ref = F1,mean × 24 × 365

Where:

W: Annual power consumption (Wh)
W_annual_ref: Annual power consumption (Wh) for F1, mean value.
F1,mean: Mean value of F1 = 1.1278×10^5 W

F1 and F2 is equivalent to the corresponding values for class C in the model of an industrial area and adapted to the annual power consumption in question. For the moment, and without specific statistics for a commercial center, this is a relevant assumption.

7 STATISTICAL MODELL FOR A RESIDENTIAL AREA

7.1 General model

Fig. 56 shows the low frequency components during a 24 hours cycle for a proposal of a load model consisting of a residential area.

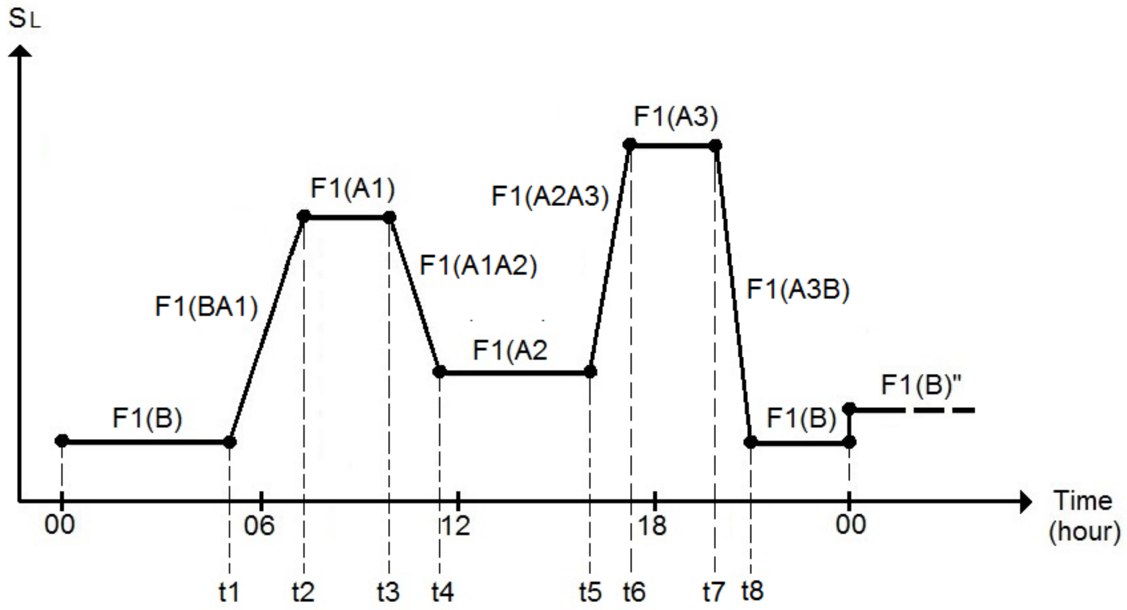

Fig. 56. Model for a residential area.

The components are as follows:

- F1(B): low frequency component during time zones 00 – t1 and t8 – 00.
- F1(A1): low frequency component during time zone t2 – t3.
- F1(A2): low frequency component during time zone t4 – t5.
- F1(A3): low frequency component during time zone t6 – t7.
- F1(BA1): low frequency component during time zone t1 – t2.
- F1(A1A2): low frequency component during time zone t3 – t4.
- F1(A2A3): low frequency component during time zone t5 – t6.
- F1(A3B): low frequency component during time zone t7 – t8.

The transition between F1(B) – F1(A1), F1(A1) – F1(A2), F1(A2) – F1(A3) and F1(A3) – F1(B), corresponding to F1(BA1), F1(A1A2), F1(A2A3) and F1(A3B), follows the same principle as discussed in section 4.3.4.1.

The time zones t2 – t3 and t6 – t7 corresponds to time zones with extra power consumption. For example between 07 - 10 and 17 - 21.

