

## Automation of data transfer and analysis of the effectiveness in the energy management of municipal institutions

A. Kharytonov

Donetsk national technical university

donetskant@yandex.ru

*A. Kharytonov "Automation of data transfer and analysis of the effectiveness in the energy management of municipal institutions". This article provides an overview of software products in the field of energy monitoring, considers the issues of creating an information system of monitoring of municipal facilities' energy efficiency in Donetsk and also describes the results of the system. Analysis of existing software was conducted and on this basis the information system for monitoring and evaluation of energy consumption for the buildings of public sector facilities has developed. Currently, this system is implemented in all schools in Donetsk. The developed information system makes it possible to prepare the generalized data on energy consumption, performs short-term and long-term predictions of it and provides information support in justifying energy saving measures.*

**Keywords:** Energy efficiency, automated system, monitoring, data collection, COM-technology, diagram "Energy-Temperature".

### Introduction

The Resolution of the Donetsk city council from 20.05.2008 № 19/14 "On the program for the implementation of energy saving measures in public sector facilities" approved a program for the implementation of energy saving measures, in which the primary role was assigned to the problem of heat supply, modernization of the objects of public sector through the introduction of energy-saving technologies and automation of metering of energy resources consumption in public sector facilities.

One of the goals of this program is to automate the accounting of energy resources consumption in public sector facilities, which is determined by the presence of automatic posts of monitoring of energy consumption and temperature regime in rooms, data transmission systems, centralized databases and software modules that allow to analyze incoming information and forecast energy consumption. Information basis of such a system is the database, which periodically fills in by monitoring entities and continuous data that is coming from automated posts. This paper focuses on the development of this system.

### Review of systems and software

In today's world there are plenty of software and hardware monitoring tools for control the consumption of energy resources.

All software tools for energy accounting can be divided into two main groups – programs for personal computers and Internet services. Each group has its own advantages and disadvantages.

Some versions of the software for the personal computer can be connected with the server

(multi-user programs FASER, METRIX). These programs are useful for companies that occupy a large area, as well as for government and municipal organizations. For use of Internet services for energy accounting (Energy Watchdog, EnergyTrax, ENSI) permanent Internet connection is required.

Most programs take into account the energy resources and constitute reports (Utility Manager [10], [11], METRIX [10], Stark Essentials [10] and others), however, some of them also allow to carry out the analysis (FASER, ENSI, etc.). Kind of analysis depends on the task and can be very different. For example, while the Energy Watchdog and EnergyTrax perform comparative analysis of consumption, the METRIX has the ability to analyze the data using multivariate linear regression. The program FASER analyzes the correlation of daily temperature and the product ENSI constructs the diagram "energy-temperature". More detailed overview is presented in table 1.

### Statement of the problem

All of the programs mentioned above can be divided into three groups depending on the data exchange procedure:

- exchange data via the web-interface (Energy Watchdog, EnergyTrax, ENSI);
- exchange data manually via the data files (Energy plan);
- without exchange data (METRIX, FASER).

While creating an automated system of the energy resources consumption accounting of Donetsk public sector, the following requirements were taken in mind:

- collection should have been fully

Table 1. – Systems and software overview

Name of the program	Country	Decision making support	platform	Types of analysis	Price
Utility Manager	USA	no	DBMS Microsoft Access	no	\$ 2500
METRIX	USA	A budget setting and consumption limits	Application Software	Multivariate linear regression	\$4,995.00.
FASER	USA	A budget formation	Application Software	Analysis of the correlation of daily temperature	\$3995
Stark Essentials Level 1	United Kingdom	Budget formation and forecasting of funds movement	Application Software	No data	No data
EZ Sim	USA	Prediction of utility bills, setting the number of indicators, during the energy-saving measures	DB Microsoft Excel	The use of utility bills for resource consumption modeling	\$299
Energy Watchdog	USA	no	WEB-Interface	Comparative analysis of consumption	Depends on the number of objects
EnergyTrax	USA	no	WEB-Interface	Data comparison	\$ 700 for 1 object
ENSI	Norway	no	WEB-Interface	ET-diagram	No data
Energy plan	Ukraine	no	Application Software	no	250 000 UAH

automatic, because of the large number of monitoring objects;

- there is no Internet connection in all public sector facilities; so transfer of data should not depend on the time.

