Hamburg University of Applied Sciences

Faculty of Life Sciences

Development of Standardized Methodologies for the Energy Efficiency Evaluation of Commercial Buildings

Bachelor Thesis

Umwelttechnik

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The Bachelor thesis was written in cooperation with the company Envidatec GmbH

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List of Abbreviations

BAS	Building Automation System
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
DIN	Deutsches Institut für Normung (German Institute for Standardization)
EE	Energy Efficiency
EnEV	Energieeinsparverordnung (Energy Saving Regulation)
EnPI	Energy Performance Indicator
GPEE	German-Polish Energy Efficiency Project
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
ISO	International Organization for Standardization

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1 Introduction

The necessity of the improvement of energy efficiency is increasing from year to year and has a worldwide importance. The simple definition of energy efficiency is "using less amount of energy to provide the same services".[1] Why the energy efficiency is so important? There are many reasons for that, but the most significant are the following ones: first of all, by saving energy the environment is being protected. It is evident as the efficient energy use means less usage of fossil fuels, which cause the carbon dioxide emissions, or usage of renewable energy sources, which is itself environmental friendly; then the efficient energy use can reduce energy costs, by implementation of different energy saving technologies for example. It is known that the most energy is consumed in industrial and transportation sector [2], but it should be mentioned, that the increase of energy efficiency is also very important for the building sector. There are too many buildings and their overall energy demand appears as a significant figure.

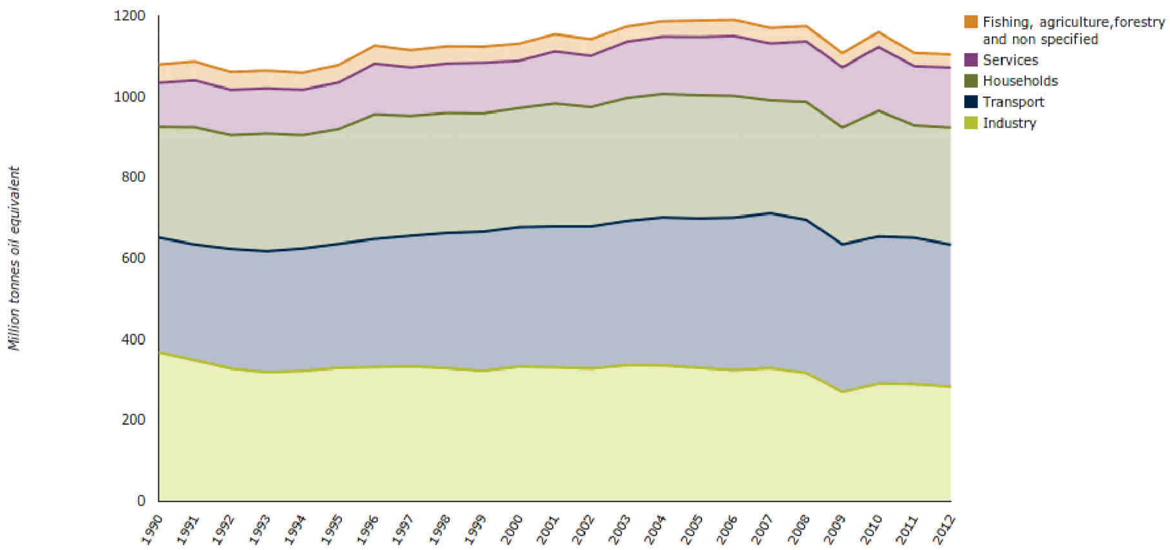

Figure 1: Final energy consumption by sector [2]

In order to find out the energy saving potentials of a building, and to implement the corresponding energy saving measures, first of all the energy efficiency evaluation should be initiated. Energy efficiency evaluation of a building means the whole analysis of its current energetic condition, its energy spread and energy consumption, detection of most energy losses and in conclusion the suggestions for efficient energy use related to energy saving potentials. Nowadays a lot of general methodologies for the energy efficiency evaluation of buildings exist. But by the evaluation described above some difficulties emerge, since there are too many different types of buildings and each of them has its own constructional and technical parameters. Developing individual methodology for each building causes a waste of time and money. Therefore the development of standardized methodologies, which can be applicable for defined type of buildings with more or less similar parameters, is important and must be quite profitable. The present thesis describes the development of standardized methodologies for the energy efficiency evaluation of commercial buildings.

The following thesis was written in cooperation with the company Envidatec GmbH. The company was founded in 2001 in Hamburg and provides wide range of energy services such as development of energy management and energy saving concepts, implementation of energy management systems according to the international accepted standard ISO 50001, conducting energy audits and implementation of energy monitoring systems. Besides, Envidatec GmbH has its own hardware and software products, which are used for energy monitoring and particular development of energy concepts. The company has many well known national and international partners and more than 250 successful projects in more than 20 countries worldwide. It was said above that the company provides energy services, and at the same time takes care of public energy awareness. Therefore the company provides also the non-material services like seminars and trainings with the aim of increasing the energy awareness of energy consumers. Moreover, Envidatec GmbH often takes part in different energy related research and development projects, most of which are realized in cooperation with academic partners. One such project is the “German-Polish Energy Efficiency Project” (GPEE).

The GPEE project concentrates on energy efficiency in cities, especially in façade technology in residential buildings. The project is running from 2013 until 2016 and is funded by the German Federal Ministry for Education and Research (BMBF) and the polish Ministry of Science and Higher Education.[3] It is a joint project by a consortia of the Lodz University of Technology (Poland) and the Hamburg University of Applied Sciences (Germany) as academic partners and Sto-ispo Sp. Z o.o. (Poland) and the Envidatec GmbH (Germany) as industrial partners. [4] There are many intended activities, which are carrying out during the project. And since the project focuses on energy efficiency in buildings, the development of standardized methodology for their evaluation is an important part of the project.

2 Standardized Methodologies for the Energy Efficiency Evaluation of Commercial Buildings

The aim of the development of standardized evaluation methods is to establish a procedure suitable for specific type of buildings, in this case for commercial buildings. Such procedures can benefit from the standardized tools and analysis approaches for commercial buildings and detection of their energy losses. Nowadays there is a wide range of methods for analyzing and evaluation of energetic situation, which are described in norms and standards as well as in diverse handbooks. The following methodologies are designed in accordance with international standard norms DIN EN 16247, ISO 50001 and ISO 50002 which are well known sources. Energy efficiency (EE) evaluation should consider all the different energy sources used in the building such as district heat, oil, gas, electricity and on-site renewable energy applications if they exist. Besides, energy consumption should be analyzed which means separate observation of energy used for heating, cooling, water, ventilation etc.

Proposed energy efficiency evaluation methodologies contain six main parts which are shown on the Figure 2. The following order explains an execution process:

1. Evaluation planning
2. Data acquisition
3. Pre-audit
4. On-site audit
5. Reporting
6. Suggestions concerning efficient energy use

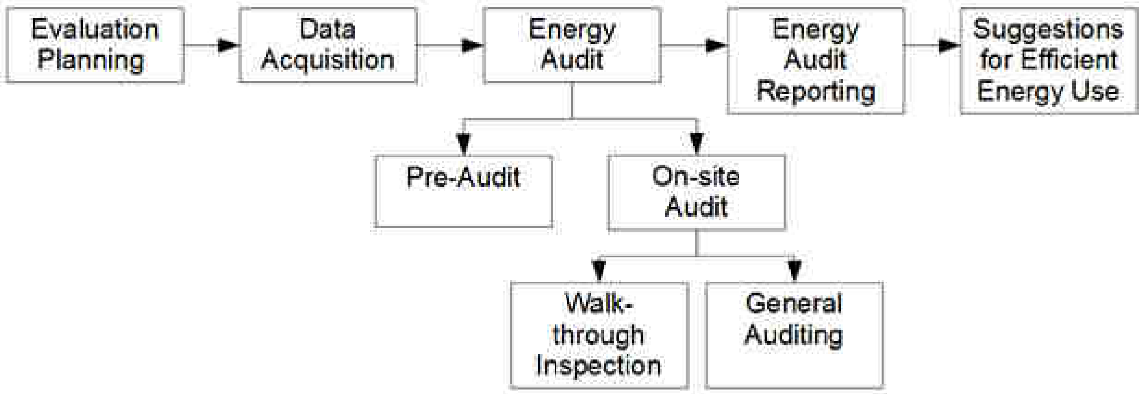

Figure 2: Energy efficiency evaluation steps

The evaluation steps are detailedly described in the following.

Evaluation Planning/Preparation

The planning of the EE evaluation is an important part and marks the beginning of the process, because successful execution of all subsequent activities depends on a good process planning. The scope and objectives of the energy efficiency evaluation are defined during the planning.

Data Acquisition

Evaluation planning is followed by data acquisition step. The energy efficiency evaluation is a particular process and requires high-quality data. The accuracy of the analyzes depends on quantity and quality of the gathered building related data, as there are a lot of factors, which can have an influence on building's energy efficiency. The more and detailed the collected information is, the exact the evaluation results are.

Energy Audit

Different norms and handbooks provide various energy performance evaluation models based on energy auditing. Energy audit is defined as a systematic analysis of energy use and energy consumption within a defined energy audit scope in order to identify, quantify and report on the opportunities for improved energy performance.[5]

Reporting

EE evaluation process must be recorded in an energy audit report. It is a document which describes the conducted energy audit activities including calculations, analyses and measurement results.

