American University of Armenia
College of Science & Engineering
COMPUTER AND INFORMATION SCIENCE

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TITLE OF PROJECT: (Note: Titles should not exceed twelve (12) words. Any changes must be reported to College of Science & Engineering in advance of filing completed works)

Comparative Analysis of Municipal Energy Information Management Approaches in Yerevan

DESCRIPTION: ***Please attach a proposal*** to this form describing the work to be performed. Proposal should include purpose, statement of problem, methods or materials to be used, expected results, timeline, etc.

SUPERVISOR: **Faculty Member** √ **Other (e.g. from industry or other university, requires Dean's approval)** ☐

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☐Thesis ☐Project requirement for the Master of Science in Computer and Information Science

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Comparative Analysis of Municipal Energy Information Management Approaches in Yerevan

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1. Introduction and Problem Statement:

Global energy consumption is increasing rapidly, causing concerns for energy costs in production of goods and services, as well as, accelerating global climate change. This creates high demand for proper management of the limited resources and the growing needs. Energy Management is systematic approach that comes to deal with this by identifying and examining the potential savings in costs and consumption and controlling the energy waste, while maintaining routine monitoring and verification of savings. Energy Management's fundamental purpose is to ensure sustainable energy consumption, reduce the ecological footprint and greenhouse gas (GHG) emissions, while staying competitive and / or maintaining low operational costs [1]. According to ISO 50001 "Energy Management Systems standard certification", which is based on common elements found in ISO 9001 "Quality Management" and ISO 14001 "Environment Management", energy management plan is based on the principle of continuous improvement. [2]. Energy Information Management (EIM) is the basis and the most critical part of the Energy Management, EIM collects data to support the Energy Management by observing and reviewing the energy flows, calculation of energy baselines and addressing the energy flows abnormalities and hotspots. [3]

There are two main EIM approaches: traditional manually done and automatically, software based. Various research studies indicate that the information and communication technology (ICT) sector has enough potential for reducing global energy resource consumption and GHG. This sector could save up 15% of global CO_2 equivalent emissions by 2020 [4,5]. However, ICT

sector itself challenges the environment and the global energy reserves and is considered to be relatively expensive.

On the other hand, EIM procedure, where practiced, in most of developing countries including Armenia is being done in traditional ways, by observation and documentation the energy flows in buildings, by hand and naked eye. Nonetheless, this procedure is very time consuming, labor intensive and also energy demanding in the context of administrative facilities which are occupied with computers, printers, heating and cooling systems and so on. Also, most critically it can be very inaccurate.

Therefore, it is considered a fundamental decision for governments and municipalities whether they choose to switch to software based EIM or prefer to stay on the traditional manual practice, because of the challenges of each method vary by country.

However, energy efficiency and energy management also helps solving practical energy security issues in energy poor countries like Armenia. It has been addressed by several laws, like in *Law on Energy Saving and Renewable Energy* of 2013 [6], which had outlined the main trends and techniques of Armenia's energy efficiency strategy. Furthermore, it underlined the critical role of training and education in energy efficiency's process, emphasizing that the energy savings topic has to be included into the curricula of elementary, secondary, graduate, supplementary and post-graduate educational institutions, also, to develop energy savings educational training programs for engineering staff. These issues have further been emphasized in Armenia's National Program on Energy Saving and Renewable Energy, 1st and 2nd (pending adoption) National Energy Efficiency Action Plans. On this path, the significance of this study comes to spread awareness and importance of energy savings and its techniques by making a comparative analysis of the previously mentioned two methods in the capital city Yerevan, in a specific time interval. The

findings of the study can further be applicable in advocated a specific approach for municipal energy management for the cities of Armenia, which are gradually attributing more importance and attention to these issues. The best testament to that is that there are already 15 cities signatories to the EU Covenant of Mayors [7]. And all the cities, as one of the most critical elements in their Sustainable Energy Action Plans must include municipal energy management. After discussing and measuring the qualitative and quantitative benefits and downsides of each method in context of accuracy, energy and other resource consumption, GHG emissions, financial and social costs and labor intensity the proper method will be recommended. In order to achieve this, many tools are going to be implemented, including; Total Quality's "Cause and Effect diagram", Carbon Footprint, financial and economic interpretation and MATLAB or R programing languages.