To solve this problem, the information model was created and implemented.

### ***The design and implementation of the information model***

Information model of automation of data transfer is presented in Figure 1. It is assumed that schools in Donetsk are equipped with meters and thermometers and readings are taken regularly from sensors in automatic or manual mode. After that indications are transmitted via the Internet and appear in the database system.

The information model that is proposed above is implemented as follows (Figure 2).

The operator takes readings from sensors (manual mode) and stores them in the local database file MS Access. The file is archived and sent by email to the address dedicated for considered purposes. The operator of the server-side software and hardware complex periodically initiates the MS Access macro to automatically receiving and processing files from all municipal facilities, with the addition of the information contained therein to the database system.

The macro runs MS Outlook through the COM technology and scans emails in "Inbox".

For each message that is not processed yet, the theme of which meets the specified criteria, the viewing of all its files is performed. Each attachment must be an «mdb» file format with the taken over time readings or file of a «rar» format where an «mdb» file is packed.

If it matches attachments, the following actions are performed. At the command of the MS Access macro (1) MS Outlook application saves a file's attachments to a temporary directory A (2). The same macro runs specially designed Java application (3) for processing the stored attachments. If the file is a «rar» archive format, a Java application launches Rar archive program (4) to unpack the archive into a temporary directory in (5). Unpacking to a separate directory is needed for an «mdb» file name to be arbitrary (minimizing the human factor) and handling the situation of the content of multiple files in the archive. The correct file «mdb» from the unpacked archive is moved to a temporary directory C (6). Indications of it are added into the main database by another MS Access macro (7).

### ***The design and implementation of the mathematical model of analysis of energy consumption***

The main tool of energy monitoring system - diagram "Energy-Temperature"; ET – diagram (ET-curve).