7.2 An example

7.2.1 Choice of F1 and time zones

An example of choice regarding F1 and time zones follows below. Also see Fig. 56. The parameter F1(B) depends on the annual power consumption. This is described in section 7.2.2.

- F1(B): Calculated as a result of annual power consumption. See below.
- F1(A1): 2.5 × F1(B)
- F1(A2): 1.5 × F1(B)
- F1(A3): 3.5 × F1(B)
- F2(B), F2(A1), F2(A2) and F2(A3): as F2(A) in section 4
- Time zones:
  - t1 = 5
  - t2 = 7
  - t3 = 10
  - t4 = 12
  - t5 = 15
  - t6 = 17
  - t7 = 21
  - t8 = 22

7.2.2 Annual power consumption

The following assumption is done (see Fig. 56):

- F1(A1): 2.5 × F1(B)
- F1(A2): 1.5 × F1(B)
- F1(A3): 3.5 × F1(B)
- Time zones:
  - t1 = 5
  - t2 = 7
  - t3 = 10
  - t4 = 12
  - t5 = 15
  - t6 = 17
  - t7 = 21
  - t8 = 22

Based on these parameters, F1(B) can be calculated according to:

Equ. 21:

$$F1(B) = \frac{W}{365 \times 47.75}$$

Where:

W : Annual power consumption (Wh)

7.2.3 Simulation result

Fig. 57 - Fig. 60 illustrate the result of simulation based on the proposed model according section 7.2.1 and section 7.2.2. Annual power consumption is 2 GWh and a phase angle of 5°.

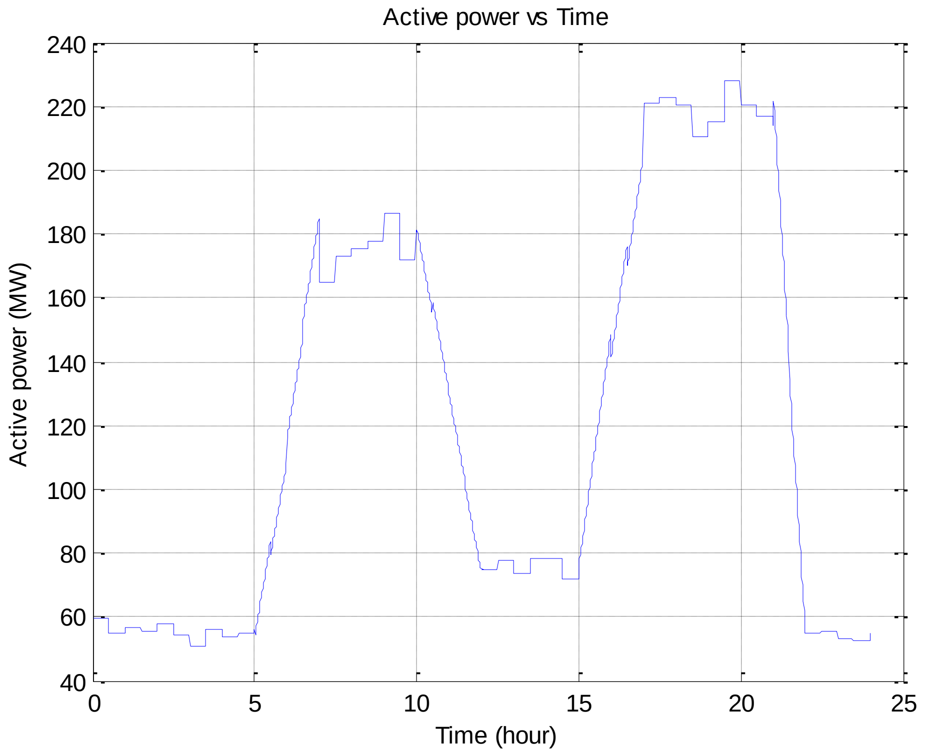

Fig. 57. Simulation example for a residential area. Active power.