Suggestions Concerning Efficient Energy Use

There are many possibilities to improve the energy efficiency of a building and an energy auditor can make suggestions regarding energy efficiency problems detected during the evaluation.

3 Evaluation Planning

An EE evaluation is initiated by energy manager of a building and should be carried out by a qualified person or an energy auditor. The energy performance evaluation of a building begins as soon as an energy auditor is appointed for the evaluation process. The first step of presented evaluation methodologies is an evaluation planning. During the planning the evaluation scope, boundaries as well as realization time of the evaluation are defined. Main objectives must be complied in details with a customer.

Besides, all necessary documentation and tools needed for the evaluation are prepared on this step.

4 Data acquisition

Data acquisition is an essential part of the energy performance evaluation of a building. Because of variety of building concerned information the data collection can be carried out in several steps. In order to systematize the data collection, special designed checklists and questionnaires were developed. They are standardized for commercial buildings and serve as evaluation tools. Analyzes conducted during the first remote audit based only on the data provided by the customer. It means that checklists must be created to collect as much as possible information apart, but at the same time easy to handle and with a clear content.

Standardized checklists used for the on-site audit as well as questionnaires may vary depending on the customer's requirements and building's specifications. Checklists and questionnaires presented in the thesis were designed in accordance with the ISO 50002 and DIN EN 16247 norms and based on the documentation provided by Envidatec GmbH. The structure and the meaning of standardized methodology tools is explained below and examples are presented in appendixes.

4.1 Data types

The data required for the evaluation can be distinguished as building related data and energy related data. Architectural and constructional features belong to building related data. Already one can see here the first obvious use of the standardized EE evaluation methodologies. Because many commercial buildings, especially office buildings and educational buildings have similar construction, in comparison with residential or industrial buildings, from which they vary a lot. This allows the use of same evaluation tools.

Sometimes building related data are not completely available, although particular facts are useful for the evaluation. This difficulty appears especially with old buildings, where documented information is not enough. In this case the building standardization can be used for the simulation and unknown parameters can be matched.

Only building related data is not enough for the energy performance evaluation. To improve building's energy performance the data concerning its energetic situation must be known. Energy related data include the following: forms of energy which are in use, the energy consumed for different needs such as cooling, heating, air ventilation and conditioning etc., as well as defined significant energy consumers. Building's energy manager usually can not provide these complete energy data, and the data provided for the pre-audit is recordings from main meters and energy suppliers. In the course of subsequent evaluation steps a more detailed information is gathered. During the on-site audit an interview with the customer and complete energy related measurements take place.

There are many factors influencing the efficient energy use. Apart from the constructional and energetic aspects of a building, its location, environmental and weather conditions have a great impact.

4.2 Evaluation tools

Standardized tools for the performance evaluation of commercial buildings were designed within this thesis. The tools are highly useful auxiliaries for the EE evaluation and make the process easier and more structured. Among tools are checklists, questionnaires, templates for reports and other documentation. Since EE methodologies include two auditing steps, there are different types of checklists and questionnaires. Checklists used for conducting the pre-audit must be completed by the customer and provide the first information about the auditing building. They are less detailed than the questionnaires used for the on-site auditing. For clearness checklists are hereinafter called as “pre-audit checklist” and “on-site audit checklist”. Their structure and contents are described in the following chapters.

4.2.1 Pre-audit checklist

Information from the pre-audit checklist gives the first overview of a building such as the size and the age of the building. By analyzing pre-audit checklist some specifics of the building and possible reasons for energy losses can be detected. Besides, the building can be considered by different parameters and compared with commensurable buildings to enable benchmark among buildings.

The standardized pre-audit checklist has several fields to complete which are separated in two main sections: *Building Related Data* (Figure 4) and *Energy Related Data* (Figure 5). It includes a place for an actual and meaningful photo of audited building. (1) A short explanation on how to work with the checklist is given below the picture. (2)

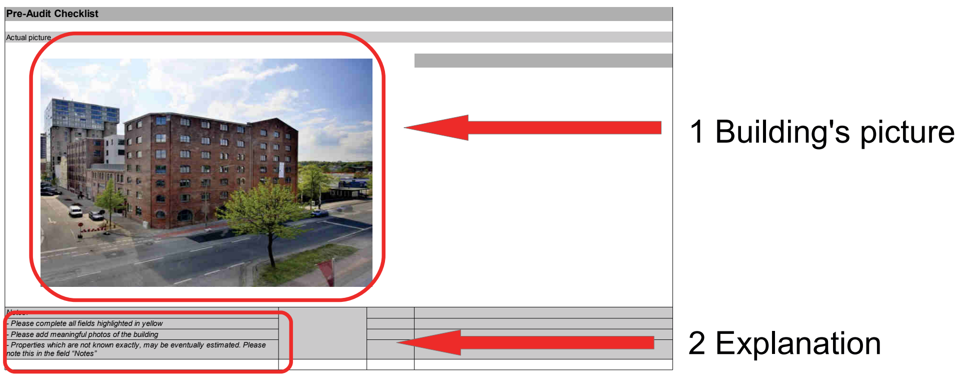

Figure 3: Pre-audit checklist (upper part)

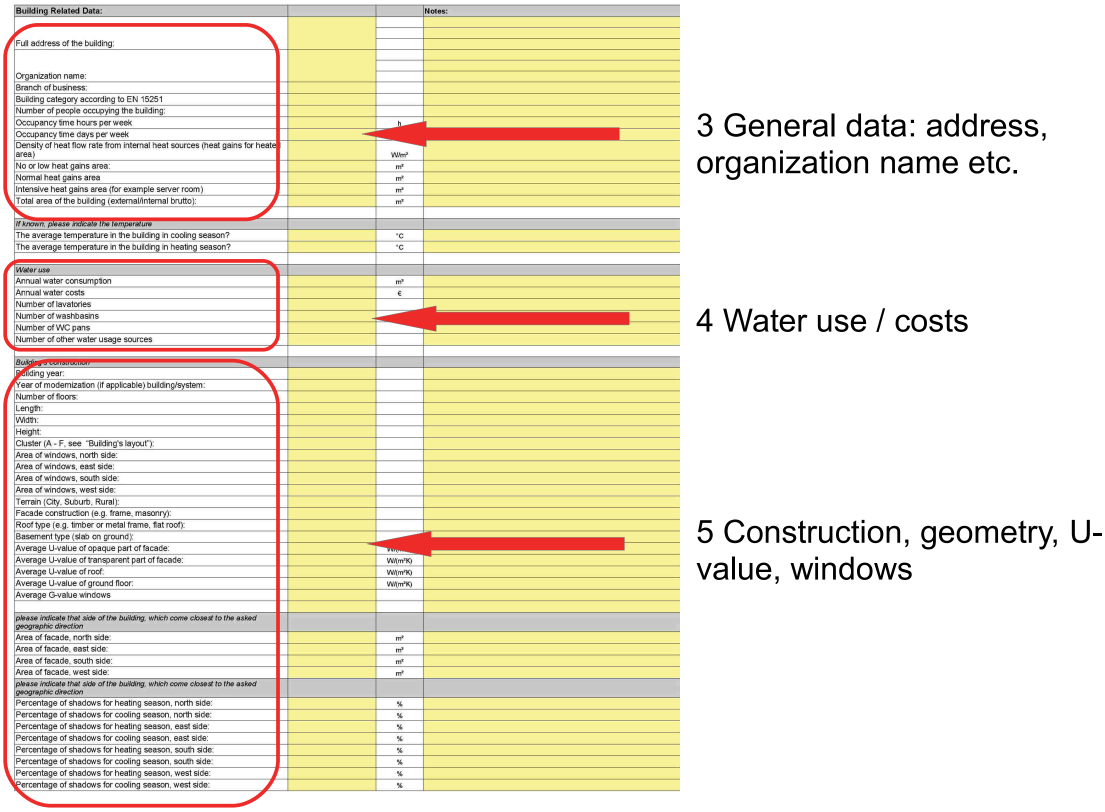

Figure 4: Pre-audit checklist (Building related data)

Fields of the section *Building Related Data* provide a general information about the building (3): branch of the business, number of occupying people and the corresponding occupancy time. Then follows the sub-sections to collect some particular data such as a temperature, water use (4) etc.

There is also an information about building's constructional features (5): age of the building and modernization, building's size, roof type, lightning system etc. The building's layout can be chosen from six proposed types.