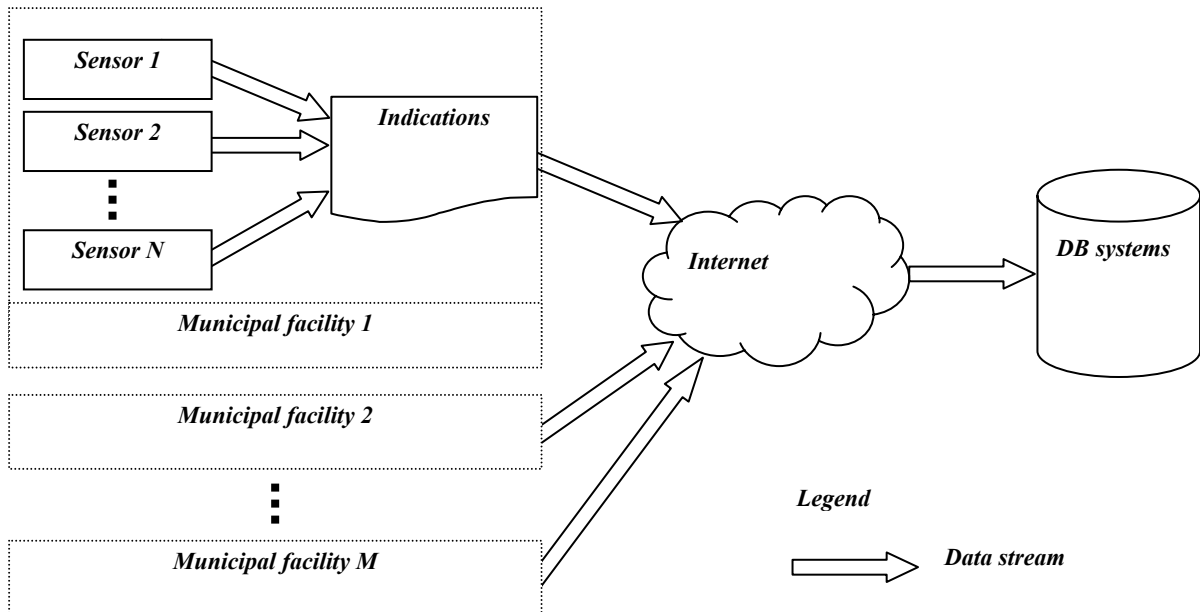


Figure 1. – Information model of automation of data transfer

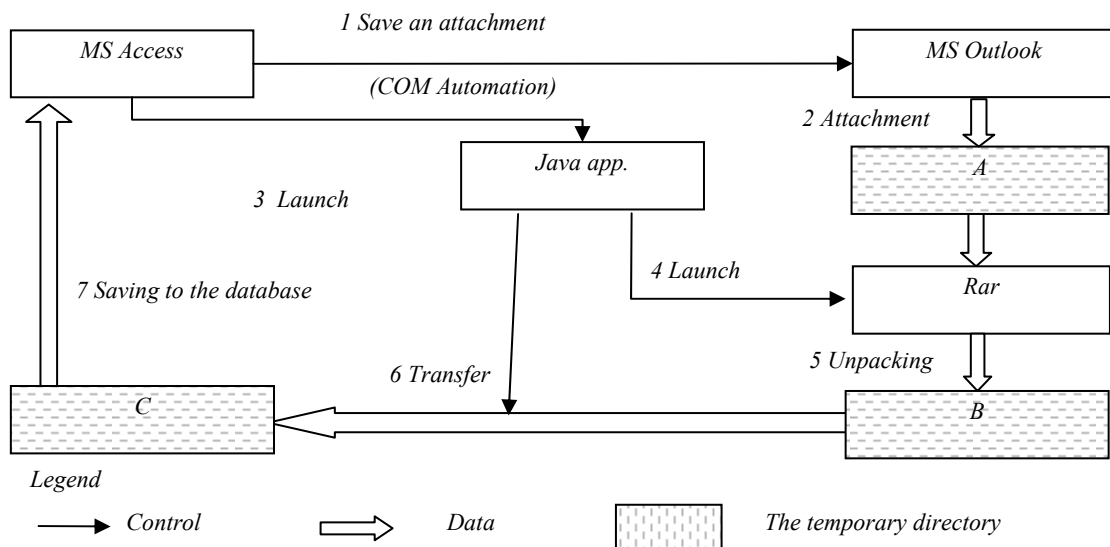


Figure 2. – One iteration of processing an email

The horizontal axis represents the “average outdoor temperature” (air) for [° C], and the vertical axis – the “Energy consumption” in the heated area [giga-calorie].

ET-diagram shows the recorded energy consumption and outer temperature during the day. The constructed line as a result of measurements is called “ET-curve”.

During the heating period, the power consumption increases with decreasing of outdoor temperature. By increasing the outdoor temperature energy consumption is reduced, approaching the minimum level, which corresponds to the absence of heating. Each building has a unique (unique) ET-curve. In order to construct the ET-curve for the building, information about outdoor temperature and heat consumption is required.

Besides the actual ET-diagram for analysis of energy efficiency of building heat load the calculated ET-diagram, which is constructed on the basis of the heat balance of the building is used. This is expressed by the following equations:

$$Q_1 = q_v \cdot V_b \cdot (t_{in} - t_{out}), \quad (1)$$

where  $Q_1$  – heat flow that is lost in the building to environment kW (Mcal/h);  $q_v$  – the specific heating characteristics of the building, W/(m<sup>3</sup>·K);  $V_b$  – volume of the building on the outside measurements, m<sup>3</sup>.

Compensation for these losses is carried out by supplying thermal energy from the heating network:

$$Q_2 = m_v \cdot c \cdot (\tau_1 - \tau_2), \quad (2)$$

where  $m_v$  – consumption of water in heating network, t/h(kg/s),  $c$  – water heat capacity, kJ/kg·K (operating temperature range varies slightly and can be assumed to be 4.19 kJ/kg·K).