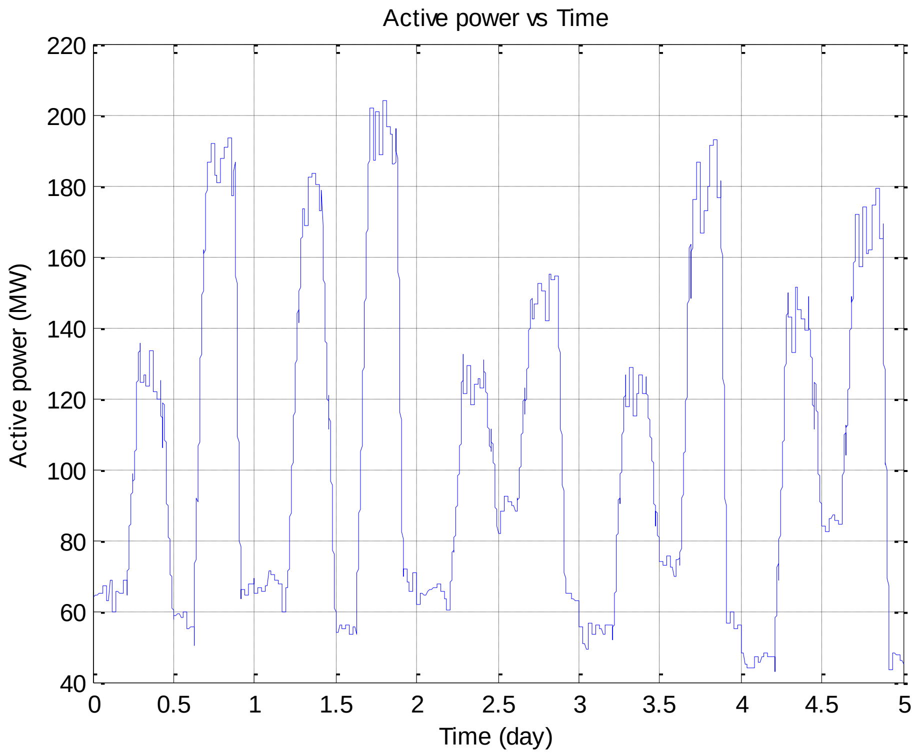

Fig. 58. Simulation example for a residential area. Active power.

