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Energy Management at McGill Research Laboratories (I)

Christopher Tegho
Matthew Gidaro Da Silva
Yining Yuan

Categories

Supervising Professors:
Francois Bouffard & Dror Etzion

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ENERGY MANAGEMENT AT MCGILL RESEARCH LABORATORIES

Christopher Tegho (260400058) - ECSE 456
Matthew Gidaro Da Silva (260207491) - ECSE 474
Yining Yuan (260351697) - ECSE 456

Supervised by
Prof. Francois Bouffard, Department of Electrical Engineering
Prof. Dror Etzion, Desautels Faculty of Management

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Project Abstract

This project aims to design an Energy Management Toolkit in research Laboratories at McGill University. According to the McGill Energy Management Plan, such a tool is essential for effective improvement of energy performance and results in 5 to 15% of energy savings. The system solution records and monitors energy consumption of research equipment of a research laboratory using power meters installed at distribution feeders servicing the entire lab space. The system has proven to be innovative and cost effective with the proposed device signature analytics and the communication network. A communication protocol and channel between the meter and the data storage system is developed. Consumption data is stored and data analysis is performed with an understanding based on the survey of researchers' equipment usage patterns. Analytical aids to help users understand the data and use that understanding to effectively reduce energy consumption in their lab are provided. The final toolkit is a product which, after validation with the pilot lab, requires the installation of a power meter and includes a software package, and a user manual.

Acknowledgements

This project was possible with the collaboration of our supervisors Prof. Francois Bouffard and Prof. Dror Etzion, and with the collaboration of Jerome Conraud from Utilities and Energy Management. Special Thanks to Dr. David Noble Harpp who provided us with funding, Prof. Ronald Gehr who guided us through his lab, Mr. Marc-Etienne Brunet for his inputs and suggestions, and all other labs that welcomed us. Thanks to Prof. Jim Nicell and Prof. Subhasis Ghoshal for their support. Thanks to Shivan Kaul Sahib for his recommendations, research and inputs about energy consumption data visualization. Thanks to Hubert Marcil for his inputs about the electrical configuration of the pilot labs in MacDonald Engineering, rooms 571 through 574.

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List of Abbreviations Used in the Report

EMIS: Energy Management Information System
ANN: Artificial Neural Network
SWIG: Simplified Wrapper and Interface Generator

1. Introduction and Motivation

McGill University is one of the largest energy consumers among post-secondary education institutions in Canada [1]. Despite the fact that the Ministère de l'Éducation, du Loisir et du Sport has mandated that by "2010- 2011 postsecondary institutions should reduce the intensity of their energy consumption relative to 2002- 2003 figures by 14%" [1], the energy system of the downtown campus remains inefficient.

Research laboratories are identified as "one of the three most energy intensive building types overall" by the US department of Energy with a significant part of that energy consumed by fume hoods or freezers [2]. Audits performed on McGill's Downtown campus confirm that buildings with research laboratories consume more energy per square foot than other buildings without such laboratories. For instance, research equipment in the Genome building consumes 17% [3], and in the McConnell Engineering 18% of the total building energy usage [4].

Understanding energy consumption in laboratories is essential for effective improvement of energy performance [5]. Our project aims at developing an energy management information system (EMIS) for research laboratories. The system provides relevant information to laboratory users to help them manage their energy use and costs.

Energy savings resulting from the implementation of "a quality Energy Management Information System typically ranges from 5 to 15%, on average" [1, 5, 6]. Furthermore, direct feedback about consumption is essential and quite valuable in influencing behavior [7], and information awareness combined with incentives encourage people to actively participate and provide indirect monetary benefits [8, 9, 10].

This EMIS serves as a key element of the McGill Energy Management Plan which includes developing and implementing improvement opportunities and conducting energy audits. Our work is supervised by Prof. Francois Bouffard from the department of Electrical Engineering, Prof Dror Etzion from the Desautels Faculty of Management. We are also collaborating with Jerome Conraud from Utilities and Energy Management. Dr. David Nobel Harpp, Tomlinson Chair in Science Teaching and Macdonald Professor of Chemistry, funded our project with $4000.

While our EMIS delivers information regarding electricity consumption only, other projects on campus, including the one undergone by Marc-Etienne Brunet, currently in progress are developing tools to monitor and manage energy consumed by fume hoods, waste and other elements in research laboratories.

2. System Overview

Figure 1 provides an overview of the system to be developed. The system comprises of power meters and sensors that monitor the energy consumption of the entire laboratory and/or individual elements in the lab. The measured parameters include active and reactive power, current and voltage [5, 6, 11]. A communication medium ensures the transmission of the data to a data center, which includes data acquisition software, data processing software, multiple databases, and a user interface.
Further details about the elements, features and deliverables of an EMIS are found in Appendix A.

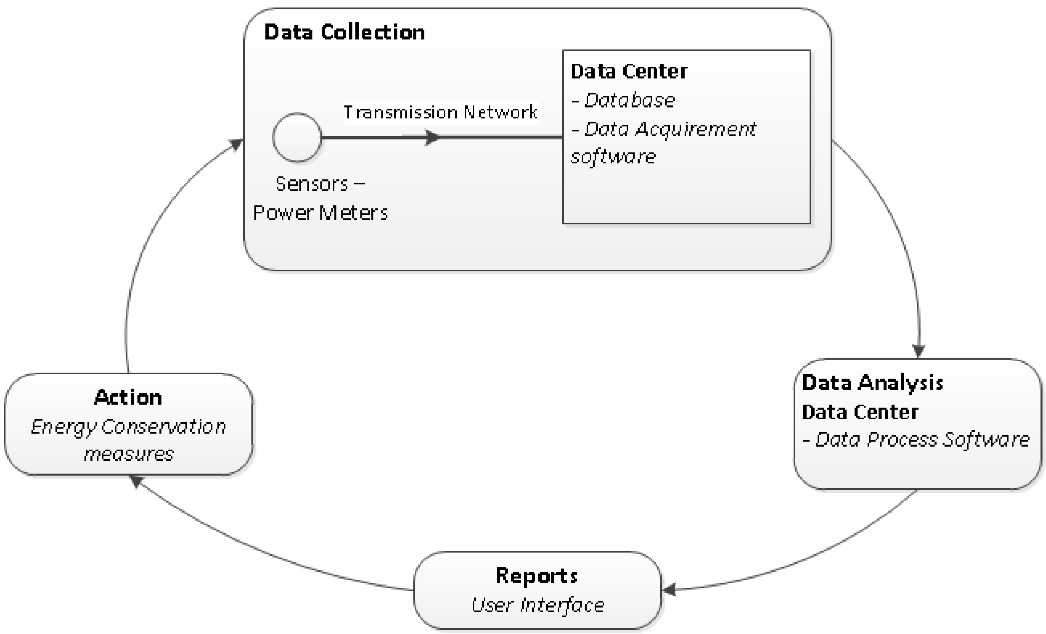

Figure 1 - Energy Management Information System Overview

3. Literature Review and Related Work

Power Monitoring

Multiple devices and methods for power monitoring exist on the market. A simple method is suggested by Patel et al: for a device of a known constant power consumption, it is possible to use a sensor that detects the electrical noise on power line created by the abrupt switching of the electrical device. “Machine learning techniques are used to recognise an electrically noisy events such as turning on or off the device.” [12] Knowing the power consumption profile of a device, it is only necessary to know when this device is on to monitor its energy consumption. However, in the event of turning on or off two or more devices simultaneously, errors in classification might be produced because of combined transient noises. To avoid the problem, separate metered units are needed, which is not the case in most research labs at McGill. In addition, “the electrical lines may be so long that the noise does not reach the analyser” [12].

It is also possible to measure high frequency electromagnetic interference which propagates on a power wiring and which is produced during operation of a device. Unlike the previous method, this approach works even when similar devices are switched on simultaneously. Although these two methods are quite promising, the devices for which the energy consumption is to be monitored need to be switch mode ones, which might not be the case in research labs.

Another well-known sensing device are the current clamp meters. They have two jaws which open to allow clamping around an electrical wire. The current is measured with magnetic sensors since the magnetic field variations near power lines directly correlate with the current flowing inside the wires [13]. However, such meters do not measure the voltage and assume the voltage value which results in measurement errors since the voltage in the outlets in McGill's buildings are not constant. They can also deteriorate after a short circuit because of magnetisable materials used in the design.