2. Goals and Objectives:

The main aim of this study is conducting a comparative analysis between manual and software based EIM approaches in areas of energy consumption, GHG emissions, costs, benefits and accuracies for Capital city Yerevan. Which helps to determine the proper method to manage the energy information.

The objectives are:

- Illustrate the importance and necessity of the EIM in overall Energy Management process of public organizations, as an additional argument in support for Energy Management.
- Suggest the proper EIM method that insures low costs and footprint, yet accurate and quick results.

- Summarize guiding criteria and recommendations to public and private sector decision-makers on the choice of particular EIM approaches, establishment of energy information accounting system, for better analysis, planning and management aimed at sustainable energy use.

3. Literature Review:

The following cases represent three different types of organizations that have implemented EIM in their environments, through these cases we can notice several reasons for these implementations, and highlight, the benefits and lessons from proper EIM systems.

1. University of California, Santa Barbara (UCSB) [8]: - Educational sector buildings -

The reason for applying energy information systems (EIS) had been the dedication from UCSB to energy conservation and efficient use of the EIS. The UCSB has 4.5 million square feet of building area, it has many laboratory buildings which are more energy-intensive. The EIM software application was useful in identifying suspicious energy consumption patterns and chances of energy savings. For example, in Physical Science Building, the electricity load profile was flat. The energy manager found that the supply and exhaust fans were operating 24 hour every day at 100% load. Then he reported the problem and convinced the building staff to reduce the operation speed of the fan 50% between 12 am and 7 am. This contributed to significant energy savings without effecting the good air quality. The campus's overall energy savings in one year was $295,000, with payback period of 1.2 years. The energy and the facility manager were spending notable amount of time in observing and evaluating energy projects, and gathering data and reports. Now, they have more time to plan future energy saving projects. Unlike the cost

savings, these benefits cannot measured easily. The advice that comes from this study, as the energy manager of the UCSB stated, that, if facilities did not have a proactive individuals to analyze the data, the EIS would be useless.

2. Tower Companies ("Tower")[9]: - Commercial sector buildings -

The Tower Companies ("Tower"), are three large, multi-tenant office buildings locates in Washington D.C. The reasons to implement EIS in Tower Companies were to optimize energy use and eliminate the wasted energy, due to understanding about energy use in each building and catch the random energy flows. Total project expenses resulted from software based EIM implementation averaged around $48,000 per building, ($144,000 for all three buildings). Including; metering, hardware, setup expenses and annual energy management and monitoring. Counting only the savings from electricity used, which declined by 13% during 12-month period, the project returned over $74,000 on total project costs of $144,000. The project also reduced maintenance expenses and increased the life of major building systems. Furthermore, the authors illustrated the lessons learnt from this case study, which emphasis the role of operational improvements in reducing energy waste, rather than large investments in building improvements. As well as, they reported that, even in high energy performance buildings, such as "Tower", better energy management prevents the wasted energy, because building systems routinely stray from optimal.

3. IBM semiconductor manufacturing [10]: - Industrial sector building -

The Bromont plant is IBM's largest semiconductor assembly facility located in Quebec, Canada. It occupies 13,935 square meters. Every system produced by IBM worldwide, uses at least one Bromont manufactured component. The key reasons for using EIM was reduction of energy costs

and CO_2 emissions. And in fact the energy savings from electricity and natural gas from 2004 to 2014 was about $6,000,000, reducing the electricity consumption 25% as compare for 2008 record. Enabling a 59% reduction in GHG emissions to the 1990 reference year, and a 24% reduction relation to 2005. On the other hand, achieving a competitive advantage in the semiconductor industry was the most critical benefit, since energy savings contributed to reduction in operating costs and facilitated the installation of advanced equipment to manufacture new semiconductor technologies. Nonetheless, IBM got certified with ISO 50001. The authors later indicated the lessons learned from this implementation, which includes the necessity of engaging the staff with the EIM procedure and invest in training the personnel that using the energy management tools. Also, establish energy performance criteria with procurement staff.