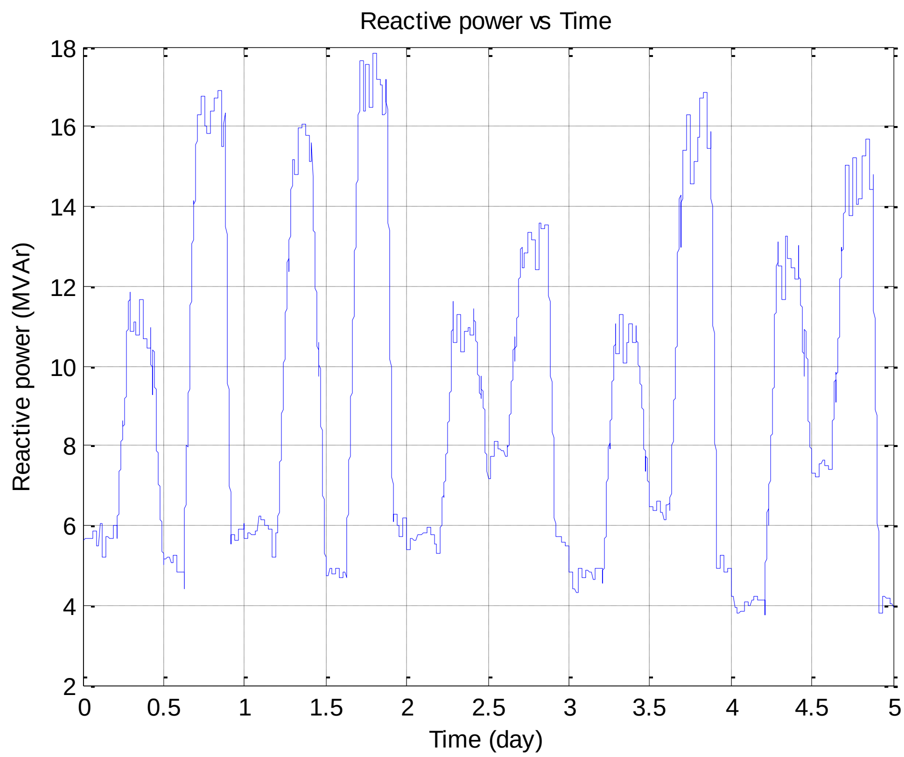

Fig. 59. Simulation example for a residential area. Reactive power.

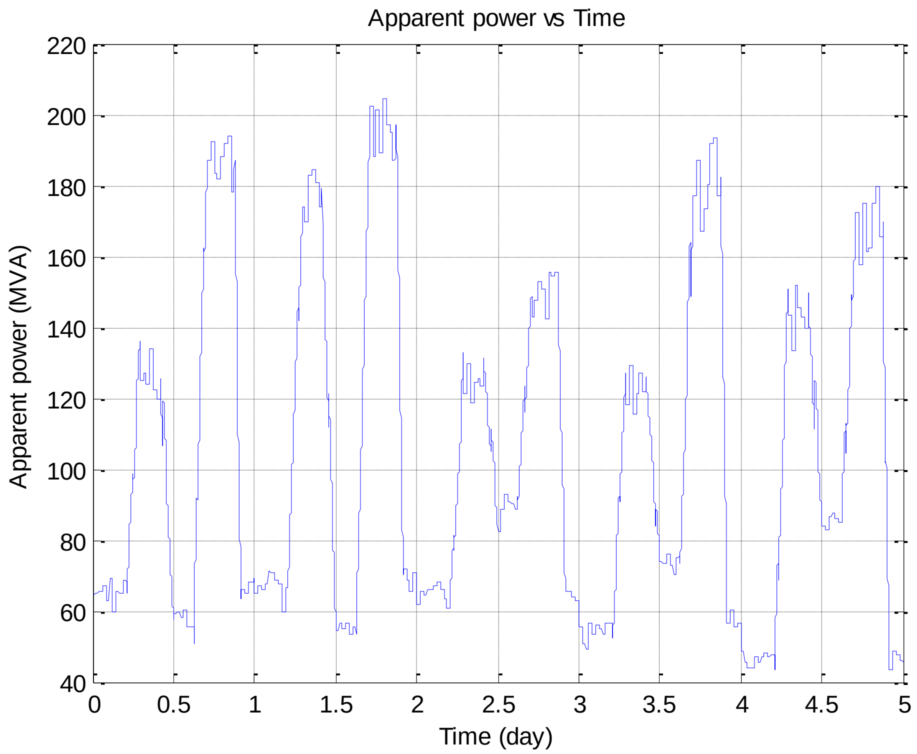

Fig. 60. Simulation example for a residential area. Apparent power.

8 STATISTICAL MODEL FOR A MIX OF INDUSTRIES, COMMERCIALLY CENTER AND RESIDENTIAL

Fig. 61 shows an area consisting of 4 industrial complexes, 1 commercially center and 12 residential complexes.