The Fraunhofer Institute has developed a power measuring device based on magnetic field sensors. Although the device is still not on the market, it is a very promising one [14]. The sensor is clipped to the power cable and does not require unplugging the load. The device includes multiple magnetic field sensors that are mounted in the form of application specific integrated circuits. These sensors measure the magnetic field not only perpendicular to the surface of the chip on which they are mounted, but also in tangential directions, improving measurement accuracy. The device does not use any magnetisable material and can measure voltage, offering a great remedy to the clamp-on meters.

Some direct-sensing devices measure real-time electricity consumption per outlet. For example, Kill-A-Watt and Watts Up devices provide accurate measurements but require in-line installation between a standard AC plug and the outlet [13, 15]. Although this is not a problem for some devices in a research lab, some other devices such as electric boilers do not have standard AC plugs or "are hard wired to the main power lines".

One cheap and easy method is the use of plug-in electricity meters. The meter is plugged into an outlet and the load is plugged to the meter. However, this constitutes a major challenge in a lab, where many devices cannot be turned off or unplugged. Other limitations include inaccuracy in readings particularly for low power devices, especially when in standby mode. To improve accuracy, a standard load such as an incandescent light bulb can be added to the circuit to get out of the low power zone and the difference in power consumption is measured [16].

Other sensing methods include recognizing and classifying events based on sound [17], which can be more beneficial for behavioural studies than monitoring power consumption. A similar approach consists of measuring signals (acoustic and others) emitted by an appliance when it consumes energy [13]. The measured signals come from magnetic, light and acoustic sensors. This does not require any monitoring device in-line with the electric wire. An autonomous sensor calibration framework is developed to avoid uncertainties in installation of indirect sensing methods, changes in conditions and sensor variability. Adding an adaptive filtering mechanism would reduce external noise to which indirect sensors are generally more prone.

Data Transmission and Communication Network

The communication and transmission network of the system includes two parts: a bus network that transmits data between the meters and the data collectors and another bus network, either wired (Ethernet) or wireless, that transmits data between data collectors and a computer or a server [18]. The network can include communication servers, Ethernet devices or internet and bus networks. The communication servers serve as the communication controller, the front end processor, and the communication manager [18]. Figure 2 summarizes the structure of the communication and transmission network.

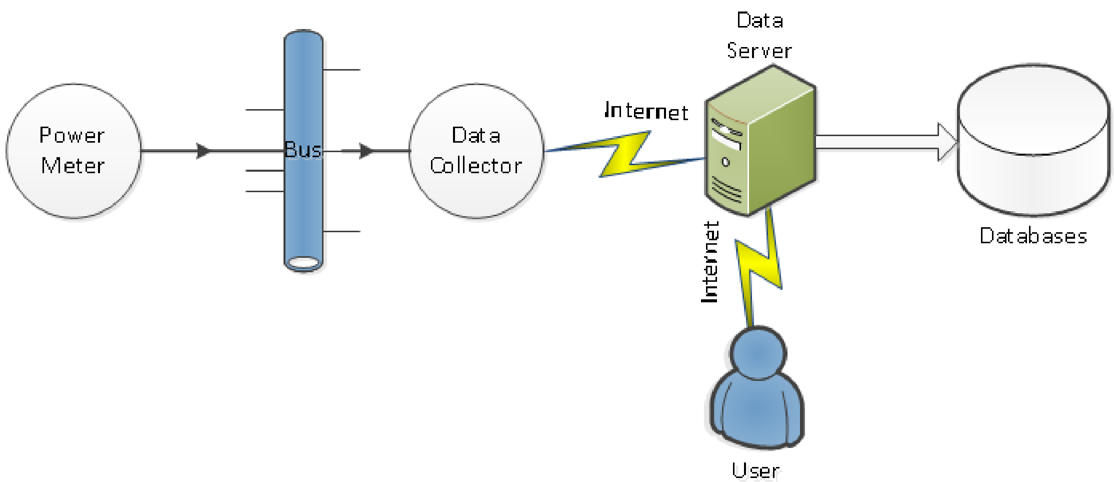

Figure 2 - Structure of the Transmission and Communication Network

There are two methods which can retrieve a meter reading with little human intervention: Automatic Meter Reading (AMR) and the automatic polling mechanism (APM). The AMR method is the mechanism where the energy meter sends the recorded power consumption data every certain interval of time to a reader which could be a PC or a server; whereas with the APM method, the reader, e.g. PC or server, polls the meter to get the meter reading [19]. A Bluetooth technology based on any of these methods was developed by Koay et al. to allow a wireless communication system. Other communication methods or systems are summarized in Appendix C.

Most technologies for smart energy management systems use IEEE 802.15.4 and ZigBee [25]. Sun et al [26] explain that the ZigBee technology is an emerging wireless communication technology which can be used in the electrical power automation area for "wireless meter reading, power system monitoring, and electrical parameters measurement" and is very effective in monitoring power system operations and in improving system efficiency and reliability.

The ZigBee network has multiple advantages [27] for power monitoring:
- Data rate suitable for power monitoring systems, up to 250 kbps.
- Low power cost.
- Large capacity as it can support up to 65000 nodes, which is suitable to a complex power system.
- Short time delay that last for 15 to 20 ms allowing real-time data transmission.
- Low cost for installation, and operations, and maintenance is simple.
- Strong safety
- Strong anti-interference

Bocheng [28] suggests to configure data servers, responsible for management and saving of data, with the Redundant Arrays of Inexpensive Disks (RAID) in order to ensure data safety. Two databases are necessary for managing energy consumption data: one that saves the data transmitted from the metering devices and another one that serves as a terminal database and that saves the processed data.

Device Signature

Device signature identifies the devices that are consuming electricity and their amount of consumption in real time. It is an important feature in an EMIS, as it helps pinpoint the devices and research processes, which needs special attention in terms of electricity conservation. Furthermore, device signature can be used to develop load-shifting techniques, to analyze electricity expenditure per device and to study occupant activity.

Device signature is still a technology being tested in research labs, and on home appliances. There are no commercially available products with device signature features for research labs; neither is there any research prototypes being tested on lab equipment (i.e. quasi-industrial loads, as opposed to home appliances).

The main challenges in developing an accurate device signature algorithm are presented as follows:

1. Devices with similar current/voltage/power draw [29, 33]: The algorithm should differentiate among devices with similar consumption signatures. For such an algorithm to work, parameters as part of the device signature need to be representative of a device's energy consumption behavior.
2. Devices with multiple working modes [29]: Unlike home appliances, lab devices have at least three modes in general (i.e. on, off, and stand-by modes). The algorithm should accommodate several signatures associated with each single device.
3. Simultaneous on/off events generated by multiple devices [30]: It is common for a lab to be operated by multiple lab users at the same time. Therefore, the algorithm should be capable of clearly identifying which devices are on/off rather than confusing the difference in the total instantaneous power signal (caused by multiple devices' on/off events) with a single device on/off event.
4. Device noises [34]: Some lab devices have transient states and steady states. The algorithm should recognize devices' transient state signals, and not relate one device's transient signal to another device's steady state signal by mistake. In addition, the algorithm should be able to anticipate a steady state signal of the same device after spotting a device's transient signal.
5. Environmental noises [29]: Regardless of the pattern recognition algorithm/ machine learning language used, a database of pre-profiled device signatures is used to decompose the total power signal. The algorithm should filter out or clearly identify a device that has not been previously stored in the database.
6. Introduction of new devices [30]: The algorithm should provide a long-term solution with minimum maintenance required for the profiling process of newly purchased lab devices.

7. Timely algorithm feedback [29]: The algorithm should be able to provide real-time device consumption data, in order to engage occupants.

8. Devices without distinct states [29]: The algorithm should isolate, if not identify, devices with continuously changing power consumption. Otherwise, such devices will contribute noises to the total power signal.

In A.G. Ruzzelli et Al. [29], the design methodology of a RECAP (RECongition of electrical Appliances and Profiling) system is presented. A RECAP system is single-point real-time monitoring system. A database of individual device signatures is obtained from the sensor clipped to the main electrical unit, by turning on only one device at a time. This database is then used as a training set for a three-layered ANN (Artificial Neural Network), which recognizes device usage in real time. The ANN algorithm used in a RECAP system is able to decompose the total power signal generated by multiple simultaneously on/off devices. The parameters taken into consideration for the device signature database includes real power, power factor, peak current, RMS current, peak voltage, RMS voltage, signature length and sampling frequency.

