Applied Data Analysis in Energy Monitoring System

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Abstract. Software and hardware system organization is presented as an example for building energy monitoring of multi-sectional lighting and climate control / conditioning needs. System key feature is applied office energy data analysis that allows to provide each type of hardware localized work mode recognition. It is based on general energy consumption profile with following energy consumption and workload evaluation. Applied data analysis includes primary data processing block, smoothing filter, time stamp identification block, clusterization and classification blocks, state change detection block, statistical data calculation block. Time slot consumed energy value and slot time stamp are taken as work mode classification main parameters. Energy data applied analysis with HIL and OpenJEVis visualization system usage experimental research results for chosen time period has been provided. Energy consumption, workload calculation and eight different states identification has been executed for two lighting sections and one climate control / conditioning emulating system by integral energy consumption profile. Research has been supported by university internal grant №2016/PI-2 «Methodology development of monitoring and heat flow utilization as low potential company energy sources».
***Keywords*:** energy data, energy monitoring, energy data visualization, applied data analysis, pattern recognition, OpenJEVis, Janitza.

Analiză aplicativă a datelor în sistemul de energomonitorizare

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Rezumat. Se studiază un exemplu de organizare software şi hardware a sistemului de monitorizare a consumului de energie electrică în oficii la necesități de iluminat multi-secțional şi de sistemul de climatizare/ventilare. Particularitatea siustemului constă în analiza aplicativă a datelor oficiului, ce permite recunoaşterea regimurilor localizate de funcționare a fiecărui tip de utilaj în baza profilului energetic consolidat cu estimarea ulterioară a consumului de energie şi evoluții. Analiza aplicativă a datelor cu caracter energetic include blocul de prelucrare primară, filtru trece jos, blocul de identificare a mărcii intervalului de timp, blocurile de clasterizare şi de clasificare a datelor, blocul de estimare a consumului netipic, blocul de calcul al consumului netipic, blocul de calcul al indicilor statistice de funcționare în clase şi blocul de calcul al consumului de energie. În calitate de paramentri de bază a clasificării regimului de funcționare sunt utilizate valorile de energie consumată pentru un anumit interval de timp şi marca de timp a slotului. Se oferă estimarea rezultatelor cercetărilor experimentale ale analizei aplicative a datelor cu utilizarea echipamentului pentru modelarea seminaturală şi a sistemului de vizualizare OpenJEVis pentru perioada aleasă de observări. Pentru două secții de iluminat studiate şi a unei instalații, care imitează sistemul de dirijare a ventilației, utilizând curba de sarcină integrală a fost efectuată identificarea de opt stări posibile de punere în funcțiune, a fost calculat consumul de energie şi evoluția. Lucrarea a fost efectuată cu suportul grantului Universității PNIPU №2016/PI-2 «Elaborararea metodologiei de monitorizare şi utilizare a fluxurilor termice, ca resursului de potențial termic scăzut al intreprinderii».
***Cuvinte-cheie*:** datele de consum de energie, monitorizare energetică, vizualizarea datelor, analiza aplicativă a datelor, recunoaşterea imaginilor, OpenJEVis, Janitza.

Прикладной анализ данных в системе энергомониторинга

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Аннотация. Рассматривается пример программно-аппаратной организации системы мониторинга потребления электрической энергии офисными помещениями на нужды многосекционного освещения и управления климатом/вентиляцией. Особенностью системы является прикладной анализ энергетических данных офиса, позволяющий произвести распознавание локализованных режимов работы каждого типа оборудования на основе сводного энергетического профиля с последующей оценкой энергопотребления и наработки. Прикладной анализ энергоданных включает блок первичной обработки, сглаживающий