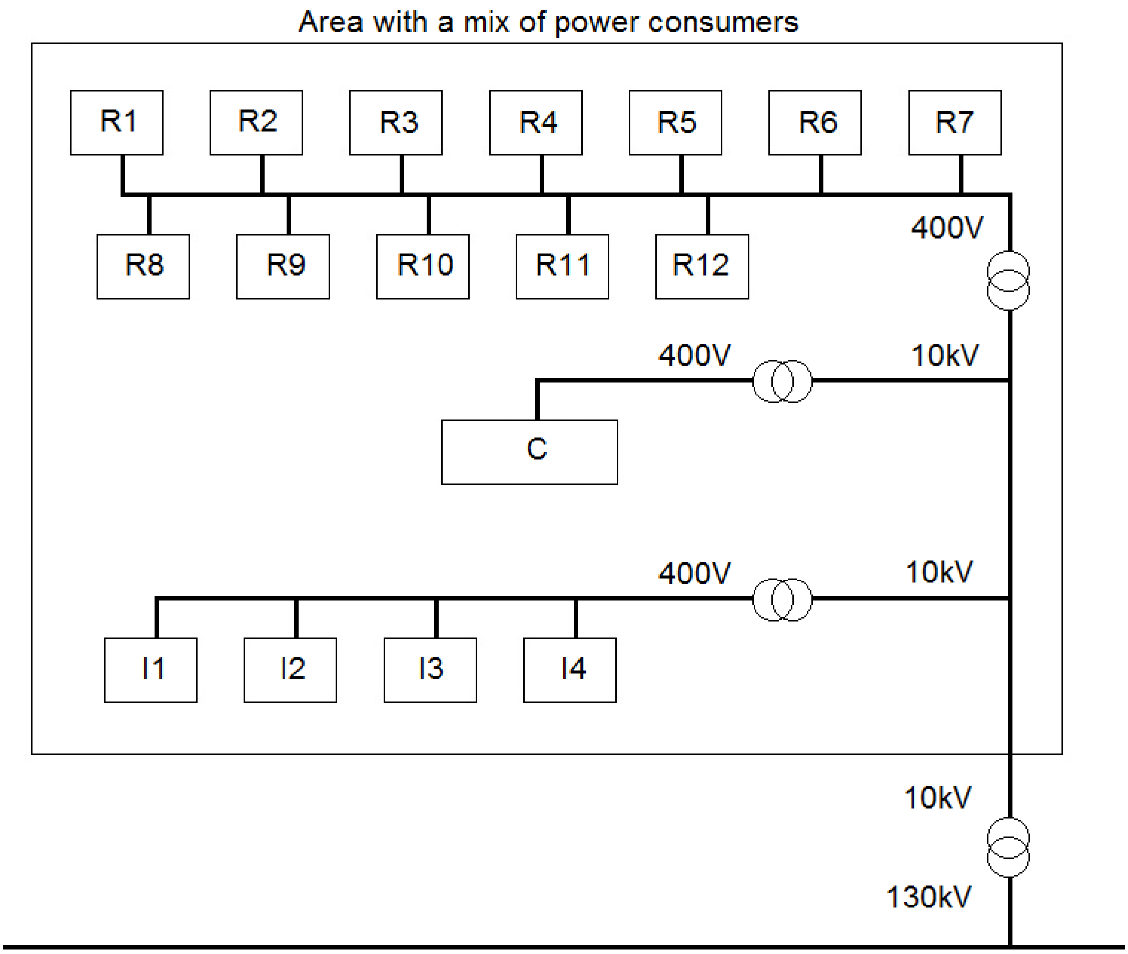

Fig. 61. An area with a mix of power consumers.

Abbreviations in Fig. 61 are according to:

- I1 – I4: 4 industrial complexes
- C: Commercially center
- R1 –R12: 12 residential complexes

A simulation is done with following assumptions:

<u>Model for industrial area</u>

- As in section 5 with total (all complexes) annual power consumption: 1 GWh
- Phase angle, time 06 - 21 (day time): +40°
- Phase angle, time 21 – 06 (night time): + 5°

<u>Model for commercially center</u>

As in section 6 with annual power consumption 0.5 GWh and a phase angle of - 5°.

<u>Model for residential area.</u>

As in section 7.2 with annual power consumption 2 GWh and a phase angle of + 5°.

The output result is related to total power consumption of all consumers. This corresponds to the connection point at the 130 kV-line in Fig. 61.