In Markus Weiss et Al. [30], the design and the implementation of AppliSense algorithm. This algorithm identifies time points where changes between two levels of apparent/real power consumption in the total power signal. The difference between the two levels of power consumption will be matched to a device switching event in the pre-profiled device signature database. A filter is used to decrease the number of spurious events and to smoothen the signal. In addition, a device signature recording feature allows user to record the device signature of a newly purchased device.

In addition to the research prototypes examined above, additional pattern recognition algorithms and machine learning languages, which are an essential part of device signature, have been studied.

Simple Markov Chains is able to identify one device at a time [29]. However, this system cannot be built to handle multiple devices. Multistate Markov Chains are a possible solution. However, the complexity increases as the number of devices increases. In addition, a newly purchased device cannot be added into the system easily, which makes the long-term maintenance of the system difficult.

Bayesian classifier is able to yield reasonable results with a limited amount of data [30]. However, Bayesian classifier does not respond well to parameter variations. Real time parameters of the device signature, such as voltages, vary all the time, due to load fluctuations as well as upstream electricity distributor's equipment upgrades. Therefore, Bayesian classifier is not an ideal candidate.

[38] identifies the key advantage of ANN, which is the ability to learn complex mappings between inputs and outputs, especially when the underlying relations between inputs and outputs are not well understood. The most commonly used ANN is the feed-forward network, with MLP (MultiLayer Perceptron) for feature matching. This machine learning algorithm will be particularly useful for this project, since the inputs and outputs are clearly defined, whereas the underlying relation (i.e. what lab devices are on at any given time) is unknown. Through the supervised training phase, the ANN should be able to adapt to the data and recognize the patterns.

With the recent increase in computing power, fuzzy logic has been used extensively in pattern recognition. [39] Fuzzy logic mimics the human decision making process, which usually demands a timely response based on vague, ambiguous, noisy and imprecise input. Fuzzy logic requires some numerical parameters in order to operate. Such numerical values include what is considered a significant error and a significant rate-of-change-of-error, but exact values of these numbers can be found by trial and error, when optimizing the system performance. Fuzzy logic, essentially a control methodology, widely used in pattern recognition, is not ideal for this project. The noises in the input will be filtered out, prior to entering the device signature algorithm, in order to ensure the accuracy in identifying large lab devices and quick system feedback. In the rare case where the input is noisy and imprecise, the clustering classification method [38] in ANN can be used to resolve this problem.

Additional literature review on device signature can be found in Appendix D.

Databases

Aside from traditional database choices such as Excel and Access, whose data can only be published dynamically via Microsoft's licensed server software, Sharepoint; other databases have been researched, including flat-files, NoSQL and SQL databases.

Flat-files are a computer file system which stores data in a single file path without any traditional directory or folders [42]. The lack of organization increases the speed of such a database. However, this lack of organization hinders navigation, especially when confronted with a large amount of data.

NoSQL has an increased popularity, in response to the need to handle "Big Data". Since NoSQL has a distributed and flexible schema, it is believed to have an advantage over SQL databases, in terms of speed. [41] compared several commercial NoSQL and SQL databases, in terms of speed on their read, write, object instantiation and key iteration. Yishan Li et Al. concluded that NoSQL is faster than SQL in some operations and that no all NoSQL databases are necessarily faster than SQL databases.

SQL databases are categorized as a relational database management system (RDMS), in which each table consists of numerous fields (columns) and records (rows). Indexing of a primary key (associated with a specific field) and a foreign key (associated with table relationships) facilitates fast data retrieval through multiple large tables. [42]

Data Analysis

Microsoft Office Developer and Visual Basic for Applications (VBA) were used to develop and program the software of the energy information system suggested by Swords et al [69]. This software environment provides "faster development cycles, support for and protocols and interfaces and the development of desktop customized applications and web-based analysis systems". Furthermore, VBA allows the programming of data analysis objects and data querying for spreadsheets to provide data acquisition. A combination of linear regression (best fit), cumulative sum charts and control charts techniques can be utilized to build reports [69]. Energy data are captured from power meters but data about occupancy, weather and activity can also be used in the analysis.

The energy efficiency of a utility can be determined by comparing the baseline energy use and the Normalised Post-Installation Energy use. Simplified energy calculations can be used for equipment. However, a regression model established from existing data may be used for whole facilities in order to provide a normalised base model. Such a model may be used to predict energy usage and verify savings [69].

The power rating of each device in the lab can be included in the raw data database for comparisons and to set a target. However, a survey completed in UBC research labs show that the actual measured power consumption of equipment in labs was always lower than the power rating determined by the manufacturer [70].

Occupant engagement

Labs21 offers an online energy benchmarking tool, which can be used as targets or baselines for lab devices [31]. The occupant can compare the real time energy consumption data generated by the device signature algorithm, to the benchmarks from Labs21, in order to gain an understanding of how much more or less energy they are consuming based on the standards set by Energy Star.

[64] discusses the effectiveness of Community-Based Social Marketing (CBSM) on energy conservation for sustainable university campuses. Doug McKenzie, who developed CBSM, identified the following principal barriers to sustainable actions: lack of motivation, forgetfulness, lack of social pressure, lack of knowledge and structural barriers (i.e., safety, money, time, weather, etc.). In response to the above listed hindrance, CBSM tailored a five-step process for universities to further promote sustainable energy usage:
1) Selecting a specific behavior to promote;
2) Identifying potential barriers and benefits to that activity;
3) Developing strategies to conquer these barriers;
4) Piloting the strategy initially into a small portion of the community;
5) Putting in place and evaluating the program on a broad scale.

Gamification has a recent surge in popularity with the development of information systems. Gamification introduces game mechanics into non-gaming applications in order to increase user engagement, motivation, and participation [65]. Recent research has shown that gamification yields the desired progress from a behavioral perspective, as mentioned in [66], [67]. Additional literature review on occupant engagement is found in Appendix E. Recommendations from Shivan Kaul's report on energy data visualisation are found in Appendix F.

4. Market Research

Meters

An initial round of market research on meters was done, in order to gain a preliminary understanding of the power meter marketplace. A summary table of the initial market research can be found in Appendix G Tables 4 and 5. The criteria for meter selection is outlined below, with their respective reasoning explained in the design section.

1. Real time communication protocols.
2. Ability to generate all necessary parameters required to build a unique device signature.
3. A high sampling frequency for instantaneous power or instantaneous current.
4. Capability to measure voltages.
5. A high current measuring limit.
6. Operation with a known constant power consumption/ Ability to monitor its own power consumption.

Following the criteria listed above, the list of meter candidates has been narrowed down to a list of four meters. A summary table of these four meters can be found in Appendix G Tables 6 and 7.

Server-side web development language

In order to build a web-based user interface with real-time data updates, a server-side web development language is required. Four popular server-side web development languages have been examined. Two tables of their functionality comparison are presented in Appendix H. Ruby is chosen for our project, since it is a very expressive language, which is able to provide a good user experience.

Databases

Ruby is used as the server-side web development language for the proposed user interface. The databases examined here need to be compatible with Ruby without any further complications. The SQL databases that are compatible with Ruby are MySQL, PostgreSQL and SQLite [43].
Tables shown in Appendix I show that MySQL is advantageous over other databases in terms of speed and functionalities. MySQL is faster than PostgreSQL and SQLite when performing 1000 SELECT and INDEX operations in one iteration [44]. Although SQLite is faster when performing UPDATE operation, operations such as SELECT and INDEX are the main operations required for this project.

In a meeting with Alexander Ostrow, who is developing a database and a web-based user interface for McGill Energy Project's Fume Hood Management System, the team came up with minimizing memory usage on data servers by recording data only when a change has occurred, instead of recording data continuously into the "Raw Data" database. Such an approach is based on the assumption that the consumption data does not change all the time. However, this approach is not applicable to this project, since the electricity consumption in a research lab is almost constantly changing.

5. Field Work

Lab Visits

At the very beginning of this project, an initial round of three labs were visited. The purposes of these lab visits were to gain an initial understanding of the current energy usage in research labs at McGill (including the equipment nameplate ratings and how often the equipment is used). A summary of these three lab visits are summarized in Appendix L.