The following three cases represent a small proportion of large number of facilities that implemented EIM. They also illustrate the applicability of EIM in various circumstances and the critical role of energy management in entire organizations management systems.

Like done earlier, this thesis study aims to examine the advantages of applying the EIM in Capital city Yerevan and address the potential financial, social, environmental and energy security benefits of EIS in developing countries, like Armenia. However, unlike in the previous cases, the comparative analysis will be perform between manual and automatic energy management systems to differentiate the accuracy, speed, quality and expenses, as well as, carbon footprint resulted from activities performed by these systems.

4. Theoretical Background:

3.1 Emissions Factors and Global Warming Potential (GWP) indicator [11]

A single activity can produce different type of Greenhouse Gases, in general electricity use and natural gas burning, produce the following Greenhouse Gases; Carbon Dioxide CO_2, Nitrous Oxide N20, Methane CH_4.

In order to convert the energy consumption to GHG emissions we need to know the emission factors of each gas. Emission factor is the ratio corresponding to the amount of a Greenhouse Gas emitted as a result of a given unit of activity. For instance the grams of Carbon Dioxide per kWh of electricity (g CO_2 /kWh). These factors often are provided by governmental institutions, or from academic and research papers. As a signatory to the UNFCCC Armenia regularly updates its electricity grid emission factor as a standardized baseline for energy sector projects' carbon footprint. The Grid emission factor derived for use by a project activity for an electricity system is equivalent to 444 kg CO_2/MWh.

The same approach will be used for assessing the carbon footprint of other fuels. The below table summarizes all fuel emission factors to be used for calculation of carbon footprint:

Emission Factors Use in the Sustainable Energy Action Plan for Yerevan [12]

Energy carrier	CO_2 Emission factor (kg CO_2 equivalent per MWh)
Electricity	444 *
Natural Gas	202
Anthracite	341
Liquefied / compressed natural gas	227
Gasoline	249
Diesel fuel	267

*[13] the Grid emission factor calculated by CDM methodology

For natural gas the emission factor is linked to the calorific value of natural gas within a given country. Depending on the calorific value in a given year, the average conversion factor for natural gas is 202 kg CO_2/MWh produced from natural gas. The transition from volume of gas (cubic meter) to energy (kWh) is carried out using the factor of 9.186 kWh/m^3. Hence, the calculated conversion from 1m^3 of gas to CO_2 emission is 1m^3 * 9.186 * 0.202 = 1.856 g CO_2

The energy sector also generates a small amount of non-CO_2 gases with greenhouse effect. These are considered as non-key sources of climate change and are a relatively insignificant source. Should time permit, the study will also address their impact on the overall GHG emissions balance for Yerevan. The methodology to be applied is described on an example below.

Example: let's say a gas bill value of 14,356 Mł of natural gas, to calculate the GHG emissions of this activity the amount of natural gas should be multiplied by each emission factor, as follows:

14,356 Mł * 1.856 g CO_2/ Mł= 26644.736 g CO_2 ~ 0.027 t

14,356 Mł * 0.037g CH_4/ Mł= 531.172 g CH_4 ~ 0.0005 t

14,356 Mł * 0.033 g N_2O/ Mł= 473.748 g N_2O ~ 0.0005 t

We cannot just sum up all these three numbers together to come up with a total, because each of these Greenhouse Gases are not equal in term of their impacts on global warming. In order to correctly add up these emission quantities, we should convert them to a common unit, this is done by applying global warming potentials (GWP); which is a ratio denoting the effect of a quantity of a Greenhouse Gas on climate change compared with an equal quantity of Carbon Dioxide. This value is usually calculated over 100 year period and it also periodically refined.