фильтр, блок идентификации временной метки, блоки кластеризации и классификации данных, блок оценки нетипичного потребления, блок расчета статистических показателей наработки в классах и энергопотребления. В качестве основных параметров классификации режима работы использованы величины затраченной электроэнергии за один временной слот и временная метка слота. Приводится оценка результатов экспериментальных исследований прикладного анализа энергоданных с использованием оборудования для полунатурного моделирования и системы визуализации OpenJEVis за выбранный период наблюдения. Для исследуемых двух секций освещения и одной установки, имитирующей систему управления вентиляцией, по интегральному профилю нагрузки проведена идентификация восьми возможных состояний включения, проведен расчет энергопотребления и наработки. Работа выполнена при поддержке внутривузовского гранта ПНИПУ №2016/ПИ-2 «Разработка методологии мониторинга и утилизации тепловых потоков, как низкопотенциального ресурса предприятия».
Ключевые слова: энергоданные, энергетический мониторинг, визуализация энергоданных, прикладной анализ данных, распознавание образов, OpenJEVis, Janitza.

Introduction

Energy monitoring systems (EMS) are widely used in manufacturing, housing, transport, and other spheres in order to automate data acquisition, transmission, storage and analysis, energy loss estimation.

Building energy management system potential is in possibility of main consumers groups pattern recognition, such as lighting and climate control/conditioning systems [1].

The main component of building EMS is data analysis system (DAS), which is implemented on the «client-server» architecture with usage of available information analysis platforms. Mathematical module of DAS is usually presented by fixed set of standard statistical functions, which are used by energy services staff.

Lighting system separate sections workload evaluation task is being solved rarely. This caused by irregular exploitation of separate sections by staff. Such sections usage irregularity caused by change of sunlight fall direction during the day and human factor. Moreover, climate control/conditioning management system can be interesting for current research among other office consumers. Thus, for specified groups of consumers recognition implementation DAS functionality should be expanded for complex automated energy data consumption analysis implementation, of decision making on energy consumption performance increasing [2]. This could be achieved by adding new analytical blocks for classifying and clustering [3, 4].

1. Methodology

The main objective of the research is to create DAS analytical apparatus for office buildings aimed at numerical values obtaining, statistics calculation and additional information forming on lighting and climate control/conditioning system energy consumption of single consumer or group of consumers detected by general consumption profile [5].

Common office energy data can be characterized by the following set:

$$P = \begin{Bmatrix} P_1 \\ P_2 \\ \ldots \\ P_n \end{Bmatrix} = \begin{Bmatrix} p_{11} \; p_{12} \\ p_{21} \; p_{22} \\ \ldots \; \ldots \\ p_{n1} \; p_{n2} \end{Bmatrix}$$ – set of energy data points, $P_i = \{p_{i1} \; p_{i2}\}$,

where, n – number of measures, p_{i1} – time stamp (time values ranged from 0:00 to 23:45 with 15 minutes step, $p_{i1} \in \{1..96\}$), p_{i2} – energy consumption for period i.

The main tasks of DAS are to identify monitoring consumer workload states, and to assign appropriate class for each energy data value:

$S = \{S_1, S_2, ..., S_n\}$ – full set of lighting and climate control/conditioning work modes,

$S_i \to K_j, j = 1..k$,

$K = \{K_1, K_2, ..., K_k\}$ – reduced work modes set,

where k – typical work modes combinations number.

The implementation of the tasks mentioned above is provided by following DAS functions [6,7]:

– primary data processing: filtering and smoothing for state change detection;
– time stamps definition, clusterization and classification;
– statistical parameters calculation for result evaluation.

DAS functioning algorithm is shown at Figure 3.

Initially, lighting and climate control/conditioning system energy data is being filtered (F_1) by threshold criteria (Eq. 1). This step is needed to exclude errors of measuring, reading, recording, CRC etc. Further, filtered data x_i goes to the other units of DAS for the analysis.

$$F_1:\ x_{\min} \le x_i \le x_{\max} \quad (1)$$

where x_i – filtered energy data point, x_{min} and x_{max} – system defined minimal and maximal values.

Data smoothing (F_2) is implemented by the moving average method (Eq. 2) as having a low number of smoothing points results in the graph with the closest form to the original one. On the contrary, large number of smoothing points heavily distorts the form of the graph [8].

$$F_2:\ xs_i = \frac{1}{2N+1}\sum_{k=-N}^{N} x_{i+k} \quad (2)$$

where 2N+1 – the number of smoothing energy data points, xs_i – is smoothed energy data point.