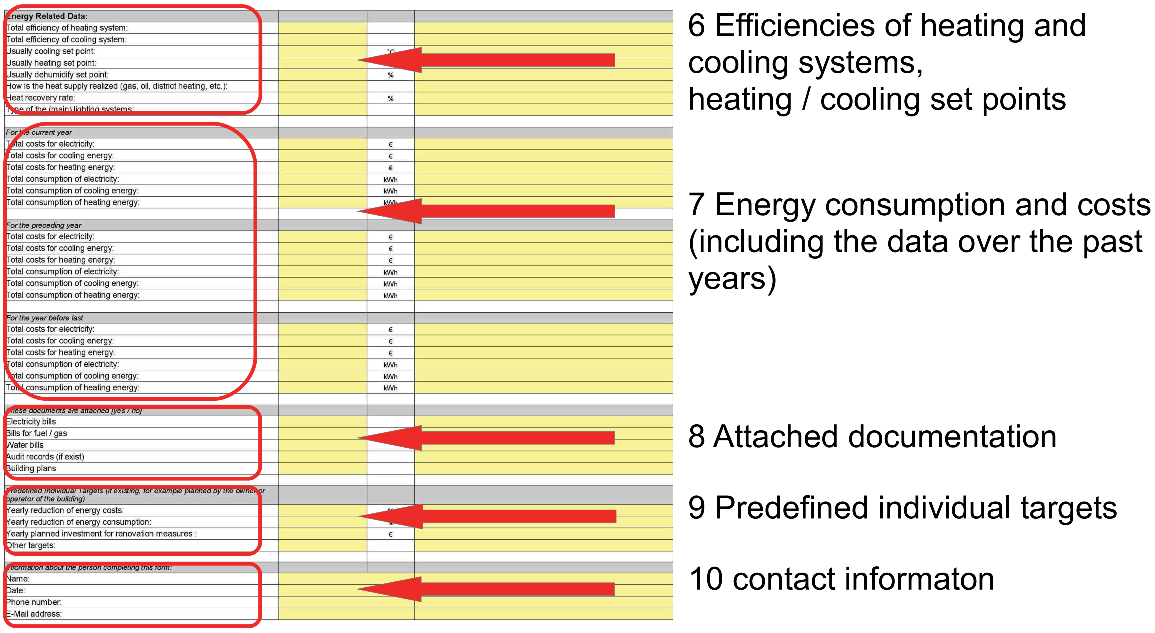

Figure 5: Pre-audit checklist (Energy related data)

The next section named *Energy Related Data* describes efficiencies of heating and cooling systems (6), information about energy consumption and annual energy costs. (7) If the building's plan and energy consumption are provided, it must be noted in corresponding fields. (8)

The sub-section *Predefined Individual Targets* (9) should be completed only if there are already existing individual targets, which were planned by the owner or operator of the building. In general, it describes the yearly reduction of energy costs and consumption. The last fields (10) of the checklist must include a contact information about the person who completed the form.

Checklists and questionnaires for the on-site audit ensure more particular data comparatively to the pre-audit checklist, since they are completed during on-site visits.

4.2.2 Questionnaires

The questionnaire was developed specially for the building assessment during the walk-through inspection conducted within the on-site audit. The intention of the questionnaire is to interview the customer's part and to verify abnormalities discovered after the pre-audit. The questionnaire as against the pre-audit checklist is completed by the person conducting the EE evaluation. The questionnaire is a standardized tool and applicable for commercial buildings, although its structure and some questions can vary depending on building's specifics. Questions mainly concern heating and cooling systems, existing equipment and other circumstances influencing the energy performance of a building. There may be no concrete answers on questions and some comments must be made. The questionnaire has following sections to complete: *General, Lighting, Heating and Cooling, Electrical Equipment, Water Use and Building Envelope.*

The first section *General questions* is about the energy management of the building. It is important to get to know, because if there exist any energy management or energy controlling system, the EE evaluation execution will change.

Questions of other sections are aimed on finding out an ineffective energy use and unnecessary energy consumers.

4.2.3 On-site audit checklists

Suitable on-site checklists are prepared after the on-site inspection and the questionnaire analysis. The number of required checklists and their content depend on the building's specifications and measurement points. But since the EE methodologies are intended for assessment of commercial building, a draft with estimated fields was designed. The on-site checklist is necessary for record of measurements and the results of on-site observations. After completing this, complete analyses of energetic condition of a building can be made.

4.2.4 Documentation templates

Appropriate documentation templates were also designed within the thesis. They are used for on-site auditing and reporting. Templates of tables serve for denoting measurement points, pointing out energy losses, defining some facts and recording measurements results.

In order to facilitate the creation of diagrams and graphs concerning the energy consumption, template tables for the pre-audit report were designed. The data for diagrams is taken from the checklist form.

Energy Consumption			
	electricity	*heat*	*cooling*
For the current year	23165	16639	
For the preceding year	21304	11422	
For the year before last	21376.42	12652	

Figure 6: Pre-audit report template (table)

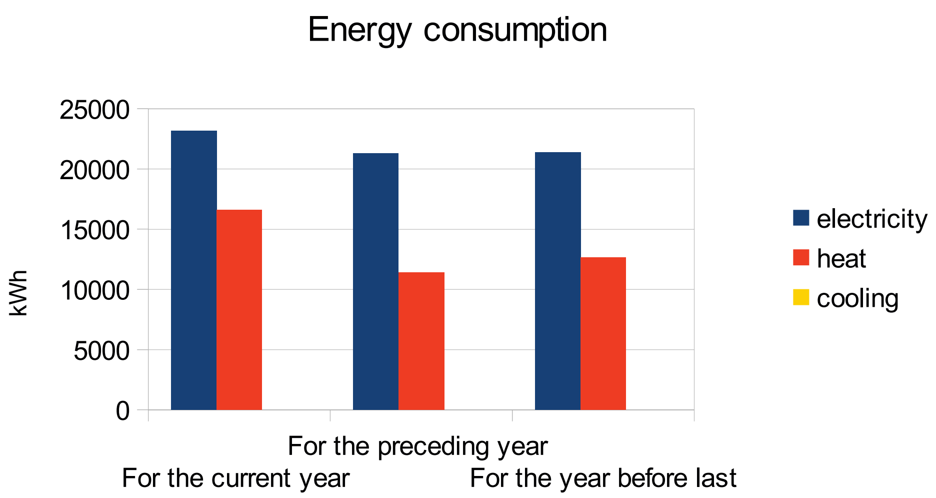

Figure 7: Pre-audit report template (bar chart)

5 Pre-audit

A special emphasis of the pre-audit is a proper planning of following evaluation activities related to specifics and features detected in the first audit. In present methodologies pre-audit is a conduction of the audit without visiting an object, which means, that analyzes strongly depend on the quality of delivered primary data. The data is collected by means of checklist and the completed form can serve for analysis of energy performance characteristics of a building. Additional information concerning energy consumption such as energy bills and historic energy usage data are useful. Pre-audit is comparatively simple although has a great meaning for further performance evaluation. Usually irregularities and abnormalities in energy spread of a building appear on this stage. All detected abnormalities are recorded and prepared for subsequent on-site auditing. As it is a remote audit, it is allowed to get a simplified view on a building which helps to observe the situation distantly. Simplification of the building can be realized by standardization and generalization of some building's parameters such as construction, building materials, layouts etc.

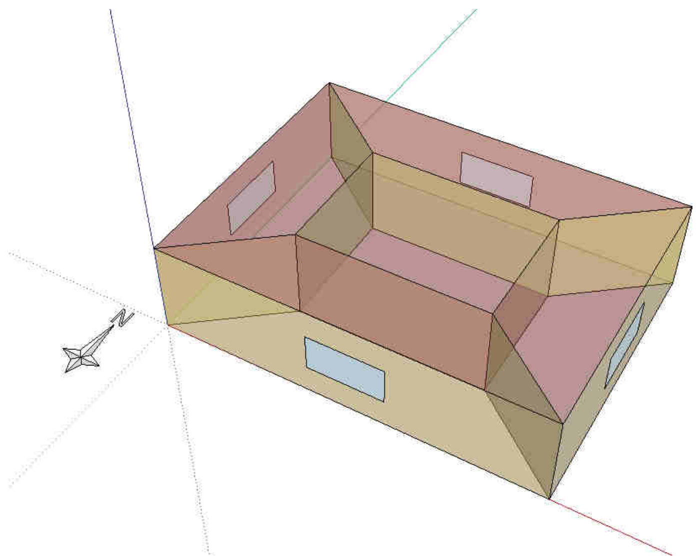

Figure 8: Building's layout presented in the pre-audit checklist [6]

5.1 Energy Performance Characteristics

Different commercial buildings have different energy performance characteristics. It depends on organizations and companies occupying the building, their branch of business etc. A load profile analysis give a good overview on the energy performance characteristic of a building.

The load profile is defined as a graphical visualization of changes in electrical load by the time. It can be various depending on the location, temperature, building type and seasons. In many European countries the electricity consumption of buildings with an annual consumption of more than 100.000 kWh or maximum power of 50 kW is recorded by electricity operator in 15 minutes intervals. These recordings can be requested by customers. [7]

The load profile analysis enables a detection of unreasonable peaks and significant energy consumers of a building, as it is apparently on the load curve. It is very profitable data source and can serve, if available, as a basis for further analyzes. Analysis of the load profile is especially suitable for detection of energy losses in commercial buildings, since in such buildings many energy consuming equipment has to operate permanently and uninterrupted.

The Austrian company “e7 Energie Markt Analyse GmbH” has developed their own analysis tool for evaluation and interpretation of the load profile data. It represents the energy consumed by different objects in the graphical form in the time scale. The tool is based on MS Excel and correspondingly easy to handle. By means of the tool it is also possible to monitor the energy consumption related to different reference parameters such as area, employees etc.

There are various graphical representations of load profiles to detect all abnormalities and irregularities concerning energy consumption.