Because GWPs are based on carbon dioxide, the GWP for CO_2=1, the results of applying GWP is expressed in Carbon Dioxide Equivalent (t CO_2), GWP for CH_4 =25 this means that emissions of 1 tons of CH_4 have the same effect on climate change over the 100 years as emissions of 25 tons of CO_2. Now they can summed up to provide a single value representing the GHG emissions resulting from this bill.

0.027 t * 1= 0.027 t CO_2e

0.0005 t * 25= 0.0125 t CO_2e

0.0005 t * 298= 0.149 t CO_2e

Now when each of the emissions have the same unit, they can be summed up to provide a single value representing the GHG emissions resulting from that activity provided by that bill.

0.027 t CO_2e + 0.0125 t CO_2e + 0.149 t CO_2e = 0.1885 t CO_2e

As follows to calculate the complete organizational carbon footprint we have to perform these calculation for each activity data point collected within reporting period. This means doing this on each natural gas or electricity bills. Then when we have all GHG emissions resulting from each activity as quantity of Tones Carbon Dioxide Equivalent we can sum these values up and determine how much GHG resulted from each activity over reporting period, often one year.

3.2 Cause and Effect diagram (Fishbone diagram) [14,15]

Cause and effect diagram is one of the seven Total Quality's tools that enables today's employees, whether engineers or technologists, managers and decision makers to do their job in more effective manner, that insure the continual improvement of provided products or services. As well, it is the only tool of the seven that is not based on statistics.

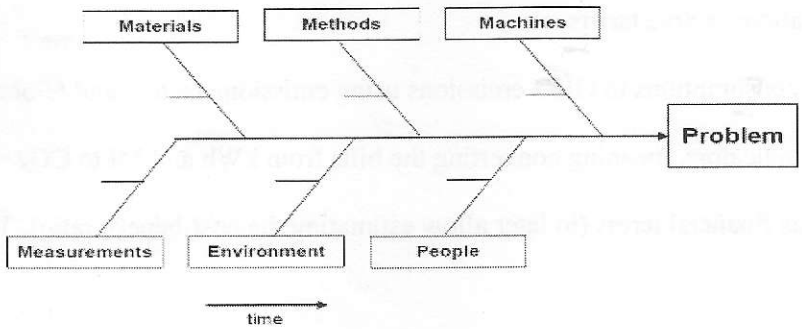
This technique was developed by Dr. Ishikawa, a well-known Japanese quality expert. So sometimes it's called by his name as (Ishikawa diagram). Also, it could be called as Fishbone diagram because it looks like it.

The Cause and effect diagram is an easy yet powerful tool, basically used to visually describe the potential root causes for a particular problem and showing how various factors associated with a process affect the process's output. By knowing the causes, we can change or modify them to meet our goals and objectives. By understanding the nature of the cause and effect principle, the diagram could be helpful to solve everyday problems every time.

It is constructed as follows:

1- Define the problem (effect) to be solved. This is the most critical step, since the problem should be defined clearly and accurately. On the diagram this is represented by drawing a horizontal line.
2- Highlight the key causes of the problem. These causes usually are grouped under the following categories; Materials, Measurement, Methods, Machines, Environment, People.
3- Identify the reasons behind the key causes, in order to find out various causes behind each key cause.