After the project scope has been laid out in detail, one or two pilot labs are selected to work with, in the prototype solution phase. The pilot lab selection criteria includes:
1) Motivation of Lab Users: cooperation with lab users is needed for the project implementation.
2) The lab can be electrically shut down for around fifteen minutes if needed, in order for the power meter to be installed in the circuit breaker panel.
3) The lab has a wide variety of devices, in an effort to cover as many different devices as possible in the prototype solution.
4) A minimum restoration time is required for devices which need to be on 24/7, in order to avoid monetary and time losses for normal research processes.

At the moment, the Benedek Integrated Laboratories in Environmental Engineering [79] is chosen as the pilot lab. This lab is particularly ideal, since it has a lot of equipment with large power consumption. This means that their device signatures cannot be filtered out as noises. The lab equipment in this lab is a good representation of common lab equipment being used in most labs at McGill University.

In collaboration with McGill's supervising electrician as well as Utilities and Energy Management, in the chosen pilot lab, three three-phase service breaker panels on location within the chosen lab space, or a possible main breaker panel in the electrical room have been identified for the installation of the power meters. According to McGill employed master electrician Mr. Hubert Marcil (of Facilities Operations and Development), as per health and safety standards, all power meters must be installed inside a locked box with a short switch, and no wires can be loose. This box is procured either in house or through a third party contractor. In order to measure power with high quality results, he recommended the use of three current transformers (one for each phase) per power meter, and two potential transformers for accurate voltage readings. Mr. Marcil also advised that one of the district electricians will be responsible for analyzing the electrical plans in order to determine the most efficient monitoring points for the lab in question.

6. System Solution Design

System Overview

The proposed system solution includes the installation of a power meter at each distribution feeder in the research lab. The power consumption data is transmitted through the transmission network to a first "Raw Data" database. Analysis is performed with device signature methods which would deliver information about the power consumption of the entire lab as well as each equipment in the lab with major power consumption. The resulting data is stored in a terminal database. The user accesses the information through a user interface and has the choice to input any actions undertaken to improve the energy consumption in the lab. The information collected is used to further improve the system data analysis as well as the recommendations and solutions for energy conservation in laboratories. This feature might not be developed during this project due to time limitations and when implemented, it will remain optional to the user. More details about each element of the design are found below.

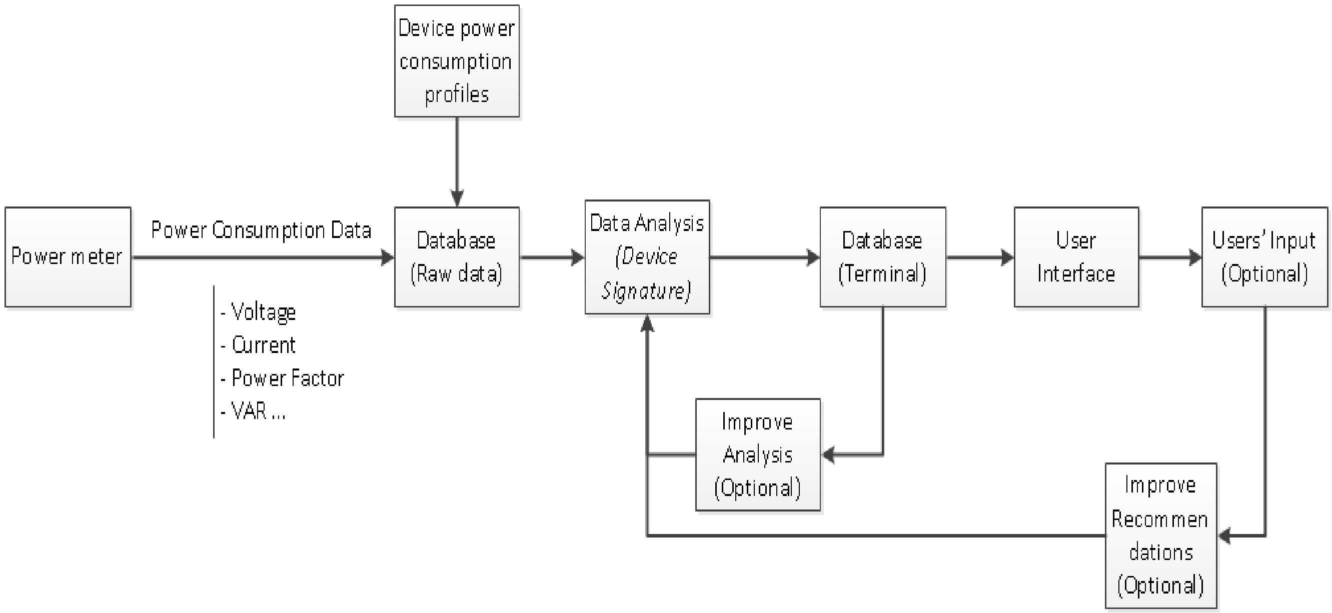

Figure 3 - Structure of the Proposed System Solution

Power Meter

In a multi sensor system, real time consumption data from individual devices is transmitted to the data server. However, such system has a high cost and requires lots of maintenance. Furthermore data from different meters needs to be synchronized in terms of frequency/timestamps [61-63]. To keep the system simple and inexpensive, a single sensor system is chosen. Although real time power signal for the whole lab is the only signal generated, the amount of data produced is easier to manage compared to a multi-sensor system. A device signature algorithm is to be developed to get the power consumption of individual devices in the lab.

A clamp on current meter (that connect the current transformers with input terminals or jacks) and a power transformer are installed at each distribution feeder. This choice offers enough accuracy, has lower costs than the shorting switch current meter and satisfies the criteria outlined in Table 1. The intervention of McGill employed electricians and a 15 minute shutdown of the lab might be necessary to install the power meter.

Up to now, the meter brand has not been selected. The final decision on meters is pending input and technical expertise from a McGill electrician.

Table 1 - Criteria and Reasoning for each Meter Selection Criterion Mentioned in the Market Research Section

Criterion	Details
1. Real time data transmission protocols	In order to establish a real-time EMIS, real time energy consumption data needs to be transmitted from the power meter to the data server.
2. Ability to generate all necessary parameters required to build a unique device signature	For reasons which will be explained later in this section, it has been determined that instantaneous voltage, instantaneous power or current, power factor, and timestamps are necessary in order to generate a unique device signature

3. A high sampling frequency for instantaneous power or instantaneous current	For reasons which will be explained later in this section, Fast Fourier Transform will be used to generate individual device's current frequency signature. Without a high sampling frequency, Fast Fourier Transform will not yield an ideal device's frequency signature.
4. Capability to measure voltages	During the initial market research on meters, it has been noticed that some meters only measure real-time currents and assume that the voltages are constant at 120V. McGill University is located at the end of long distribution feeders, which is frequently subjected to voltage fluctuations, due to downstream load variations and upstream equipment's switching events or upgrades. In order to gain accurate real-time voltage signals, the power meter needs to be capable of measuring voltages.
5. A high current measuring limit	Plugged loads are large electricity consumers in research labs. A power meter with a high current measurement limit (i.e. above the circuit breaker amperage limit) is able to accommodate the electricity need of research labs.
6. Operation with a known constant power consumption/ Ability to monitor its own power consumption	A power meter consumes electricity from the feeder to which it is clipped. To ensure the accuracy of generated power signal and to eliminate unnecessary power signal noises, the power meter should either operate with a known constant power consumption or be able to monitor its own power consumption.

Transmission Network

Some of the interesting metering devices are only provided with physical (hardware to software) interfaces such as RS 232 and RS 485. However, it is preferable to use a wireless communication system to avoid McGill's Betwork and Communications Services costs. To do so, an analog I/O ZigBee adapter can be used in order to deliver that connectivity. Digi International [71] offers a range of adapters that connect through mesh networks. A programmable ZigBee to IP gateway [72] is then used to collect the device data and securely send it over the internet to a device cloud [73] which will host the processing software. The device cloud is a cloud computing system that hosts data and information in an "a nebulous assemblage of computers and servers accessed via the Internet" [74]. This service is provided by separate administrative entities, constituting a security threat to the outsourced data [75]. Although access to the data becomes dependant to the supplier stability, it allows easier access to data from different locations and by different people at a lower cost and without the need of a desktop.

Many sensors can be added to the network without doing any changes to the system, allowing a simple and easy expansion of the system to other research labs or even monitoring other types of energy (e.g. gas, fume hoods, etc.).