To transfer heat inside the building the special devices (radiators, convectors) are used. Heat transferred by the radiators, determined by the expression:

$$Q_3 = k \cdot F \cdot \Delta t, \quad (3)$$

where  $k$  – average heat transfer coefficient from the water circulating in the heating devices to the air in the rooms, W/(m<sup>2</sup>·K) or kcal/(h·m<sup>2</sup>·K);  $F$  – heat exchange surface area of heating appliances installed in the building, m<sup>2</sup>;  $\Delta t$  – the average value of the logarithm of the thermal pressure between the heaters and air in the rooms.

In the stationary regime, in the absence of internal sources of heat, rooms are warmed by solar insolation, etc.:

$$Q_1 = Q_2 = Q_3. \quad (4)$$

The thermal counter records the heat, which is transferred from radiator in view of the heat transmitted from the pipes of inner heating circuit (and it can also be taken into account in formula (4)). By this reason for any regime

$$Q_2 = Q_3. \quad (5)$$

Thus, by determining experimentally the average temperature inside of the building in the absence of internal heat (best suited nighttime when there is no rain and strong wind), the temperature pressure from a heating system of the building can be found. Taking into account (5) the value of the complex is calculated:

$$k \cdot F = \frac{Q_2}{\Delta t_{cp}}. \quad (6)$$

Then the actual parameter  $\Phi_o$  of the heating system (which determines the heat output of the heating systems) is described by the correlation [2]:

$$\Phi_o = k \cdot F \cdot \left( \frac{t_{in} - t_o^p}{t_{in} - t_{out}} \right)^{0.2}. \quad (7)$$

The internal heating circuit must be in good state (washed, repaired, space heaters should not be cluttered up etc., they have to be in condition of normal operation). In this case,  $\Phi_o$  is constant for each regime, and at any temperature condition. Reduction of this characteristic will indicate the clogging of heating appliances and the need for its inspection and cleaning.

Internal heat in a building with a certain degree of accuracy can be determined by the following formula:

$$\Delta Q_{ms} = q_v \cdot V_b \cdot (t_{in} - t'_{in}), \quad (8)$$

where  $t'_{in}$  – the average indoor temperature which is created by a heating system without internal heat sources.

The product  $q_v \cdot V$  is the heating curve of the building. This characteristic is defined as:

$$q_v \cdot V_{in} = \frac{Q_2}{(t'_{in} - t_{out})}, \quad (9)$$

and should remain a constant in the stationary regime of heating. Changing of this parameter will indicate a change of the thermal resistance of the building structure and can be the result of the strong winds, fences wetting etc. However, the heating characteristics of the building, calculated only on the basis of the heat meter, usually have a significant range of values. For this reason its actual value can be found as the average over the entire heating season.

Based on the heating characteristic of the building the estimated heating load can be determined, which serves as the basis for the formation of the estimated ET-diagram:

$$Q'_o = q_v \cdot V_b \cdot (t_{in} - t_{out}^p). \quad (10)$$

### **The result of an information system. Analysis of heat**

As an illustration we consider the operation of the information system by analyzing the effectiveness of heat consumption in schools of Voroshilov district of Donetsk.

For the analysis of heat consumption 4 characteristics are used:

1. The actual consumption of school;
2. Consumption rate for the year in accordance with government standard;
3. The amount of heat per year at their calculated ET-diagram;
4. The amount of heat per year according to the actual ET-diagram.

Consider these characteristics in detail.

1. The actual consumption of school according to data of paying organizations is taken from the accounts, which specify natural indicators.

2. Consumption rate according to Construction Rules and Regulations 2.04.07-86 “Heating networks” for a year is taken from the table “Consumption norms of heat for heating administrative buildings and structures in Gcal/(m<sup>3</sup> for year) for the heating period”. Consumption rate for the year by Construction Rules and Regulations, Gcal is presented in the resulting table.

3. The amount of heat per year estimated by ET diagram is determined on the basis of heat balance equations of building. For each scheme the linear trend is constructed. The resulting linear equations are shown in Table 2.

Since ET-diagrams are based on the hourly consumption of electricity and each point on the curve indicates the energy consumption per hour for a particular day there is a need to determine temporal characteristics of the heat consumption for the year.