The final shape of the diagram will look like this:



5. Methodology:

First let us indicate that by saying energy management systems in Yerevan city we mean planning, controlling and managing the municipal energy use. To effectively carry out this task, the municipality needs to have a detailed and accurate database for a number of consequent years for all forms of energy consumption in individual municipal buildings (administrative buildings, kindergartens, hospitals, policlinics, athletic and cultural facilities, where delegated – the schools as well), as well as street lighting, municipal water supply, irrigation, water fountains, municipal fleet and public transportation vehicles, electric transport (metro, trolleys), municipal garbage and sanitation service vehicles, even the municipal greenhouse. Including commercial and private ones is a decision that the community makes based on the scope of its authorities, available resources and political leverage. Hence, the methodological approach is as follows:

1- Collect data about the types of main sources of energy consumption in both methods: which are in forms of electricity and natural gas bills in case of manual EIM, and estimated energy demand in case of software based. These will be available from the "Sustainable Energy Action Plan" of Yerevan" developed by the Foundation of to Save Energy NGO and from the software vendors themselves. Assess the scope of additional information necessary, such as the physical parameters of energy consumers, climate data, installed technological equipment, beneficiaries in service, compliance with national standards and regulations, active tariffs, etc.

2- Convert the energy consumptions to GHG emissions using emissions factors and Global Warming Potential indicators, meaning converting the bills from kWh and MJ to CO_2 equivalent, as well as financial terms (to later allow estimating the cost-benefit ratio). This

calculations and the necessary plots will be done using MATLAB or R programming languages.

3- Use the above data analysis to identify potential uncertainty ratio. The quality of sample data manually collected by the municipality will be analyzed based on historical trends, comparative benchmarks and comparison of per unit energy use (e.g. kWh electricity per square meter), as well as accounting data on financial expenses for utility bills' payment. The results of the analysis will reveal what share of the data has statistical inaccuracies, which may cause sensitivity of the energy data analysis, as well as consequent conclusions and recommendations. Tools to be used included uncertainty analysis, sensitivity analysis, and risk analysis.

4- Highlight the qualitative benefits and downsides of each method. For example, illustrate the poor quality of data collection and management process from using the manual based EIM and the limitation of the software based EIM, by implementing Total Quality's "Cause and Effect diagram".

5- Execute financial and economical interpretation by performing Benefit/Cost Analysis, and calculate the payback period of each method and the effectiveness of energy management in general.

6- Based on the previous procedures make conclusions and recommend the proper approach that is justified financially, socially and environmentally for Municipalities in Capital City Yerevan.

6. Expected Results:

Taking into consideration the current limited resources of Armenia, the study is expected to compare the traditional manual based EIM with the software based EIM for Capital City Yerevan, in context of their energy consumption, GHG emissions, costs, benefits and accuracies.

On the other hand, the results of this study would strongly depend on the context of the energy user, as well as the decision-makers range of priorities, whether these financial, environmental or political…

The fundamental targeted results for this comparative analysis study are the follows:

- Spread awareness and educate decision-making on introduction of EIM which is the basis for proper energy management process that results in solving energy savings and energy security issues in Armenia.
- Highlight the significant role of EIM in addressing the energy hotspots, which helps decision makers to prioritize the urgency of energy saving plans.
- Reveal the applicability of EIM in private sector, where information is easy to access and potentials of investments in energy savings are relatively high.
- Comparing the manual and software based EIM methods in terms of their footprints, is the first step to remark the relation and connection of the energy consumption rates to corresponding emissions and causes of global warming and climate change. And try to make it a prior decision when choosing any equipment or system, whereas a boiler in a house, a machine in a factory or a software for a facility.

- Emphasize the critical role of quality assurance when choosing and implementing any EIM method. And make it from major comparing factors, rather than focusing only to the financial costs and expenses.
- The recommended method by this study could be endorsed for implementation in municipalities of other cities in Armenia, including the 15 cities that are already signatories to the Covenant of Mayors.

7. Timeline:

	January	February	March	April	May
Literature Review					
Data collection					
Emissions Calculation via MATLAB/ R					
Brainstorming for Setting up the Fishbone Diagram					
Cost/Benefit analysis, Uncertainty analysis, Payback period calculation					
Deeply clarify pros/cons of the two methods					
Comprehensive results interpretation					
PPT creation & oral presentation review					
Thesis submission & defense					

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