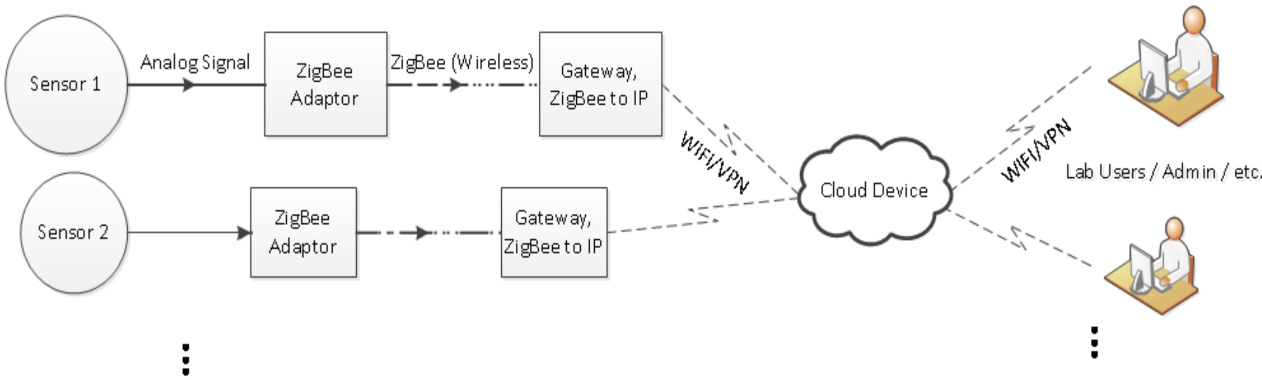

Figure 4 - Architecture of the Communication Network

User Interface

As mentioned in the market research section, Ruby is chosen to be the web-development language of the user interface. The proposed user interface consists of two pages. One is for the general lab users, which is shown in Appendix J. The page aims to present the lab energy consumption and analyzed data with visual aids. The other page is for energy analysts or consultants, where users can extract analyzed or unstructured energy consumption data for further analysis.

Databases

Based on the literature review and the market research conducted, it is determined that MySQL can be used to build a database for our project. Although Device Cloud and meter vendors offer data servers for minimum cost, a database will be built to store data, in order to ensure the privacy of McGill's energy usage data.

The database design decisions are preliminary and pending the final metering data. However, the following decisions have been made on database design [42].

Design Decision	Approach	Reasoning
1. Data organization through normalization	Identify data fields, table relationships, primary keys and foreign keys in advance	To minimize redundancy
2. GUI implementation	Use SQL GUI mechanisms	For easier navigation to data and access to functions

Table 2 shows preliminary decisions on fields to be included and which tables are to be included in the database.

Table 2 - High Level Database Management

Tables	Fields
Raw Data (ID: A)	timestamp, current, voltage, power factor, apparent power
Pre-processed Data (ID:B)	timestamp, current, voltage, power factor, apparent power, FFT of current signal
Analyzed Data (ID:C)	timestamp, device IDs
Device Signature (from plug-in meters) (ID:D)	device ID, current, voltage, power factor, apparent power, timestamp (@ one type of sampling frequency)
Device Signature (from the main power meter) (ID:E)	device ID, current, voltage, power factor, apparent power, timestamp (@ a different type of sampling frequency)
Consolidated Device Signature (ID:F)	device ID, current, voltage, power factor, apparent power, timestamp (@ consolidated frequency)

Device Signature

Two device signature algorithms will be developed, one is a feed forward back propagation ANN with a three-layer MLP (Multi Layer Perceptron), and the other is a simple difference algorithm, which is used to introduce new lab devices.

The ANN algorithm is used in real-time to decompose the signals from the power meter installed in the circuit breaker panel, into a combination of individual device signatures. The ANN is determined as the best fit for this project, since the input and output are clearly defined, with the underlying relation constantly varying and unknown. ANN has the capability to adapt to such a data environment. The back propagation scheme involves an optional lab user response in the testing phase, where the lab user can escalate the training process of the ANN algorithm by providing a binary response to the algorithm output, “TRUE” and “FALSE”. A three-layer feed forward neural networks is chosen, out of consideration on the fast algorithm feedback requirement [29]. The input data goes through the following two steps:

Step 1. As shown in Figure 5 below, the raw data from the power meter will goes through a filter, where environmental noises and device transient noises will be filtered out. The type of filter will be determined, once a better understanding of the raw data has been established during the implementation phase of this project. This filter ensures output accuracy and concentrates on major lab devices. Then, the instantaneous current signal goes through an FFT Frequency Processing stage, where the transformed instantaneous current signal is easily used for feature matching. At the same time, other parameters from the power meter will be segmented from the original time series in the raw data into a sequence of trend segment [40]. The power meter has a higher sampling frequency than the meter’s data transmission frequency. In addition, the ANN algorithm has a lower output frequency than the meter's data transmission frequency. In order to avoid data congestion, some incoming data are to be ignored by the system. The segmented data is normalized, which addresses the voltage fluctuation problems. The incoming data at any given time are not necessary measured at the same voltage level, as the individual device signatures. The output data from Step 1 is a Short Term Fourier transform (STFT) of the current signal and pre-processed parameters as explained above. Further details about the STFT are found below.

Step 2. As shown in Figure 6 below, the ANN algorithm consists of three layers, which are inputs, hidden weight functions and outputs. Each input corresponds to one device signature parameter (such as voltage, current, etc.), with an additional input being an optional input from lab users. Once the output is generated, the user will have the opportunity to provide a quick binary response, i.e. "TRUE" or "FALSE", regarding the algorithm output. This user feedback is provided as an error signal input in this closed-loop design. In the second layer, a set of initially random weight functions are provided only for the first iteration of the training process. Starting from the second iteration in the training process, the error between the output and the experimentally generated training set are taken into consideration by the initially random weight functions. The output is binary and in vector form, where the total number of outputs are the product of lab devices and their states. If one state of a certain device is on, the corresponding vector element is one. Otherwise, it is zero.

The implementation of the ANN algorithm involves three phases, an initial enrolment phase, a learning phase and a testing/recognition phase. In the initial enrolment phase, the device signatures of each device in the pilot lab is collected using a plug-in meter or the main power meter and stored into a separate database. At the very beginning of the learning phase, [29] all weights are random. After the first iteration, the comparison results between the output and the training set are considered in the weight functions for the following iterations. By doing this, eventually, the ANN algorithm yields an output, which matches the training set within a pre-set tolerance. The final phase is the testing/recognition phase, where the ANN algorithm is put to real-world implementation, and is subject to receiving optional input from lab users.

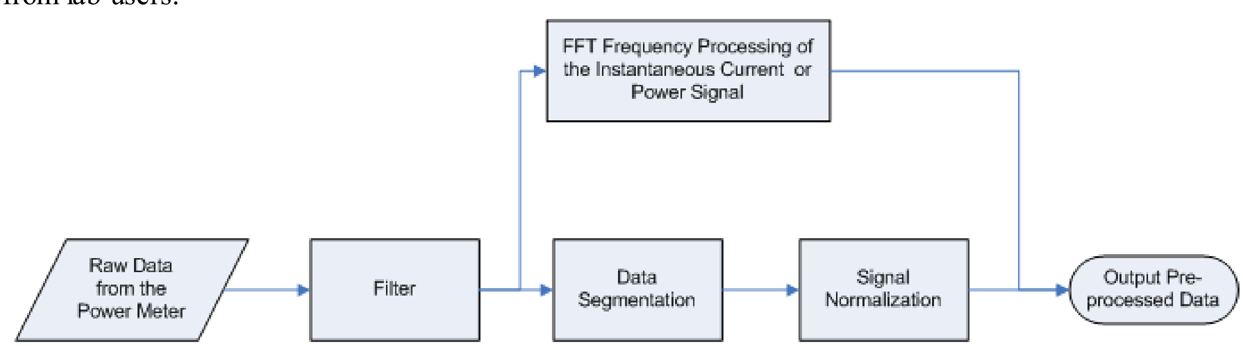

Figure 5 - Diagram of the Different Steps of the Data Processing

The difference algorithm is developed so that lab users can introduce new device signatures into the database, with one simple click, "RECORD". Assuming one device is switched on at a time, the difference in the total power signal is equal to the recently switched-on device's signature. When the lab user introduces a new device, they need to make sure that the new device is the only device being turned on, from the moment when they click on "RECORD" in the user interface till the end of a certain sampling period. During this sampling period, previously switched-on devices can remain on, however, no other devices can be switched on.