State change (F_3) of monitored system (for instance, change of working energy consumers combination) is detected by smoothed and filtered data comparing (Eq. 3). Received data used for classification accuracy evaluation and work mode of lighting and climate control/conditioning system definition [9, 10].

$$F_3:\ \Delta x_i = x_i - xs_i \quad (3)$$

Time stamps definition block (F_4) converts time into numerical value (Eq. 4). Time values ranged from 0:00 to 23:45 with 15 minutes step (96 values per day) [11, 12].

$$F_4:\ t_i = getTime(x_i),\ t_i \in \{1..96\} \quad (4)$$

Clusterization (F_5) is carried out according to the k-means method (Eq. 6). Number of required lighting and climate control/conditioning system work mode clusters is determined by Eq. 5. K-means aimed to minimize standard deviation of cluster points from cluster centroids:

$$k = 2^m \quad (5)$$

$$F_5:\ V = \sum_{j=1}^{k}\sum_{x_i \in S_j}(x_i - c_j)^2 \to \min \quad (6)$$

where m – number of real consumers, V – standard deviation, k – is the number of lighting and climate control/conditioning system working combinations, S_j – cluster j, c_j – is centroid of $x_i \in S_j$ [13].

Consumers classification (F_6) is carried out on the basis of clusterization (Eq. 7). Figure 4 shows obtaining and visualization of information on energy consumption.

Total consumption is determined by the consumption of particular consumers $E = \sum_{j=1}^{n} E_j$. Every work mode consumer class f_j can be represented through the simplified model in the following way:

$$F_6:\ f_j = \begin{cases} 0, t_2 < t < t_1 \\ c_j, t_1 \le t \le t_2 \end{cases} \quad (7)$$

where c_j – is amount of energy consumption (centre of cluster). Time intervals t_1 and t_2 are determined by values of cluster edge elements.

Statistical data calculation block (F_7) required for object workload computation for different lighting and climate control/conditioning system work modes (Eq. 8).

$$F_7:\ wl_j = \frac{15 \cdot \sum_{i=1}^{n} \frac{t_i}{t_i}}{t_{total}} 100\% \quad (8)$$

where $t_i : x_i \subset S_j$, t_{total} – duration of analyzed period in minutes.

Result evaluation block (F_7) compares results of consumers classification (F_6) and state change detection (F_3) and provides percentage of accuracy. Moreover it calculates total worktime (Eq. 9) and consumption (Eq. 10) for every lighting and climate control/conditioning system work mode [14].

$$F_8\text{: } twt_j = 15 \cdot \sum_{i=1}^{n} \frac{t_i}{t_i} \quad (9)$$

$$F_8\text{: } tc_j = 15 \cdot \sum_{i=1}^{n} \frac{t_i}{t_i} x_i \quad (10)$$

2. Technology description

The developed EMS has two levels: first level – data collection, second level – data processing and storage. Its block diagram is shown at Figure 5.

EMS hardware is based on power analysers UMG104 and UMG604 by Janitza electronics GmbH. These devices are used for reading data and transmitting it to the server. Their main characteristics are shown in Table I.

Table I. Power analysers characteristics

Parameter	UMG 104	UMG 604
4 inputs for measurement current &voltage	+	+
RS-485& RS-232 interfaces	+	+
Ethernet port	–	+
Built-in memory	4 Mb	128 Mb
web interface	–	+
Modbus master	–	+

Software of EMS includes 2 software products:

- GridVis – used for remote setting of power analysers and data processing for transmitting it to storage server [15].
- OpenJEVis – basis of EMS software. It consists of various open source program units. This software supports plug-in system, which allows to expand its abilities. Moreover, it has wide integration capabilities and compatibility with other program products [16, 17].

EMS analytical functionality is provided by its integration with complex mathematical software such as MATLAB or Octave via OpenJEVis plug-in system [18, 19, 20].