Table 2. – Calculated and actual characteristics

School buildings	Approximating linear trend for the calculated ET-diagrams	Number of Gcal per year according to data of calculated ET-diagrams	Approximating linear trend for the actual ET-diagrams	Number of Gcal per year according to data of the actual ET-diagrams	Real data approximation error
School №3	$y = -4,1555x + 74,799$	323,2958	$y = -3,5983x + 86,658$	359,2589	0,0867
Gymnasium №15	$y = -5,3699x + 96,659$	407,6043	$y = -4,6512x + 92,592$	387,9623	0,5795
Gymnasium №18	$y = -4,2467x + 76,441$	322,3087	$y = -3,006x + 93,349$	382,4295	0,12
Educational complex KORN	$y = -4,9797x + 89,634$	377,916	$y = -2,5595x + 72,569$	298,5809	0,2226
Educational complex №5 (housing 1)	$y = -11,345x + 204,21$	861,14	$y = -6,2258x + 203,5$	830,4906	0,3007
Educational complex №5 (housing 2)	$y = -0,9646x + 17,364$	73,18349	$y = -0,7147x + 19,741$	81,3072	0,1409
School №9	$y = -12,172x + 219,09$	923,8896	$y = -7,0246x + 181,29$	749,0794	0,5622
Educational complex (housing 1)	$y = -4,2483x + 76,47$	322,4687	$y = -3,7015x + 67,381$	283,9294	0,6133
Educational complex (housing 2)	$y = -4,3902x + 79,023$	333,1939	$y = -5,0319x + 100,76$	422,0271	0,3842
Educational complex (housing 3)	$y = -3,3713x + 60,683$	255,8779	$y = -2,4804x + 94,84$	385,8311	0,0762
Lyceum №22	$y = -5,4563x + 98,213$	414,1259	$y = -4,394x + 102,63$	426,1713	0,6897
Educational complex №1 (housing 1)	$y = -0,6222x + 24,933$	101,2715	$y = -0,9302x + 32,166$	131,2846	0,244
Educational complex №1 (housing 2)	$y = -2,6257x + 65,105$	269,5021	$y = -1,4987x + 70,528$	285,1519	0,1321
Educational complex №1 (housing 3)	$y = -0,3104x + 16,698$	67,26147	$y = -0,6235x + 20,57$	84,09874	0,1961
School №13	$y = -4,305x + 77,49$	326,7449	$y = -3,9655x + 91,455$	379,4719	0,3562
DSPMS №17	$y = -6,8609x + 123,5$	520,7902	$y = -4,5761x + 111,23$	460,9417	0,3325
School №2	$y = -4,29x + 77,221$	325,5529	$y = -3,2738x + 102,08$	418,3226	0,72
School №14	$y = -5,6117x + 101,01$	425,944	$y = -4,0412x + 111,58$	459,6084	0,5172

Table 3. – Summary of indicators of consumption analysis, Gcal

	The fact according to RSA	Consumption rate for the year by Construction Rules	Gcal per year (calculated ET-diagram)	Gcal per year (real ET-diagram)
School №3	264,19	445,295	323,295804	359,25888
Gymnasium №15	328,26	252,7866	407,604334	387,9623
Gymnasium №18	328,07	451,60395	322,308672	382,429541
Educational complex KORN	329	230,1885	377,915976	298,580928
Educational complex №5	810,98	742,095	934,323444	911,797821
School №9	710,81	712,908	923,88961	749,079437
Educational complex	930	558,44138	911,540539	1091,78753
	481,92	1072,9224	414,125928	426,171259
Lyceum №22	628,6	712,057	438,035071	500,53524
Educational complex №1	347,43	1317,325	326,74488	379,47192
School №13	479,04	554,829	520,790199	460,941702
DSPMS №17	409,3	1817,92	325,552872	418,322616
School №2	425,13	1397,043	425,944008	459,608352

For this purpose it is necessary to know the number of heated hours in schools based on the basis of existing regulations.