Choice of Parameters to be considered in Device Signatures

Each device has a unique set of energy consumption parameters, which is characterized as device signature. [29, 30] According to a device's internal circuit, it can be resistive, capacitive or inductive. In an inductive load, current lags voltage, yielding a lagging power factor. The opposite is applicable to a capacitive load. When voltage and current are out of phase, the real power transferred to the device is different from the product (i.e. apparent power) of voltage and current. Power factor is real power divided by apparent power, therefore power factor is a device signature parameter. In addition, it is assumed that each device has a unique current frequency, due to the device's internal electronics design. In conclusion, the following parameters are being considered as device signature for this project, voltage, current, current frequency, power factor and power.

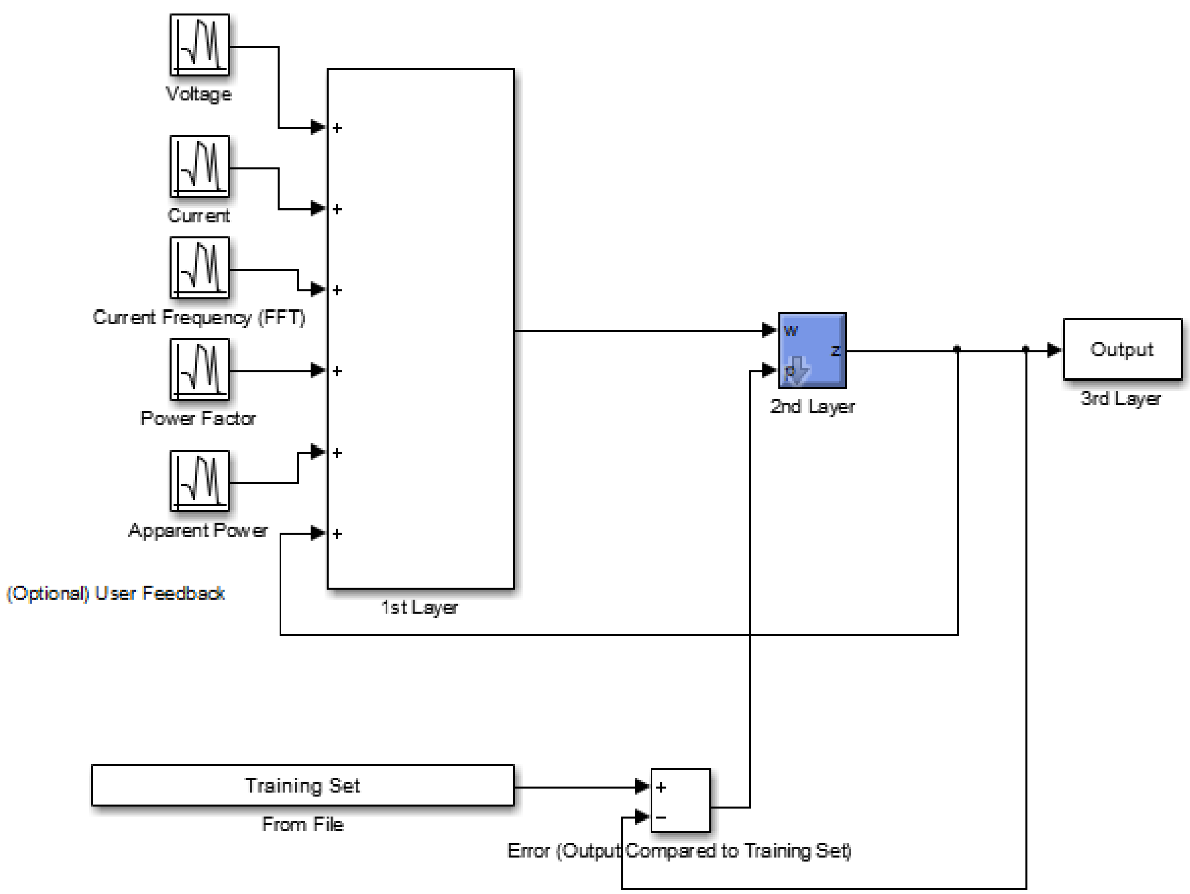

Figure 6 - Summary of the Device Signature Methodology

Obtaining the Frequency Response of a Current Signal

The FFT frequency processing of the instantaneous current signal is explained as follows.

Let x[n] be the sampled current signal.
The signal x[n] is divided into segments as follows:

$x_r[n]\begin{cases} x[rL+n]\ , & 0 \le n < N \\ 0\ , & else \end{cases}$, where L is the length of the segment.

The signal is divided into frames, or segments, where each segment has the same length. Each segment overlaps the following one by an amount of 25% to 50% [76, 77].

Each segment is multiplied by a window term, and its short-term Fourier transform is computed. This process is repeated for each segment, from the first to the last. The short term frequency spectrum $X_r[k]$ of the segment X_r is:

$$X_r[k] = \sum_{k=0}^{N-1} x[n]w[k-n]e^{-j\left(\frac{2\pi k}{N}\right)n}$$

Where w[n] is the mathematical expression of the window.

$$w[n] = \begin{cases} 1\ , & 0 \le n \le N-1 \\ 0\ , & otherwise \end{cases}$$

The magnitude of the STFT is obtained for easier feature matching. MATLAB has different functions such as fft() and abs() that can be used to obtain the STFT of a current signal.

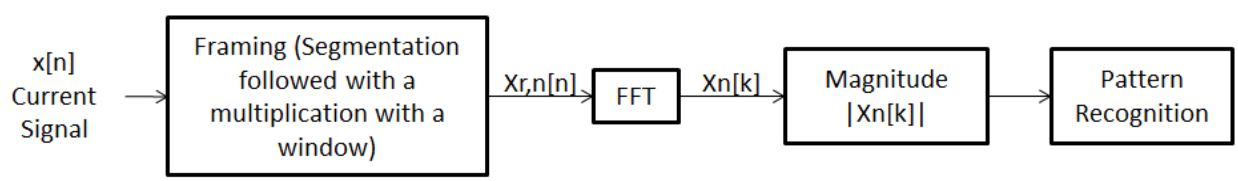

Figure 7 - Complete Diagram of the Short Term Fourier Transform

Data Analysis Platform

As determined in the previous sections, ANN is used to design a device signature algorithm. The ANN device signature algorithm can be implemented using Ruby's script or a third-party data analysis platform. This data analysis platform needs to be compatible with MySQL databases and can be embedded in Ruby's script for real-time data updates, in order to establish a working integrated system. MatLAB [68] satisfies the aforementioned design requirements. In addition, MatLAB has a neural networks toolbox, which simplifies the implementation of the ANN device signature algorithm. Therefore, MatLAB is chosen to implement the device signature algorithm.

Energy Conservation Measures

Our system can also provide users with energy conservation measures or suggestions. An idea from the Dr. Jon Sakata consists of rotating a freezer to store tissues and samples while a lab thaws their freezer. An example of recommendations for each type of equipment in a research lab is found in Appendix N.

Lab Survey

Plan to collect device signatures

Lab devices are categorized into two types. The first type are devices that can be switched on/off at any given time. The device signature of these devices will be collected using the plug-in meter on loan from McGill Utilities Management. The sampling period ranges from one minute up till five minutes, depending on the internal circuit of the lab devices. The second type are devices that need to stay on 24/7. When installing the power meter in the circuit breaker panel, there is a potential lab power shutdown, according to experienced employees from the Utilities and Energy Management at McGill University. After the meter has been installed, each of the 24/7 devices will be turned on sequentially with at least a one-minute time period in between. The device signature of these devices are obtained using the difference method, based on the data from the main power meter. In this way, device signatures of all the lab devices can be collected, while causing only minimum interruption to the normal operation of research labs.

From the recent meeting with supervising electrician Mr. Marcil, the installation of power meters may not require a power shutdown. This will depend on the installation schematics of the power meter purchased. If this is indeed the case, all device signatures will be obtained through the plug-in meter.

Usage Frequency

The greatest energy saving potential could be in lab devices with large energy consumption or with frequent usage. A survey on how frequently each lab device is used can be performed using SurveyMonkey[R].