3. Results

Experimental research was carried out in the typical office using 2 sectional lighting and laboratory equipment for climate control / conditioning (CC/C) HIL simulation [4]. Research was provided with hardware which is shown on Figures 1 and 2 by exporting the office energy data to EMS within the period from 20.11.2015 to 20.12.2015.

Lighting and climate control/ conditioning system energy consumption are presented as a graph of the open source energy visualization tool – OpenJEVis at Figure 6. Filtered total energy consumption (F_1) is presented by blue colour.

UMG 104 power analyser was used as a data collector, UMG 604 – as a protocol converter (Modbus RTU/Ethernet) and «data concentrator».

Fig 1. UMG 604 power analyzer (data concentrator) installed into climate/conditioning equipment HIL simulator

Fig 2. UMG 104 power analyzer (data collector) installed into lighting control panel

Office workload analysis parameters are shown in Table III. Maximum and average consumption values for the whole period: $P_{\max} = 2049{,}67 W \cdot h$, $P_{av} = 352{,}03 W \cdot h$.

Smoothed energy data (F_2) is shown on Figure 6 by green colour.

On the difference of original and smoothed graphs, state change graph has been obtained. Δx is used to detect consumers consumption modes and transitions between these modes. This is shown at Figure 7.

Current energy consumption mode can be recurrently (or cumulatively) defined. Transitions from higher consumption mode to lower can be identified by positive Δx value, from lower to higher – by negative Δx value. Insignificant Δx values ($\Delta x<100$) means consumption changes inside current consumption mode.

State change detection result was used for classification accuracy checking and confirmation.

After time stamps definition for each data point, clusterization and classification have been provided. All energy consumers in the office can be divided into three main groups, which can consist of some smaller consumers: lighting (70%), lighting (30%), climate control system (conditioning). Altogether there are $2^3=8$ possible combinations of these consumers switching. Hence, it is necessary to define eight classes and clusters. The results of the clusterization are shown at Figure 8. Time intervals are numbered from 1 to 96 per day (frequency of measuring was 15 min). Time intervals for each consumer can be determined on clusterization results.

Coordinates of cluster centroids are used in classification. Classification results are shown in Table II. For example, full lighting usage can be described by modes 7 and 8. All classes can be described by the following formula: $f_i = c_i, t_1 \le t \le t_2$.

Table II. Classification (F_6) of lighting and climate control / conditioning modes

Class	**Lighting 70%**	**Lighting 30%**	**CC / C**	**c_i, W·h**	**t_1**	**t_2**
1	0	0	0	4.7	0	96
2	0	0	1	246.1	31	82
3	0	1	0	433.6	35	80
4	0	1	1	704.9	33	90
5	1	0	0	1083.1	31	88
6	1	0	1	1235.7	38	91
7	1	1	0	1484.5	39	89
8	1	1	1	1706.1	42	66

Table III. Office workload (F_7) within the period from 20.11.2015 to 20.12.2015

Class	**Number of energy data points**	**Time, min.**	**Part of total time**	**Average consumption, W·h**	**Number of energy data points**	**Time, min.**	**Part of total time**	**Average consumption, W·h**
	All time (0:00-23:59)				***Working hours (8:00-20:00)***			
1	2156	32340	72.45%	4.76	689	10335	46.30%	5.03
2	24	360	0.81%	246.04	23	345	1.55%	250.76
3	25	375	0.84%	433.62	25	375	1.68%	433.62
4	62	930	2.08%	704.97	59	885	3.97%	700.25
5	142	2130	4.77%	1083.09	140	2100	9.41%	1083.99
6	77	1155	2.59%	1235.71	67	1005	4.50%	1238.18
7	473	7095	15.89%	1484.46	468	7020	31.45%	1484.38
8	17	255	0.57%	1706.01	17	255	1.14%	1706.01
Total	2976	44640	100.00%	-	1488	22320	100.00%	-
All lighting (3-8)	796	11940	26.75%	1299.81	776	11640	52.15%	1302.27
All CC/C (2,4,6,8)	180	2700	6.05%	965.36	166	2490	11.16%	958.09