It is known that most commercial buildings operate around 4,000 hours per year and the tool enables an observation of the energy consumption of 4,000 operating hours and the energy consumed beyond these hours. (Figure 9)

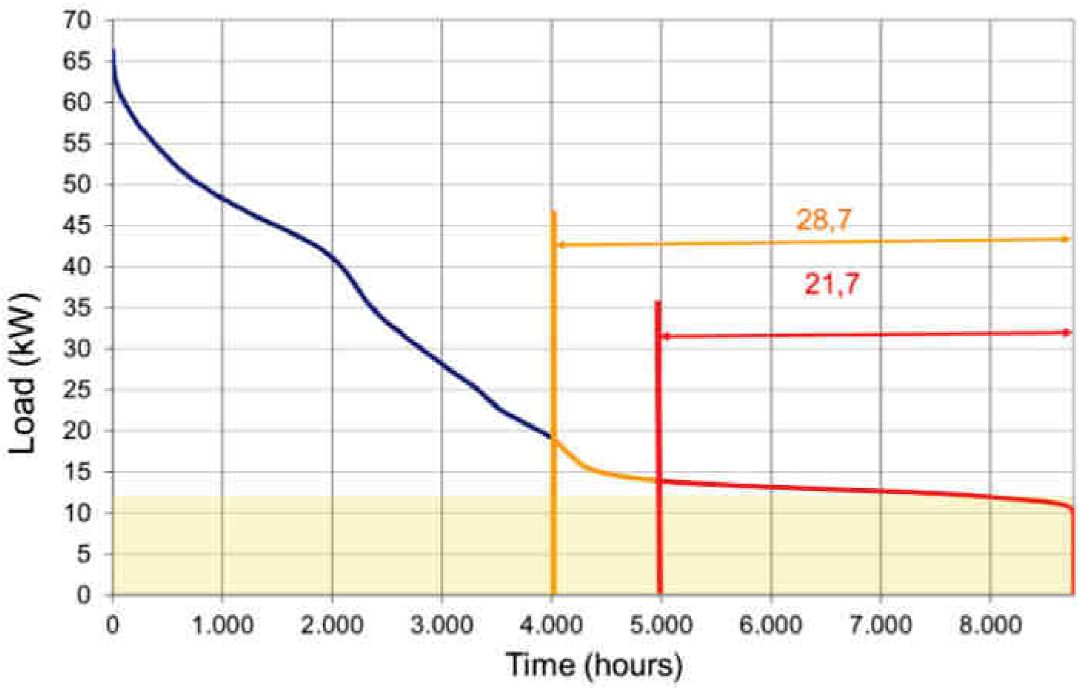

Figure 9: The load profile in 15 min. interval [7]

An arranged load profile presented by the size of the value in 15 minutes time interval. The right side of the graph divided by the orange line shows how much energy is consumed (28.7 %) beyond the operating hours scope. It can be also seen that there is a permanent load of around 12 kW (21.7 %) for more than 8,000 hours. [7]

On the Figure 10 is shown a comparison between seasonal load profiles of commercial building. The energy consumption was measured during the same weekdays but in different seasons: Tuesday 18 January and the Tuesday 5 July. From the profiles become obvious that the energy consumption in winter is higher than in summer.

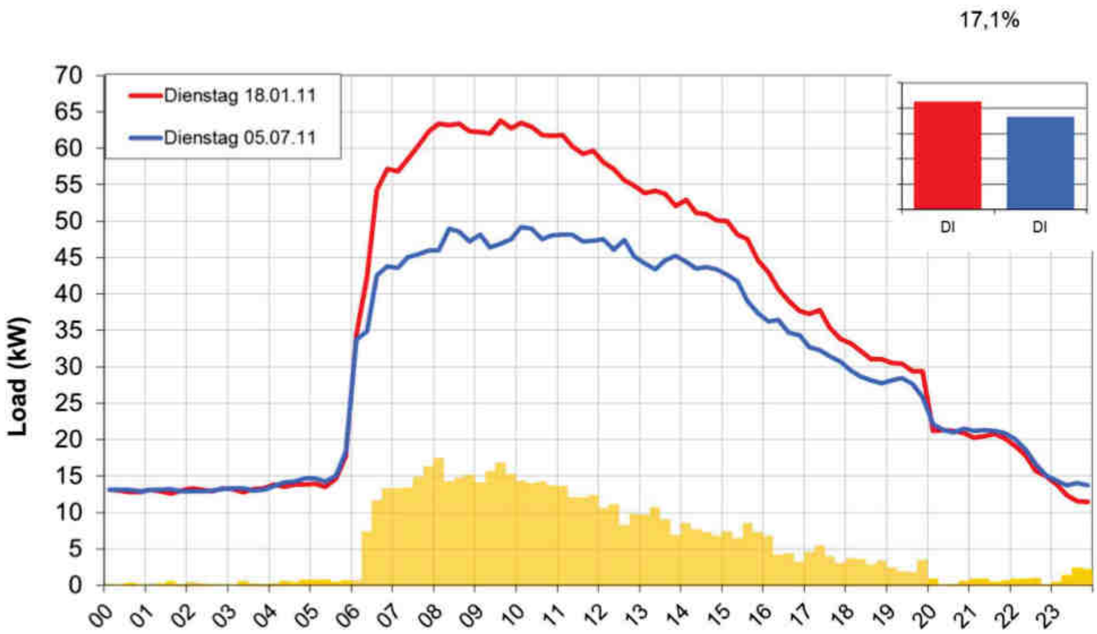

Figure 10: Comparison between seasonal load profiles [7]

While comparing such load profiles,special attention should be payed to the heating, cooling and specific seasonal consumers. The curves are almost the same during the night although start to differ from the morning. The highest electricity demand as well as the biggest difference between load profiles of a building appear between 08:00 AM till 12:00 AM. The higher electricity consumption in winter is probably caused by heating devices and illumination.

Another important figure is the load profile during holidays. (Figure 11) Curves show how much energy is consumed during each holiday. There must be no demand for energy as a building is not used during holidays. But the load profiles show that there is still a significant energy consumption.

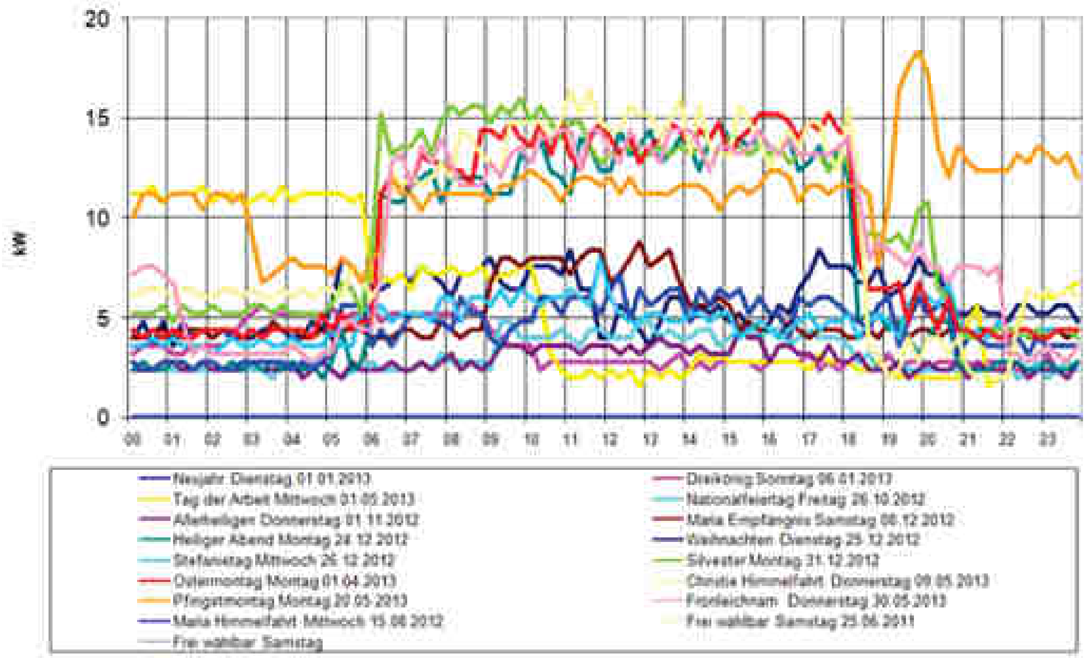

Figure 11: Load profiles during holidays [8]

The reason for the energy consumption is that on holidays some building services are kept running. The figure demonstrates that the load profile varies on different holidays. Hence, the curves can be conditionally generalized by the load of more or less than 10 kW.

Some commercial buildings have an equipment operating round the clock and a part of energy is consumed permanently independent of the occupancy of a building. In such cases the night-load profile can help to detect abnormal energy consumption arising during the night time. The Figure 12 shows the energy consumed during the night time

Figure 12: The night-load profile [7]

5.2 Pre-audit Results

Results of data analyses conducted during the pre-audit are recorded in the pre-audit report. The pre-audit report is quite simple and shorter than the final report. Because main calculations and detailed analyzes are carried out during the on-site audit. Pre-audit report includes diagrams and graphs based on the data from pre-audit checklist. This intermediate summary describes the first analyses results and detected abnormalities. And also further actions which must be initiated during the EE evaluation.

6 On-site Audit

6.1 Walk-through inspection

An on-site audit begins with the walk-through inspection and the meeting between an energy auditor and the customer, as the pre-audit is realized without visiting the building and meeting the client. The inspection, where the building and its specifics are observed, should not take longer than one day. First of all, actuality of the data provided for the pre-audit must be ensured. Additional information is collected during the interview with the client. For the interview special developed standardized questionnaires are used. During the inspection the energy auditor interviews the staff and goes through the considered building with the assistance of technical staff provided by the customer. There is no calculations and measurements during the inspection, although some reasons for irregularities detected on the pre-audit can be found. Completing the questionnaire and visual observation give a better view on building's energetic condition, which ensure the preparation of on-site audit checklists taking into account the building's characteristics and specifics. Many factors can cause unnecessary energy consumption: proper operating of power systems, condition of equipments, operating time and correct use of technique, even their arrangement. And completing the questionnaire helps to identify existing significant energy consumers and detect energy losses. Besides, it becomes clear if any energy saving measures were already implemented.