Plan to generate the training set for ANN algorithm

The training set for the ANN device signature algorithm is useful during the machine learning phase, when the ANN attempts to find the most accurate weight functions. In order to ensure the reliability of the ANN algorithm, the training set should be generated on-site in the pilot lab, rather than generated synthetically. Such a training set can be obtained during off-peak hours with the collaboration of a lab user. During such a period time, lab devices are turned on and off, mimicking normal research processes. In addition, a team member will log which devices are on and when. In such a way, the training set can be generated.

7. Impact on Society and the Environment

Applied Student Research

This project highlights some of the progress that McGill has already made in terms of sustainability, in the context of McGill 2020 and ASR Living Lab. The project was initiated by the McGill energy Project, in collaboration with Prof Dror Etzion and Utilities and Energy Management at McGill. This Applied Student Research (ASR) shifts the focus of a design project toward the campus' operations and activities, integrates research and education and offers solutions to real-world sustainability challenges at McGill [78]. This experience allow us, as students, to develop an understanding of energy systems, learn how to make change in organisations and institution, improve our community and get applying skills and knowledge.

Risks and Challenges

Outsourcing the data to another company include the risks related to the supplier stability. Furthermore, the data is private and McGill's approval about having a third party access the information is necessary. Making an impact on lab users' energy consumption behaviors and attitudes is challenging. The plan is to further develop the behavioral side of the research, connect with more behavioral scientists, and reflect the outcomes through the user interface. In addition, the proposed solution includes an optional users' feedback, which can improve significantly the energy conservation methods recommended by the system. Another risk includes fully automating the system installation process. The current solution requires that the individual device signatures, and an inventory of lab devices to be obtained manually. This approach is a hindrance in further promoting the proposed system. To resolve this issue, supervisory control and tele-metering approaches can be integrated into this system. Costs (monetary) resulting from these risks and challenges has not been estimated yet. However, they have been taken into consideration when building the implementation timeline.

8. Plan for Continuation

Time and Monetary Budget

Table 3 - Plans for the Winter 2014 semester

Item	From	Till
Installation (meter, API, device signatures)	06/01/2013	31/01/2013
Implementation (User Interface, database, device signature)	06/01/2013	01/04/2013
Component Testing	01/02/2013	01/04/2013
Validation	01/04/2013	15/04/2013

A detailed timeline is provided in Appendix M. A table of monetary budget is included in Appendix K.

9. Report on Teamwork

Member	Items
Matthew Gidaro Da Silva	1. Assisted with market research for power meters. 2. Contacted meter vendor for more information on products. 3. Performed lab visits with Fiona and Chris. 4. Proposed initial project timeline. 5. Began experimenting with power consumption data from loaned meter.
Christopher Tegho	1. Outlined and researched the different elements of the system. 2. Performed the literature review and related work for power monitoring methods, and data transmission methods and networks. 2. Proposed the system solution, and the design for the data transmission network. Completed the methodology for the STFT. 3. Conducted preliminary research of solutions for energy conservation in laboratories. 4. Communicated with people at McGill for funding.
Yining Yuan	1. Coordinated and performed all seven lab visits 2. Did literature review on device signature, pattern recognition, occupant engagement, database and data analysis platforms 3. Did market research on meters, home energy management systems, databases, server-side web development languages and data analysis platforms 4. Contacted meter vendors to obtain more detailed power meter information 5. Proposed the designs of two device signature algorithms, an SQL database implementation and a user interface

The main difficulty is time management. To resolve this issue, each team member will present a detailed timeline for their individual task assignments and will coordinate on the schedule of joint tasks ahead of time. In this way, the entire team can coordinate with one another more efficiently during the project implementation phase.

10. Conclusion

In this project, a cost effective energy management information system is designed. An integrated metering data acquisition system, which harvests metering data in real-time onto databases is developed. Device signature techniques decompose the total energy consumption into a combination of individual device consumption. In addition, a web-based user interface with real-time data updates offers direct feedback and aims to steer lab users' energy consumption patterns into a more conservable and sustainable manner. The device signature algorithm can be implemented into a wide variety of energy consumption auditing service, where the individual device energy consumption can be pinpointed and analyzed. The integrated system can be expanded to research-intensive universities and research facilities, in an effort for the management team to make an informed decision about coordinating research processes and purchasing energy-efficient equipment, with energy consumption literacy in mind. The project is going to be implemented in the Benedek Integrated Laboratories in Environmental Engineering next semester. However, our solution is generic and can be applied to any research lab, with minimum modifications required.

11. References

[1] McGill. (2010). Energy Management Plan, 2010-2015 (Building and Property Committee of the Board of Governors, Trans.): McGill University

[2] M. D. Kaplowitz, L. Thorp, K. Coleman, and F. Kwame Yeboah, "Energy conservation attitudes, knowledge, and behaviors in science laboratories," Energy Policy, vol. 50, pp. 581-591, 2012.

[3] "Genome BPA Retrocommission Report," McGill University August 12

[4] "McConnell VIP Energy Audit Report," McGill University October 2012.

[5] Natural Resources Canada, What is an Energy Management Information System? Retrieved 1/09/103 from http://oee.nrcan.gc.ca/publications/industrial/ernic/1972?attr=24

[6] Natural Resources Canada, Energy Management Information System (EMIS). Retrieved 1/09/103 from http://oee.nrcan.gc.ca/industrial/cipec/tools/10926.

[7] S. Darby. The effectiveness of feedback on energy consumption: A review for DEFRA of the literature on metering, billing and direct displays. Tech. report, Environmental Change Institute, University of Oxford, 2006.

[8] P. C. Stern. Information, incentives, and proenvironmental consumer behavior. Journal of Consumer Policy, 1999

[9] H. McMakin, E. L. Malone, and R. E. Lundgren. Motivating residents to conserve energy without financial incentives. Environment and Behavior Journal , 2002

[10] World Business Council for Sustainable Development. Energy efficiency in buildings: Business realities and opportunities. Tech. report, 2008

[11] L. Zhao, J.-l. Zhang, and R.-b. Liang, "Development of an energy monitoring system for large public buildings," Energy and Buildings, vol. 66, pp. 41-48, 2013.

[12] S. Patel, T. Robertson, J. Kientz, M. Reynolds, and G. Abowd, "At the Flick of a Switch: Detecting and Classifying Unique Electrical Events on the Residential Power Line (Nominated for the Best Paper Award)," in UbiComp 2007: Ubiquitous Computing. vol. 4717, J. Krumm, G. Abowd, A. Seneviratne, and T. Strang, Eds., ed: Springer Berlin Heidelberg, 2007, pp. 271-288.

[13] Y. Kim, T. Schmid, Z. Charbiwala, and M. Srivastava, "ViridiScope: design and implementation of a fine grained power monitoring system for homes," Ubicomp '09: Proceedings of the 11th international conference on Ubiquitous computing, 2009/09// 2009.

[14] G. Franhofer. (2012). The quick and easy way to measure power consumption. Available: http://www.fraunhofer.de/en/press/research-news/2012/may/the-quick-and-easy-way-to-measure-power-consumption.html

[15] Available: https://www.wattsupmeters.com/secure/index.php

[16] Lawrence Berkeley National Laboratory, Standby Power. Defining and Measuring Standby. Available: http://standby.lbl.gov/measure.html

[17] J. Chen, A. Kam, J. Zhang, N. Liu, and L. Shue, "Bathroom Activity Monitoring Based on Sound," in Pervasive Computing. vol. 3468, H.-W. Gellersen, R. Want, and A. Schmidt, Eds., ed: Springer Berlin Heidelberg, 2005, pp. 47-61.

[18] B. Zhong, "Design of Building Energy Monitoring and Management System," in Business Computing and Global Informatization (BCGIN), 2012 Second International Conference on, 2012, pp. 645-648.

[19] B. S. Koay, S. S. Cheah, Y. H. Sng, P. H. J. Chong, P. Shum, Y. C. Tong, X. Y. Wang, Y. X. Zuo, and H. W. Kuek, "Design and implementation of Bluetooth energy meter," in Information, Communications and Signal Processing, 2003 and Fourth Pacific Rim Conference on Multimedia. Proceedings of the 2003 Joint Conference of the Fourth International Conference on, 2003, pp. 1474-1477 vol.3.

[20] Jorge, J. Guerreiro, P. Pereira, J. Martins, and L. Gomes, "Energy Consumption Monitoring System for Large Complexes," in Emerging Trends in Technological Innovation. vol. 314, L. Camarinha-Matos, P. Pereira, and L. Ribeiro, Eds., ed: Springer Berlin Heidelberg, 2010, pp. 419-426.