ET-diagram is constructed by matching the energy consumed to ambient temperature. By this reason the average monthly temperature, according to the Hydrometeorological Center, must be used for calculations.

From the table 2 of equations by substituting  $x$  with the average temperature we obtain calculated amount of heat by ET-diagram. The calculated amount of heat in ET-diagram for each month is shown in Table 3.

4. The amount of heat per year based on the actual ET-diagram is constructed for verifying the correctness of the calculation methodology. The calculation is similar to the previous method, but the equations of the trend are built for real (measured) data. The result of the calculation of the characteristic is also presented in Table 3.

To determine the least energy-efficient schools we use 2 numerical characteristics derived from the analysis of ET-diagrams: size of reliability of data approximation of the actual ET-diagram and the difference between the real and the calculated ET-diagram as a percentage in relation to the actual ET diagram.

The value of reliability of (error) approximation calculates statistics for the range using the least squares method to calculate a straight line that is best at approximation of the data available (Table 2).

Approximation of data of the actual ET-diagram shows the imbalance of the heating system. Approximation coefficients for each building are presented in the table and the graph. The closer the reliability of approximation to 0, the higher the temporary imbalance of the system is. Temporary imbalance of the system manifests itself as follows: when there is a change of ambient temperature, the amount of heat supplied to school will not change quickly. As a result there is the delay, the mismatch of heat supplied to the current temperature.

Problems identified by the value of reliability of the approximation (approximation error) of the data of the actual ET-diagrams are the lack of timely regulation and system unbalance.

To analyze the operation of the heating system the difference between ET-diagrams, as a percentage relatively to the actual ET-diagram, is presented in Table 4.

This difference shows how much various buildings are in state of overheating or underheating. This does not include the previous measure of reliability of approximation. It means, that the system can be configured to respond to the ambient temperature, but not enough to give the necessary amount of heat According to the data provided by the heating networks, heat is supplied to all schools

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## Conclusion

Analysis of existing software was conducted and on this basis the information system for monitoring and evaluation of energy consumption for the buildings of public sector facilities has developed. Currently, this system is implemented in all schools in Donetsk.

The developed information system makes it possible to prepare the generalized data on energy consumption, performs short-term and long-term predictions of it and provides information support in justifying energy saving measures.

Table 4. – The error of approximation of the actual ET-diagram and the difference between ET diagrams

	The error of approximation of the actual ET-diagram	The difference between ET diagrams, as a percentage relatively to the actual ET-diagram
Educational complex (housing 3)	0,0762	33,68137
Educational complex №1 (housing 1)	0,244	22,86108
School №2	0,72	22,1766
Educational complex (housing 2)	0,3842	21,04916
Educational complex №1 (housing 3)	0,1961	20,02083
Gymnasium №18	0,12	15,72077
Educational complex №5 (housing 1)	0,3007	-3,69051
Gymnasium №15	0,5795	-5,06287
DSPMS №17	0,3325	-12,984
Educational complex (housing 1)	0,6133	-13,5736
School №9	0,5622	-23,3367
Educational complex KORN	0,2226	-26,5707

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**Ключові слова:** енергоефективність, автоматизована система, моніторингу, збір даних, СОМ-технологія, діаграма «Енергія-Температура».

*Харитонов А.Ю. «Автоматизация передачи данных и анализ энергоэффективности в распределенном программно-аппаратном комплексе энергоменеджмента муниципальных объектов». В статье представлен обзор программных продуктов в области мониторинга энергопотребления, рассматриваются вопросы создания информационной системы мониторинга энергоэффективности муниципальных объектов г. Донецка, а так же описываются результаты работы системы. На основе анализа программных продуктов в области анализа энергопотребления, а так же на основании поставленных задач разработано программное обеспечение, позволяющее непрерывно анализировать текущее состояние энергопотребления для зданий объектов бюджетной сферы. Данное программное обеспечение анализирует все школы г. Донецка.*

**Ключевые слова:** энергоэффективность, автоматизированная система, мониторинг, сбор данных, СОМ-технология, диаграмма «Энергия-Температура»

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