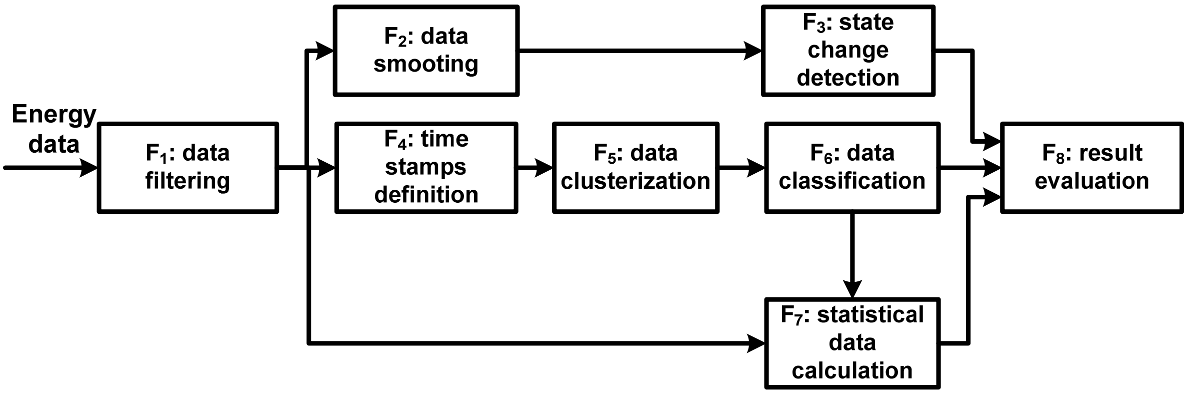

Fig 3. Workload calculation and states identification DAS algorithm

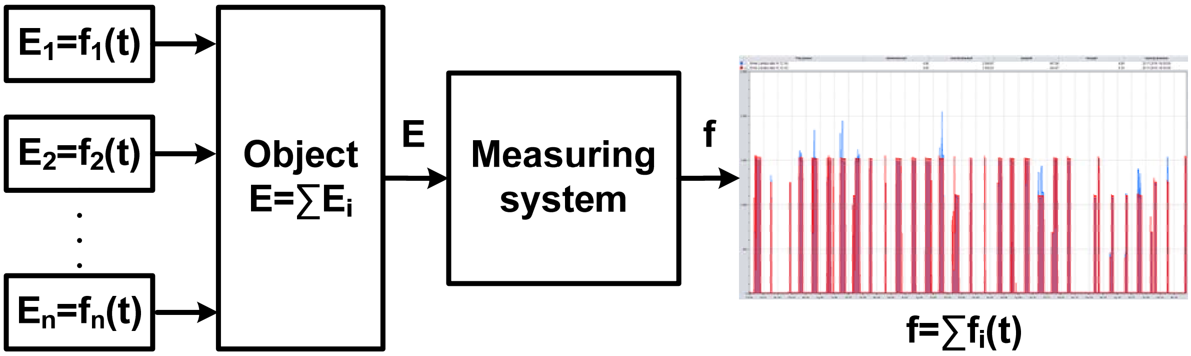

Fig 4. Obtaining and visualization of lighting and climate control/conditioning energy consumption