Basically, the pre-audit and the walk-through inspection could be realized at once. According to most of the standard norms a pre-audit is not necessary. However,the conduction of remote pre-audit leads to a concrete further evaluation.

6.2 On-site Audit

The on-site auditing may require more than one visit depending on the audited building and its features. It becomes evident after interviewing the customer and designating measurement points. The following activities are initiated during the general audit:

- Measuring meters
- Analyzing district energy systems
- Particular observation of energy consumers
- Testing power and other systems
- Analyzing equipment

However, the list of activities can be augmented.

If during the primary data analysis any irregularities were detected, these should be measured first. Measurement results must be compared with the data provided for the pre-audit to prove the data quality. Then follows a detailed analysis of equipment and systems as agreed with a client. It is important to find out how the operational characteristics affect the energy consumption of a building.

6.3 On-site Audit Results

After conducting the on-site audit all possibilities for energy efficiency improvement must be pointed out. This is reached by calculations of energy savings and analyses. The data which was unknown at the time of the first audit is collected during measurements. So, results of the on-site audit are compared with conclusions which are made after the pre-audit. Total evaluation results are documented in the final energy audit report.

7 Energy Audit Reporting

An overall outcome of the energy audit is presented in an energy audit report. The report contains supplemented information of the pre-audit report as well as results of analyses conducted during the on-site audit. The document has three main parts, but if a customer has any specific requirements for the report, the content should also be discussed. The first part defines the current state of the audited building, constructional features, the energy consumption, costs for energy and other general information.

All initiated activities, energy audit scope, evaluation plan and used evaluation methods are described in the second part of the report. It must contain detected energy losses and appropriate calculations as well as implemented measurements and also analyses of the energy performance of the building based on specific energy performance indicators. Results are presented as diagrams.

The data collected and measured at the time of audits is particularly analyzed in order to introduce measures for the improvement of the energy performance of a building. So the last part describes suitable opportunities for energy savings. There are recommendations and suggestions which can increase the total efficiency of the concerned object.

7.1 Energy Performance Indicators

Proper building's energy efficiency evaluation always requires suitable measuring units used for further calculations. The appropriate units are measures of energy intensity – the energy baseline and energy performance indicators (EnPI's). Energy Statistics Manual published by the International Energy Agency in the year 2014 defines energy performance indicators as a ratio between energy consumption (measured in energy units) and and activity data (measured in physical units). [9]

$$Energy\ efficiency\ indicator = \frac{Energy\ consumption}{Activity\ data}$$

By means of EnPI's the operational and organizational performance of any organization can be determined. Energy performance indicators can cause a quickly evaluation of energy consumption relative to different objects (e.g. energy consumption per area, energy consumption per employee etc.) It makes EnPI's very profitable for energy monitoring systems.

Service category	Unit of activity
Schools	Number of students, number of occupants
Hospitals	Bed capacity, number of occupied beds
Hotels	Number of rooms, number of nights, number of employees, floor area
Restaurants	Number of meals
Offices	Number of employees, floor area
Retail	Number of employees, floor area

Figure 13: Examples of categories within the services sector and respective units of activity [9]

The energy baseline is determined from the current energetic situation, i.e. before any energy efficiency measure was implemented. The significance of energy performance indicators often just appears in comparisons. So, if the energy baseline and EnPI's are known, it is possible to compare energy performance and evaluate proper improvements. It is pretty complicated to find out exact EnPI's because of different influencing factors like weather or raw material quality and there is no ideal EnPI. [10] Finding out suitable EnPI's totally depends on specific organization's requirements and characteristics. They can be for instance a measuring unit of energy consumption per square meter surface, water consumption per product or energy consumption per employee.

The following table summarizes energy performance indicators chosen as most profitable regarding commercial buildings.

Energy Performance Indicator	Description	Unit
Energy Effectiveness of a Building	$\frac{Energy\,Consumption}{Total\,Area \cdot Year}$	$\frac{kWh}{m^2 \cdot a}$
Specific Energy Consumption	$\frac{Energy\,Consumption}{Number\,of\,Employees}$	$\frac{kWh}{Employee}$
CO_2 Emissions of a Building	$\frac{CO_2\,Emissions}{Total\,Area \cdot Year}$	$\frac{CO_2}{m^2 \cdot a}$

Table 1: Basic energy performance indicators

Energy Performance Indicator – 1 $\frac{kWh}{m^2 \cdot a}$

The index kWh/m²a, which is already used in the EnEV (German Energy Saving Regulation), gives the kWh value consumed per m² and year.

The following index has like all EnPI's advantages as well as disadvantages.

On the one hand units of this indicator are universal ones, so that it is an internationally well known index. As the indicator consist of common units, there is no necessity of conversion into other units. It is main indicator defining the energy consumption of a building, as it represents a relation between the consumed energy and the area. It is suitable for monitoring the energy consumed for heating and cooling.

Pro	**Contra**
• Indicative for heating / cooling energy consumption • Universal units • International well known and applicable • No need of complicated conversions into other units	• Depends on external factors ◦ Norming necessary • No pointing out of different seasons

Table 2: Pros and cons of the EnPI kWh/m²a

On the other hand the indicator kWh/m²a is inexact. Because it represents values for the whole year and there is no pointing out of differences between the data during the year.

By implementation of this indicator for the monitoring of the energy performance of a building, external impacts should be also considered. Different factors such as environmental conditions or building's thermal protection may have an influence on the value.

Therefore, the value must be normalized to the real conditions. [11] This can be reached by simple calculation of so called degree days by the following formula:

$$\frac{Energy\,consumption\cdot(\frac{norm.\,degree\,days}{spec.\,degree\,days})}{Production\,volume}$$

There are normal degree days and specific (heating) degree days defining heating / cooling periods.

Energy Performance Indicator – 2 $\frac{kWh}{Employee}$

The next selected EnPI represents the energy consumption per each Employee. (kWh/Employee). This EnPI is particularly profitable for commercial (office) buildings, because the energy consumption in such buildings mainly used for lightning, office equipment and air conditioning, directly depends on the number of employees. So, it is quite relevant to monitor this. The indicator is comparatively simple and like the previous described EnPI also universal and international known. This EnPI can be very profitable especially for a benchmarking as it represents the dependence of the consumed energy and employees of a company / organization.

The energy performance indicator kWh/Emp is also not the perfect one. There are advantages as well as disadvantages. It is a big plus, that it is a physical indicator, as it means that the energy needs are related more to the working condition, not to the production volume or intensity. Then, the data concerning employment is quite exact, as it should be known how many employees are working in a building. It seems easy to define the EnPI, if a concrete number of employees and the energy consumption concerning data are known.

But there are some disadvantages which appear as difficulties concerning calculations. The difficulty of calculations is caused by different occupancy time, since some employees have various working time. Some permanent employees, who work 5 day/week for example can unexpectedly be absent because of sickness or personal needs. Besides, there are usually some part-time or external employees which makes the monitoring and calculations complicated, especially the yearly calculations. The results of monitoring of energy consumption per employee in these cases become inexact. To avoid the inaccurate measurement the indicators must be normed regarding to the working hours/days/weeks.

Pro	**Contra**
• Universal and simple indicator ◦ No need of special knowledge to work with it ◦ No need of any unit conversions • Well applicable • Very profitable for short-time periods	• Inexact unit (per year) ◦ difference in occupancy time ◦ changing the number of employees • Complicated calculations (norming) • Organization's specifications ◦ Technique and equipment

Table 3: Pros and Cons of the EnPI kWh/Employee

So, the EnPI gives a most exact output in a short periods of time, when the working time can be easily normed. In the following table are some summarized pro and contras:

Energy Performance Indicator – 3 $\frac{CO_2}{m^2 \cdot a}$

The following indicator is also profitable and representative for commercial buildings. Commercial buildings consume much electricity and it is the most significant factor contributing the CO_2 emissions. In commercial buildings the energy is used for lighting, office and other equipments, heating, cooling and ventilation. The EnPI represents the amount of CO_2 emissions per square meter of building's surface. CO_2 emissions caused not only by used electricity, but also by energy consumed for heating, which makes the indicator a universal one. [12] By monitoring this indicator it can be known, how environmental friendly and how energy effective the building is. Undoubtedly this EnPI is very useful and important.

On the other hand the indicator is pretty complicated, and there are some difficulties: CO_2 emissions depend on different factors and different types of the energy consumption which bring accordingly to complicated calculations. Then, emissions can not be easily measured or read out from any meter / counter.

Pro	Contra
• Annual calculations • Multi-functional indicator ◦ Universal comparable with other indicators ◦ Index of energy intensity ◦ Identifies the eco-friendliness	Approximately (average) results ◦ comparatively difficult calculations ◦ an automatic measurement can not be implemented • Must be different recognized concerning seasons

Table 4: Pros and cons of the EnPI CO2/m²a

Significant advantage of the indicator appears if the data concerning CO_2 emissions is available, or already calculated. In this case there is an opportunity to correlate and monitor the relation between the CO_2 emissions and any other energy related indicator. And annual calculations are also possible.