The simulation result for 10 days is illustrated in Fig. 62 - Fig. 64.

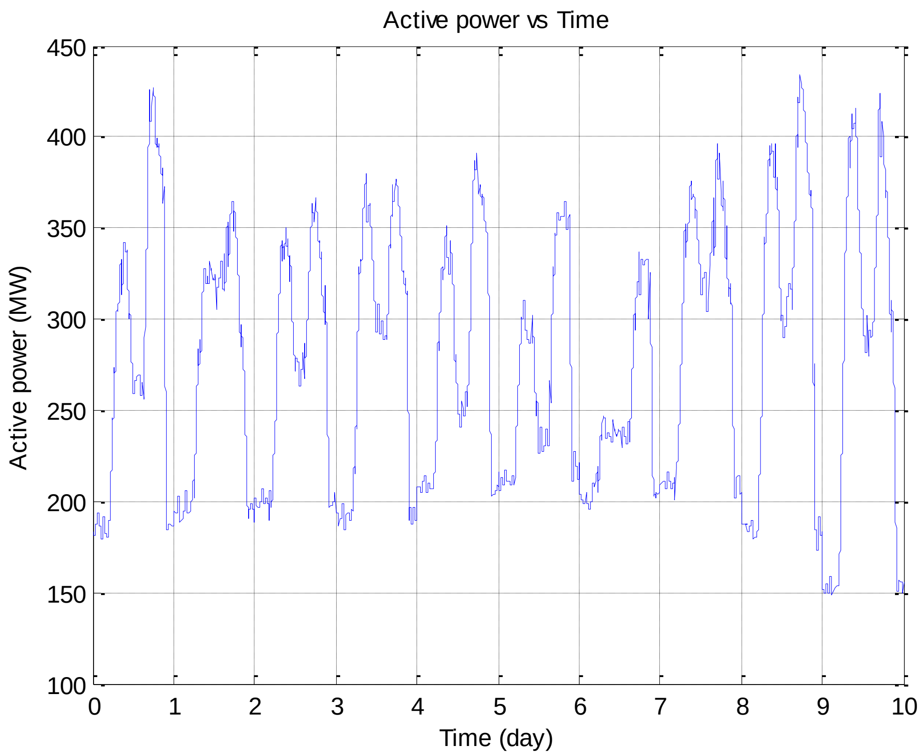

Fig. 62.   Simulated active power consumption during 10 days for the area of mixed power consumers.