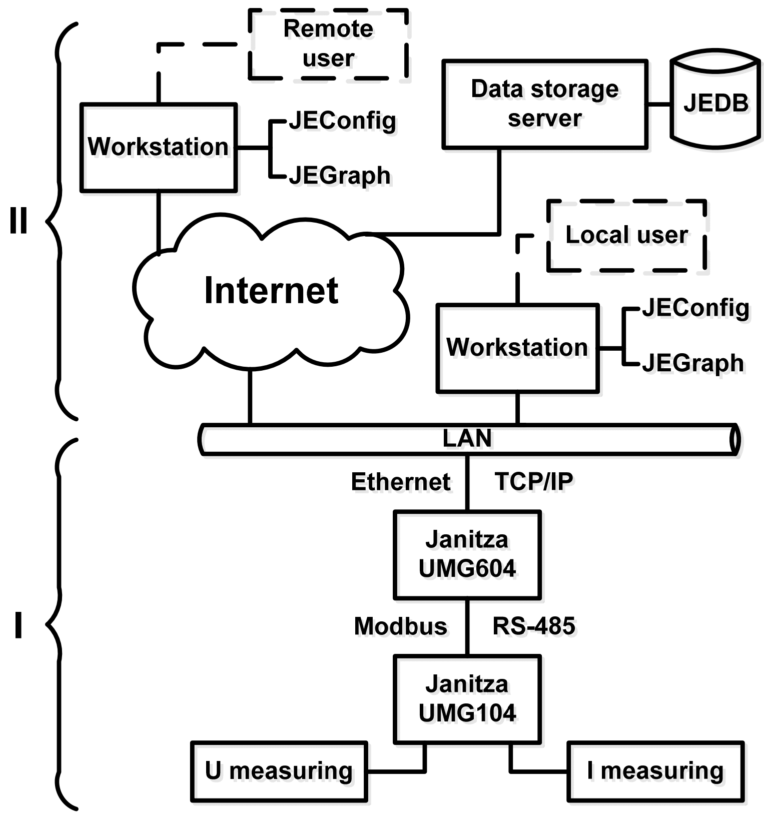

Fig 5. EMS structure based on the open source software

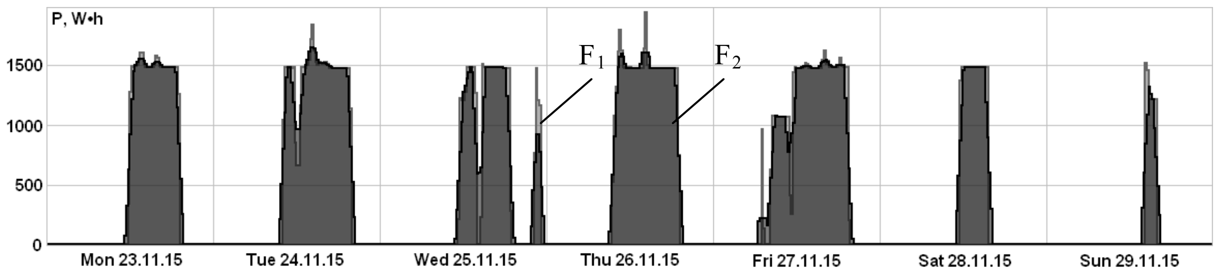

Fig 6. Filtered (F_1) office energy consumption data and smoothed (F_2) data for one week