9 Energy Performance Monitoring

In order to improve the energy performance of a building it is important to control and observe its energetic situation. This can be reached by the implementation of so called building automation system (BAS). It is an automated computer-based control system installed in buildings. The system serve for controlling of all in building existing mechanical and electrical equipments such as HVAC (heating, ventilation and air conditioning), lighting and power systems. The objective of the implementation of the BAS are an automated equipment control, reduction of energy costs and general improvement of the building's energy efficiency and accordingly operating costs. In many cases, existing building automation systems are not open documented and only applicable by the installation of complex hardware and software combinations, which cause high installation and maintenance costs. [4]

Energy Monitoring System

An alternative to the combined BAS is an energy monitoring system. The energy monitoring system is an energy efficient measure with minor investment costs which enables an overview on changes in energy performance and energy use in general. By implementing the system 3-15% of total energy consumption can be reduced by operational and low-investment measures. The percentage depends on different factors like technological maturity and technical equipments of a building as well as already implemented energy saving measures.

Nowadays many energy services companies offer such energy monitoring systems. The JEVis system is a solution for energy monitoring provided by Envidatec GmbH and has a range of advantages. It is an open source program written in Java. The program serve for the monitoring and analyzing of energy and operational data in order to avoid unnecessary energy consumption and energy losses.

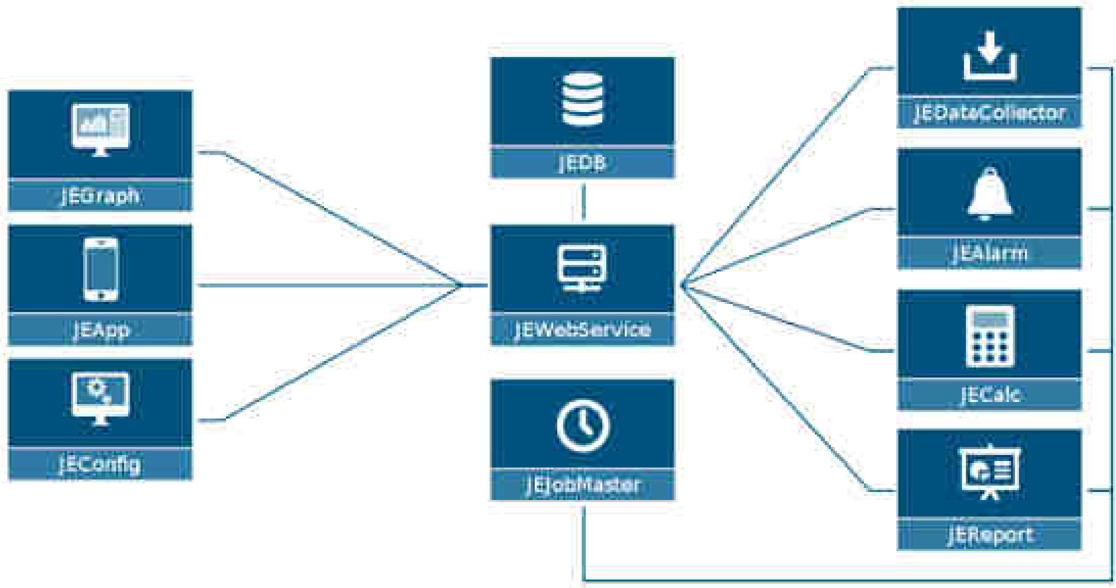

Figure 14: JEVis system structure [13]

The JEVis system has many functions as can be seen on Figure 14. JEGraph (Figure 15) is the main graphical user interface for the visualization of the energy and operational data while JEConfig is an interface for the configuration of the system. JEVis enables a creation of analyzes which can be configured correspondingly to the client's personal requirements.

The advanced settings of the visualization program makes possible the monitoring of energy consumption related to different factors (specific energy performance indicators). JEApp is a solution for mobile phones with limited functionality. These three are the front-end of the JEVis system.

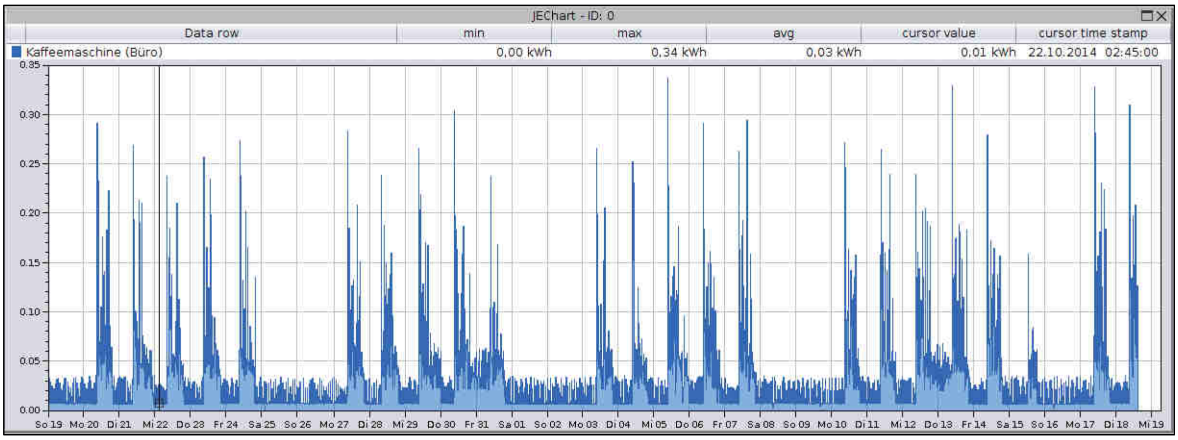

Figure 15: JEGraph user interface [13]

The system has a calculation function JECalc based on GNU Octave which is compatible with MATLAB. This function is customizable and enables data processing.

Irregularities in energy consumption and in energy flow in general such as energy peaks or unexpected equipment malfunctions are detected by an alarming function JEAlarm.

The function JEReport provides standardized reports on energy consumption at fixed time intervals. Standardized report can be configured depending on personal requirements. The daily / weekly / monthly reports gives an opportunity to detect the energy losses on time.

9.1 Energy Efficiency Map Tool

As an instrument for energy monitoring of larger areas or surfaces (eg. Big cities) the energy efficiency map tool can be used. Integration of an energy efficiency map requires special selected reference objects/buildings. Reference buildings must be analyzed and compared. After that the result of checklist analysis can be acceptable for other buildings, if they have nearly same parameters. In order to get the most exact energy efficiency map, more reference buildings are required. Simulation program can help to avoid this necessity as the program can simulate the required buildings. The energy efficiency map tool offers an opportunity to consider the whole energetic situation of buildings in a global arena.

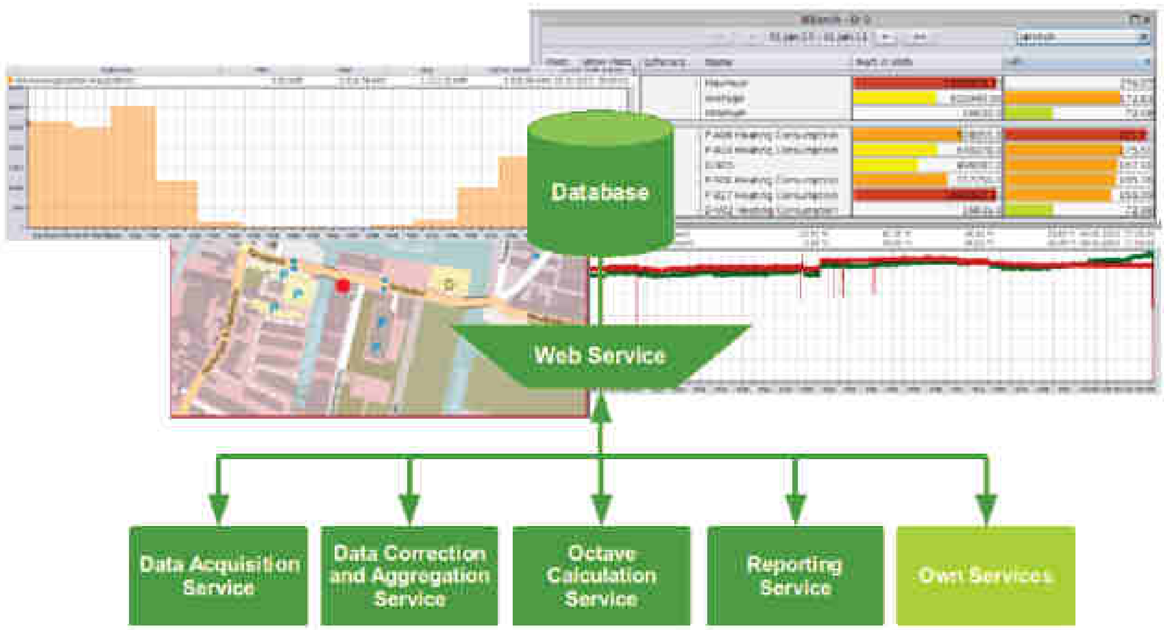

Figure 16: Overview of the user interface of the energy efficiency map tool, based on the JEVis System [4]

The input of the energy efficiency map tool will be the manual meter reading of the main meters by the local facility managers. An automated meter reading is recommended for the more detailed analysis of buildings being retrofitted by innovative energy saving technologies. The energy efficiency map tool is supported by a wide range of web services such as data acquisition services, calculation and reporting services as well data correction and aggregation services. [4]

10 Implementation of energy efficiency measures

The last step of the energy efficiency evaluation is making suggestions for the energy efficiency improvement of a building. Concrete measures depend on observed building and identified energy saving potentials. Figure 17 shows the typical energy consumption in commercial buildings.