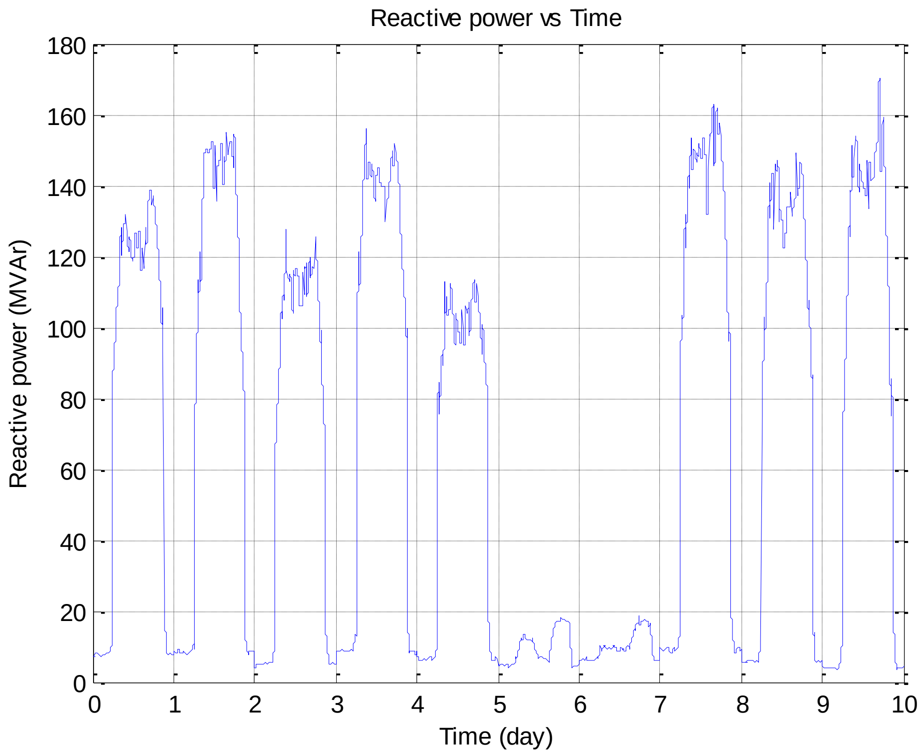

Fig. 63. Simulated reactive power consumption during 10 days for the area of mixed power consumers.

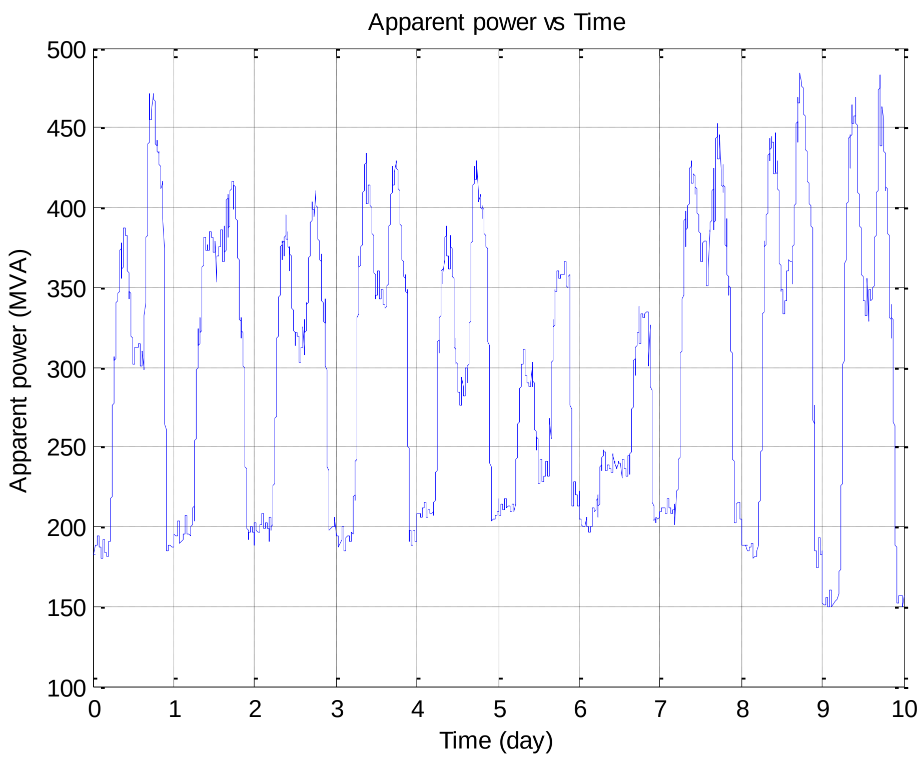

Fig. 64. Simulated apparent power consumption during 10 days for the area of mixed power consumers.

9 FUTURE WORK

The presented model proposals are based on analysis of an object, with quite small electric energy consumption (about 1.3 GWh/year) and during a relatively short time period. To broaden the base of statistics, it would be valuable to collect in and analyze more measure results. Here is some measurement objects of interest.

- Larger industrial areas
- Residential areas during different times of the year. With and without electric heating
- Commercial centers

A future measurement campaign should focus on both active and reactive power consumption.

10 REFERENCES

[1] Ingemar Mathiasson. “Stochastic modeling of an Electrical Load. A Region of different Companies”. Chalmers University of Technology, 2007.