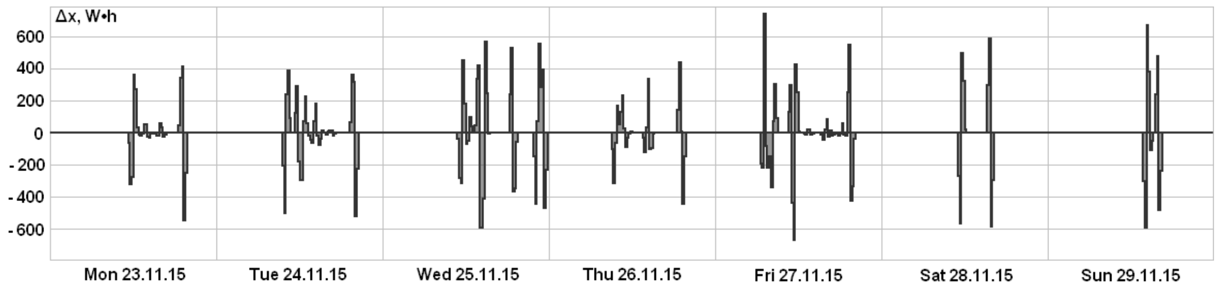

Fig 7. Difference (F_3) between filtered and smoothed energy data for one week

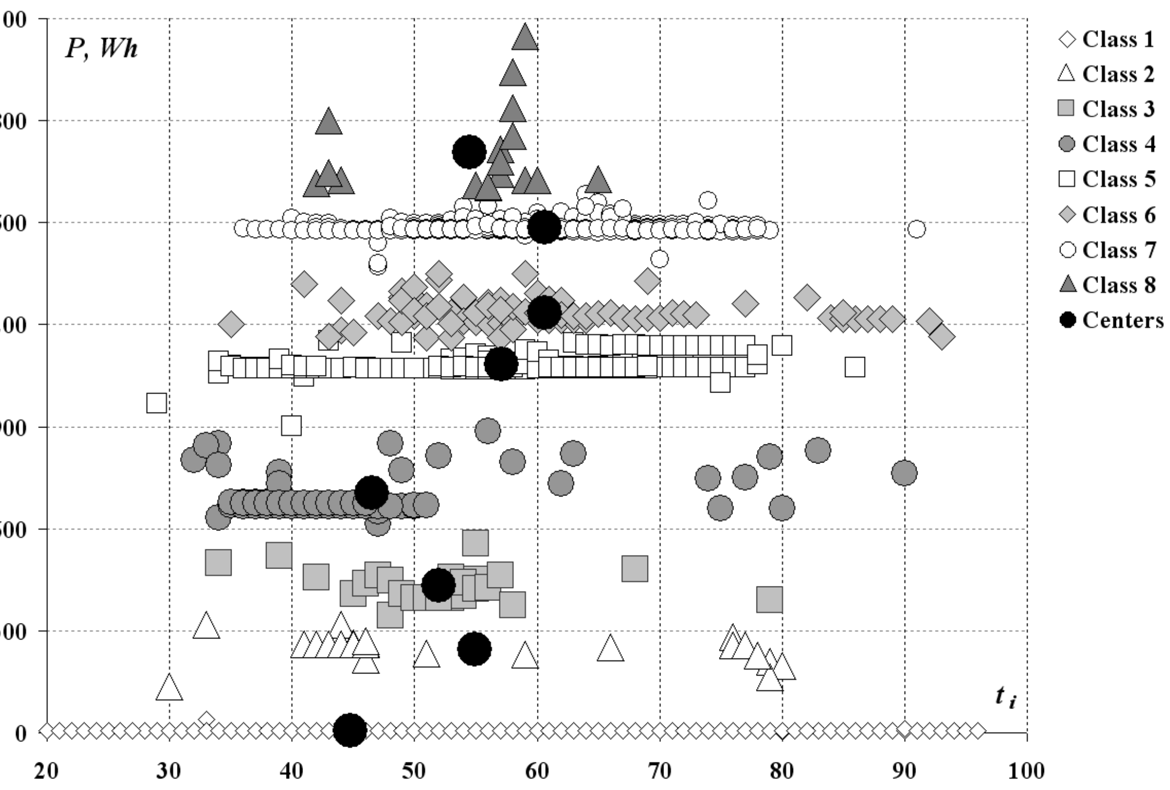

Fig 8. Results of data cluster analysis (F_5) which shows different lighting and climate control / conditioning energy consumption modes – classes 1..8 (see Table I) and their centers

Conclusion

The following results of this work have been obtained:

– the module structure and functioning principles of building energy monitoring DAS have been described. The lighting and climate control/conditioning system energy data applied analysis includes primary data processing: filtering and smoothing for state change detection, time stamps definition, clusterization and classification, statistical parameters calculation for result evaluation;

– DAS key feature is applied office energy data analysis that allows to provide each type of lighting and climate control/conditioning hardware work mode recognition. It based on general energy consumption profile with following energy consumption and workload evaluation;

– two-sectional lighting and climate control (conditioning) HIL model energy consumption within the period of one month has been analysed on practice. Total office workload during working time was 54.91%, lightning workload was 52.15%, climate control/conditioning – 11.16%.

– energy consumers were classified according to clusterization data to eight classes. Recognized average energy consumption during working time for lighting was 1302.27 W·h, for climate control/conditioning – 958.09 W·h.

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