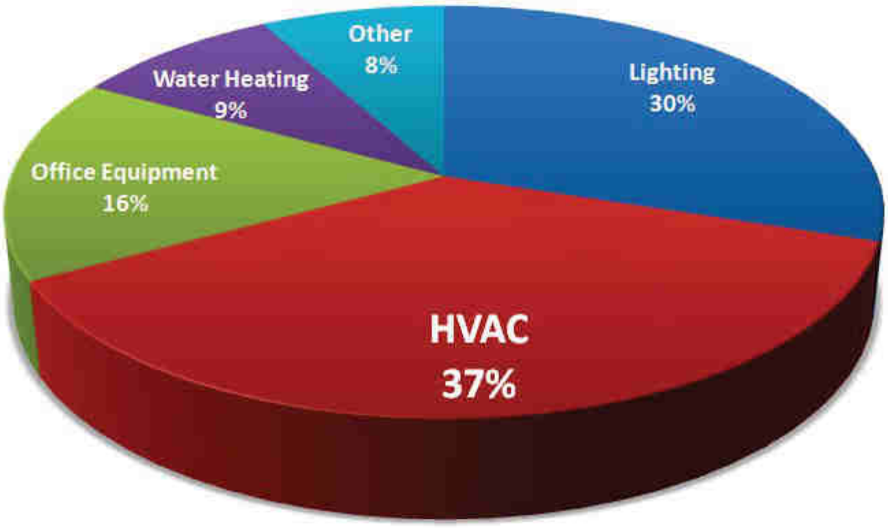

Figure 17: Energy use in commercial buildings [14]

As can be seen from the diagram, significant amount of energy in commercial buildings is used for HVAC systems, lighting and office equipments. So the aim is to reduce the energy consumption of these areas according to the evaluation results. It must be noted, that other factors such as building's construction, and envelope also influence the energy performance. Possible energy efficiency optimizations are described below.

HVAC Systems

Since the heating, ventilation and air-conditioning systems consume the most energy, they must be optimized as well as possible. The higher energy consumption can emerge e.g. because of defective systems. Another reason for energy losses is wrong and inefficient usage. Operating time and intensity of the systems must be properly set, and they should not operate without necessity. The following measures can be implemented in order to increase the energy efficiency of the HVAC systems:

- Reparation and the regular maintenance of the systems
- Modernization and renovation of systems components
- Optimization of operating times operating intensity and switching stages
  - Avoid unnecessary operations
- Improvement of the thermal protection
- Optimization of indoor air temperatures
- Demand-based control

Electricity

Almost half (46%) of the total energy consumption of commercial buildings belongs to the lighting systems and office equipments. There are different technical and organizational measures to decrease electricity costs.

- Allow in maximum natural light
- Reducing unnecessary lighting
  - Automatic lighting control system
  - Demand-based lighting in adjoining rooms

- Optimization of lighting system
    - Use of energy efficient lighting (TL5 tubes, fluorescent lamps)
    - Use of different illumination intensities

Electricity consumption of commercial buildings strongly depends on office equipments. Stand-by modes, operating time and technique malfunctions can cause unreasonable high electricity costs. After the analyses conducted during on-site audit, measures for more efficient use of equipments are suggested.

Water Use

To increase the total efficiency of a building the water consumption must be also minimized. Depending on the type of commercial building the water consumption varies a lot. Accordingly the appropriate measures for water saving are also different. Nevertheless, these general measures can be suggested:

- Maintenance and renovation of water supply systems (dripping taps)
- Stabilization of water pressure
- Metering the water consumption
- Installation of water flow sensors (wash basins, urinals, toilets)
- Use of two-piece toilet tanks

Building Envelope

Usually, a part of energy losses is caused by building's thermal protection. This problem arises especially in old buildings with a poor insulation. Basic optimizations of building's envelope are mentioned below:

- Insulation of all exterior walls (also the roof)

- The proper sealing on outer doors and windows
- Replacement of windows (double / triple glazing, low-emissivity glasses)

Correct arrangement of heating and cooling installations is also important for decreasing the energy consumption of a building, as it ensures their effective operation.

Organizational Measures

Apart from technical optimizations, implementation of different organizational measures can improve the building's energy performance. Among these measures are implementation of energy management and monitoring systems, achievement of optimal working conditions etc. The energy awareness of the stuff occupying the building has a considerable impact on the increase of building's energy performance. For this reason regular trainings must be organized.

The following table summarizes opportunities for increase of water and energy efficiency of a building.

Opportunities for increase of efficiency of a building			
№	*HVAC*	*Electricity*	*Water*
1	Reparation and the regular maintenance of the systems	Allow in maximum natural light	Maintenance and renovation of water supply systems
2	Modernization and renovation of systems components	Reducing unnecessary lighting	Stabilization of water pressure
3	Optimization of operating times operating intensity and switching stages	Automatic lighting control system	Metering the water consumption
4	Avoid unnecessary operations	Demand-based lighting in adjoining rooms	Installation of water flow sensors
5	Improvement of the thermal protection	Optimization of lighting system	Use of two-piece toilet tanks
6	Optimization of indoor air temperatures	Use of energy efficient lighting	
7	Demand-based control	Use of different illumination intensities	
8			
9			
10			

Figure 18: Basic energy efficiency measures (documentation template)

11 Conclusion

The aim of this thesis was the development of standardized methodologies suitable for the energy efficiency evaluation of commercial buildings. The advantage of the methodologies is that they have been designed taking into account the specifics of commercial buildings, which provide structured and optimal EE evaluation. Application of these methodologies ensures improvement of the energy performance of a building. Different analysis methods and the whole evaluation process was described in the thesis.

The objective was also the designing of appropriate evaluation tools, to make the evaluation process more convenient and simpler. Standardized tools are applicable for defined type of buildings and serve as useful auxiliaries by the evaluation.

In order to conduct energy related calculations and to verify later on the improvement of building's energy efficiency, suitable energy performance indicators were suggested. Indicators were chosen as most representative in the context of commercial building's.

The energy monitoring system JEVis provided by Envidatec GmbH was presented as an effective measure for the increase of the energy performance. Besides, possible energy saving opportunities have been suggested.

Energy efficiency evaluation methodologies presented in this thesis are being applied within the German-Polish Energy Efficiency project and their practicability will be verified, since the energy performance of the reference buildings will be evaluated by means of these methodologies.

Improvement of the energy performance is worldwide important and successful application of the EE evaluation methodologies within the GPEE project ensure their possible future implementation.

Summary

Within the thesis methodologies for the energy efficiency evaluation of commercial buildings were developed. The objective of the development of the methodologies was to find out a standardized procedure applicable for energy performance assessment of defined type of buildings.

The thesis was written in cooperation with Envidatec GmbH, which has provided an active support. The energy performance evaluation requires several steps including interviewing, auditing, reporting, etc. Methodologies describe step wise activities of the EE evaluation process. Moreover, specially designed standardized tools, which are needed for the evaluation, were presented within the thesis. Tools are partly based on the documentation provided by Envidatec GmbH and were designed according to the international standards. In conclusion an implementation of energy efficiency measures was suggested.

Evaluation tools (checklists, questionnaire, documentation templates) are attached in appendixes and saved in Excel format.

Bibliography

[1] Lawrence Berkley National Laboratory, “What is energy efficiency?”, [Online]. Available: http://eetd.lbl.gov/ee/ee-1.html [Accessed 28.03.2015]

[2] European Environment Agency, “Final energy consumption by sector and fuel”, 01.01.2015 [Online]. Available: http://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-8/assessment-2 [Accessed 29.05..2015]

[3] German-Polish Energy Efficiency Project, [Online]. Available: http://gpee.net/ [Accessed 05.04.2015]

[4] German-Polish Energy Efficiency Project, *Project Report* 02.10.2013 [Online]. Available: http://gpee.net/downloads/Public/Reports/gpee_wp1_report.pdf [Accessed 03.04.2015]

[5] ISO 50002:2014(E), “Energy Audits – Requirements with guidance for use”, ISO copyright office, Switzerland, 01.07.2014 (First Edition)

[6] Envidatec GmbH, *Documentation,* Hamburg, 15.01.2015

[7] Institute for Energy and Transport, “Proceedings of 8th International Conference Improving Energy Efficiency in Commercial Buildings (IEECB’14)”, Paolo Bertoldi, Andrea De Luca 1 - 3 April 2014, Frankfurt

[8] G. Benke, M. Schlögl, “Lastganganalyse”, e7 Energie Markt Analyse GmbH, Wien, 2014

[9] International Energy Agency, "Energy Efficiency Indicators: Fundamentals on Statistics" [Online]. Available: http://www.iea.org/publications/freepublications/publication/IEA_EnergyEfficiencyIndicatorsFundamentalsonStatistics.pdf [Accessed 15.04.2015]

[10] International Energy Agency, "Energy Efficiency Indicators: Essentials for Policy Making" [Online]. Available: http://www.iea.org/publications/freepublications/publication/IEA_EnergyEfficiencyIndicators_EssentialsforPolicyMaking.pdf [Accessed 15.04.2015]

[11] Envidatec GmbH, "Energy Controlling Basics" Hamburg, 11.12.2014

[12] Sustainable Energy Authority of Ireland, "Commercial micro-CHP Field Trial Report" [Online]. Available: http://www.seai.ie/Publications/Renewables_Publications_/CHP/Commercial_micro-CHP_Field_Trial_Report.pdf [Accessed 15.04.2015]

[13] Envidatec GmbH, "JEVis System Components" Hamburg, 12.01.2015

[14] Pride Distributing, *Commercial Energy Usage,* [Online]. Available: http://www.pridedistributing.com/pridetintdistributing_commercialtint.php [Accessed 17.04.2015]

[15] DIN EN 16247-1:2012, "Energieaudits", Beuth Verlag, Berlin, October 2012

[16] Motiva Services Ltd., SAVE-project AUDIT II, "Guidebook for Energy Audit Programme Developers", Finland, 2003 [Online]. Available:http://www.motiva.fi/files/1805/GB_Printversion.pdf [Accessed 18.04.2015]

[17] European Environment Agency, "Consumption and the Environment" 18.02.2015 [Online]. Available: http://www.eea.europa.eu/soer-2015/europe/consumption [Accessed 10.04.2015]

[18] DIN ISO 50001:2011, "Energy management systems – Requirements with guidance for use", Beuth Verlag GmbH, Berlin, 2011.

[19] International Energy Agency, "Energy efficient building envelopes" 18.12. 2013 [Online]. Available: http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyEfficientBuildingEnvelopes.pdf [Accessed 18.04.2015]

[20] Passipedia – The Passive House Resource, *Energy use – measurement results.* 18.09.2014 [Online]. Available: http://passipedia.passiv.de/ppediaen/operation/operation_and_experience/measurement_results/energy_use_measurement_results [Accessed 10.04.2015]

Appendixes

Some evaluation tools are presented in following appendixes. The full documentation is available on CD. (Including completed forms)

Pre-audit checklist

Pre-Audit Checklist

Actual picture

Notes:			
- Please complete all fields highlighted in yellow			
- Please add meaningful photos of the building			
- Properties which are not known exactly, may be eventually estimated. Please note this in the field "Notes"			
Building Related Data:			**Notes:**
Full address of the building:			
Organization name:			
Branch of business:			
Building category according to EN 15251			
Number of people occupying the building:			
Occupancy time hours per week		h	
Occupancy time days per week		days	
Density of heat flow rate from internal heat sources (heat gains for heated area)		W/m²	
No or low heat gains area:		m²	
Normal heat gains area		m²	
Intensive heat gains area (for example server room)		m²	
Total area of the building (external/internal brutto):		m²	
If known, please indicate the temperature			
The average temperature in the building in cooling season?		°C	
The average temperature in the building in heating season?		°C	
Water use			
Annual water consumption		m³	
Annual water costs		€	
Number of lavatories			
Number of washbasins			
Number of WC pans			
Number of other water usage sources			
Building's construction			
Building year:			
Year of modernization (if applicable) building/system:			
Number of floors:			
Length:			
Width:			
Height:			
Cluster (A - F, see "Building's layout"):			
Area of windows, north side:			
Area of windows, east side:			
Area of windows, south side:			
Area of windows, west side:			
Terrain (City, Suburb, Rural):			

Facade construction (e.g. frame, masonry):			
Roof type (e.g. timber or metal frame, flat roof):			
Basement type (slab on ground):			
Average U-value of opaque part of facade:		W/(m²K)	
Average U-value of transparent part of facade:		W/(m²K)	
Average U-value of roof:		W/(m²K)	
Average U-value of ground floor:		W/(m²K)	
Average G-value windows			
please indicate that side of the building, which come closest to the asked geographic direction			
Area of facade, north side:		m²	
Area of facade, east side:		m²	
Area of facade, south side:		m²	
Area of facade, west side:		m²	
please indicate that side of the building, which come closest to the asked geographic direction			
Percentage of shadows for heating season, north side:		%	
Percentage of shadows for cooling season, north side:		%	
Percentage of shadows for heating season, east side:		%	
Percentage of shadows for cooling season, east side:		%	
Percentage of shadows for heating season, south side:		%	
Percentage of shadows for cooling season, south side:		%	
Percentage of shadows for heating season, west side:		%	
Percentage of shadows for cooling season, west side:		%	
Energy Related Data:			
Total efficiency of heating system:			
Total efficiency of cooling system:			
Usually cooling set point:		°C	
Usually heating set point:		°C	
Usually dehumidify set point:		%	
How is the heat supply realized (gas, oil, district heating, etc.):			
Heat recovery rate:		%	
Type of the (main) lighting systems:			
For the current year			
Total costs for electricity:		€	
Total costs for cooling energy:		€	
Total costs for heating energy:		€	
Total consumption of electricity:		kWh	
Total consumption of cooling energy:		kWh	
Total consumption of heating energy:		kWh	
For the preceding year			
Total costs for electricity:		€	
Total costs for cooling energy:		€	
Total costs for heating energy:		€	
Total consumption of electricity:		kWh	
Total consumption of cooling energy:		kWh	
Total consumption of heating energy:		kWh	
For the year before last			
Total costs for electricity:		€	
Total costs for cooling energy:		€	
Total costs for heating energy:		€	
Total consumption of electricity:		kWh	
Total consumption of cooling energy:		kWh	
Total consumption of heating energy:		kWh	
These documents are attached [yes / no]			
Electricity bills			
Bills for fuel / gas			
Water bills			
Audit records (if exist)			
Building plans			
Predefined Individual Targets (if existing, for example planned by the owner or operator of the building)			
Yearly reduction of energy costs:		%	
Yearly reduction of energy consumption:		%	
Yearly planned investment for renovation measures :		€	
Other targets:			
Information about the person completing this form:			
Name:			
Date:			
Phone number:			
E-Mail address:			

Walk-through questionnaire

Walk-though questionnaire		
General (EnMS)	**Answer**	**Notes:**
Does the company have an energy manager?		
Is an energy controlling carried out periodically?		
How is the energy controlling executed? (short explanation)		
Is there an energy cost management?		
Does any energy efficiency analysis has already been carried out?		
Are regular internal energy trainings conducted?		
Does the company already has a management handbook for other standards (e.g. DIN EN 14001)		
Did the the company already has introduced other standards (ISO 9001, DIN EN 14001)		
Is there a peak load management for electricity?		
Do the company's staff properly know how to use all existing equipment? (e.g how and when electrical equipment must be activated on energy saving or standby mode / switched off, manual regulation of heating and ventilation systems)		
Lighting		
Do there unnecessary lighting exist? (Where natural lighting can be used)		
Are the lighting installed to cover a maximal area?		
Are all lighting systems in working condition?		
Is there an automatic lighting system for intermittently occupied spaces?		
Do all windows allow in maximal natural light? (may be blocked by furniture etc.)		
Are there energy saving lamps installed? (it concerns all lighting systems)		
Heating and Cooling		
What is the temperature at normally heated areas?		
What is the temperature at less heated auxiliary areas?		
What is the temperature at not heated auxiliary areas?		
What is the temperature at normally cooled areas?		
What is the temperature at less cooled auxiliary areas?		
What is the temperature at not cooled areas?		
How the temperature vary during the day?		
How is the staff feelings about the temperature? (too cold / too hot)		
Do all space heating systems work properly? (may need a maintenance or reparation)		
Are heating systems equipped with a temperature regulation valves(TRV)? If yes, are they set correctly?		

Are heating systems operate efficient? (may be blocked / wrong installation)		
Do the heating have a different temperature range for the night time and holidays?		
Do there unnecessary heating or air conditioning exist? (unused or rarely used spaces)		
Do heating and cooling systems operate at the same time?		
Do there an electric heating equipment?		
Are external windows and doors open when the heating or cooling is on?		
Do cooling systems have an automatic temperature regulation?		
Is it possible to use the natural ventilation? (opening windows)		
Electrical equipment		
Are all electrical equipment in operating condition? (they can consume more electricity than they actually need)		
Are electrical equipment placed correctly? (some equipment can have an influence on functioning and performance of other one)		
Are all electrical equipment switched off at the end of the day?		
Is there any equipment which has to operate round the clock?		
Are printers, photocopies, fax machines and other temporary used equipment on energy saving mode during the day?		
Is there any equipment which can be switched off during the day?		
Do the staff use external / portable devices consuming electricity? (Laptops, mobiles etc.) How many and how often?		
Building Envelope		
Is the building well insulated? (walls, windows, roof)		
Are windows and doors properly sealed?		
Do building's windows have blinds? If yes, are they closed at the end of the day during heating season?		
Do the building have shutters on windows? (to avoid overheating in summer and save the warmth in winter)		
Water Use		
Is there any water leakage?		
Are all taps and water supply systems in operating condition? (Do they need a maintenance?)		
Are the taps left running?		
Are there automatic taps?		
Is there a hot water supply? Or there is an internal water heating system? (Boilers)		
If exist, do boiler's timer set properly?		

Documentation Templates

Main energy consumers	
№	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Measurement points	
№	
1	
2	
3	
4	

Opportunities for increase of efficiency of a building			
№	*Electricity*	*HVAC*	*Water*
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Opportunities for increase of efficiency of a building		
№	*Construction*	*Organizational*
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Energy Consumption			
	electricity	*heat*	*cooling*
For the current year			
For the preceding year			
For the year before last			

Energy Costs			
	electricity	*heat*	*cooling*
For the current year			
For the preceding year			
For the year before last			

	heating performance
For the current year	
For the preceding year	
For the year before last	

Total energy consumption values	***Value***	
Energy consumption per consumers		***Energy costs***