[21] T. Nagata, "An electric power energy monitoring system in campus using an Internet," in Power Engineering Society General Meeting, 2006. IEEE, 2006, p. 6 pp.

[22] S. Yimin and W. Zhengli, "The energy consumption monitoring platform design for large-scale industry users based on the GPRS," in Mechanic Automation and Control Engineering (MACE), 2011 Second International Conference on, 2011, pp. 7827-7830.

[23] M. Huczala, T. Lukl, and J. Misurec, "Capturing Energy Meter Data over Secured Power Line," in Communication Technology, 2006. ICCT '06. International Conference on, 2006, pp. 1-4.

[24] C. Liting, J. Wei, and Z. Zhaoli, "Networked wireless meter reading system based on ZigBee technology," in Control and Decision Conference, 2008. CCDC 2008. Chinese, 2008, pp. 3455-3460.

[25] H. Dae-Man and L. Jae-Hyun, "Smart home energy management system using IEEE 802.15.4 and zigbee," Consumer Electronics, IEEE Transactions on, vol. 56, pp. 1403-1410, 2010.

[26] Z. Qiang, Y. Sun, and C. Zhenhui, "Application and analysis of ZigBee technology for Smart Grid," in Computer and Information Application (ICCIA), 2010 International Conference on, 2010, pp. 171-174.

[27] S. Zengyou, Z. Tao, and C. Chenghua, "Design of Electric Power Monitoring System Based on ZigBee and GPRS," in Computer Network and Multimedia Technology, 2009. CNMT 2009. International Symposium on, 2009, pp. 1-4.

[28] B. Zhong, "Design of Building Energy Monitoring and Management System," in Business Computing and Global Informatization (BCGIN), 2012 Second International Conference on, 2012, pp. 645-648.

[29] A.G. Ruzzelli et Al., "Real-Time Recognition and Profiling of Appliances through a single electricity sensor", IEEE 2010

[30] Markus Weisset Al., "Leveraging smart meter data to recognize home appliances", IEEE 2012

[31] Rick Diamond et Al., "Evaluating the Energy Performance of the First Generation of LEED-Certified Commercial Buildings" [online], Available: http://escholarship.org/uc

[32] EPA, "EPA's New Lab Benchmarking Initiative – Laboratories May Become Eligible to Earn the Energy Star" [online], Available: http://www.labs21century.gov/

[33] M.L.Marceau et Al., "Nonintrusive load disaggregation computer program to estimate the energy consumption of major end uses in residential buildings", in Energy Conversion and Management, volume 41, pages 1389-1403, 2000

[34] S.Patel et Al., "At the flick of a switch: Detecting and classifying unique electrical events on the residential power line." In Ubicomp 2007: Ubiquitous Computing, LNCS 4717, Springer, pages 271-288, 2007

[35] Ki-Seung Lee, "EMG-Based Speech Recognition Using Hidden Markov Models with Global Control Variables, IEEE Transactions on Biomedical Engineering", Vol 55, No. 3, March 2008
[36] Md. Maruf Monwar et Al., "Multimodal Biometric System Using Rank-Level Fusion Approach", IEEE Transactions on Systems, Man, and Cybernetics - Part B: Cybernetics, Vol. 39, No.4, August 2009
[37] Raphael Fuchs et Al., "Visual Human + Visual Learning, IEEE Transactions on Visualization and Computer Graphics", Vol. 15, No. 6, November/December 2009
[38] Jayanta Kumar Basu et Al., "Use of Artificial Neural Network in Pattern Recognition", International Journal of Software Engineering and Its Applications, Vol.4, No.2, April 2010
[39] Steven D. Kaehler, "Fuzzy Logic - An Introduction" [online], Availabe: http://www.seattlerobotics.org
[40] Xinyu Guo et Al.,"A Stock Pattern Recognition Based on Neural Networks", Third International Conference on Natural Computation,Volume 02, 2007
[41] Yishan Li et Al., " A performance comparison of SQL and NoSQL databases", IEEE 2013
[42] JS van der Merwe et Al., "Development of an Online Energy Auditing Software Application with Remote SQL-Database Support", UPEC 2011 – 46th International Universities' Power Engineering Conference – 5-8th September 2011 – Soest – Germany
[43] Ruby Programming [online], Available: http://www.tutorialspoint.com/ruby/ruby_database_access.htm
[44] SQLite [online], Available: http://www.sqlite.org/
[45] System Properties Comparison MySQL vs. PostgreSQL vs. SQLite [online], Available: http://db-engines.com/en/system/MySQL%3BPostgreSQL%3BSQLite
[46] Ruby, A Programmer's Best Friend [online], Available: https://www.ruby-lang.org/en/about/
[47] Python [online], Available: http://www.python.org/
[48] PHP [online], Available: http://php.net/
[49] Perl [online], Available: http://www.perl.org/
[50] P3International[online], Available: http://www.p3international.com/products/p4400.html
[51] TEDEnergy [online], Available: http://www.theenergydetective.com/tedprostore.html
[52] Belkin [online], Available: http://www.belkin.com/us
[53] EnergyHub [online], Available: http://www.energyhub.com/smart-meters/
[54] PlugWise [online], Availabe: http://www.plugwise.com/docs/productcatalogue
[55] VisibleEnergy [online], Available: http://www.visiblenergy.com/
[56] Black and Decker [online], Available: http://blackanddeckermediakit.com
[57] Brultech [online], Available: http://www.brultech.com/products/
[58] ACCUENERGY [online], Available: http://www.accuenergy.com/
[59] watts up? [online], Available: https://www.wattsupmeters.com/
[60] James Bullivant (2013, Nov 20), *WattsupMeters*[online]. Available e-mail: jbullivant@wattsupmeters.com Message: Web Site Contact from Support Page
[61] Dolph Rodenberg (2013, Nov 22), *TED Support* [online]. Available e-mail: drodenberg@theenergydetective.com Message: Inquiry about TED Model 5000 Meter
[62] Ben Kar (2013, Nov 18), *Brultech* [online]. Available e-mail: ben@brultech.com Message: Inquiries about Brultech ECM-1240s Meter
[63] Josh Mears (2013, Oct 29), *Accuenergy* [online]. Available e-mail: josh.mears@accuenergy.com Message: Additional Meter Information

[64] Jennifer Aronoff et Al., “Teaching Old Dogs New Tricks”, IEEE Power & Energy magazine January / February 2013
[65] Philipp Herzig et Al., “A Generic Platform for Enterprise Gamification”, 2012 Joint Working Conference on Software Architecture & 6th European Conference on Software Architecture
[66] J. Thom et Al., “Removing Gamification from an Enterprise,” in proceedings CSCW, 2012, pp. 1067-1070
[67] J. Yang et Al., “Virtual Gifts and Guanxi: Supporting Social Exchange in a Chinese Online Community.” in Proceedings CSCW, 2011, pp. 45-54
[68] Mathworks [online], Available: http://www.mathworks.com/
[69] B. Swords, E. Coyle, and B. Norton, "An enterprise energy-information system," Applied Energy, vol. 85, pp. 61-69, 2008.
[70] K. Ko, ""Carbon Neutral for all?" Laboratory Equipement Energy Efficiency Survey," UBC, Sustainability 2010.
[71] http://digi.com/pdf/ds_xbeeadapters.pdf
[72] http://digi.com/products/wireless-routers-gateways/gateways/connectportx2ezb#overview
[73] http://www.etherios.com/products/devicecloud/
[74] Jiyi Wu; Lingdi Ping; Xiaoping Ge; Ya Wang; Jianqing Fu, "Cloud Storage as the Infrastructure of Cloud Computing," Intelligent Computing and Cognitive Informatics (ICICCI), 2010 International Conference on , vol., no., pp.380,383, 22-23 June 2010 doi: 10.1109/ICICCI.2010.119
[75] Cong Wang; Kui Ren; Wenjing Lou; Jin Li, "Toward publicly auditable secure cloud data storage services," Network, IEEE , vol.24, no.4, pp.19,24, July-August 2010 doi: 10.1109/MNET.2010.5510914
[76] J. B. Allen, "Short term spectral analysis, synthesis, and modification by discrete Fourier transform," Acoustics, Speech and Signal Processing, IEEE Transactions on, vol. 25, pp. 235-238, 1977.
[77] C. Cole, M. Karam, and H. Aglan, "Spectral Subtraction of Noise in Speech Processing Applications," in System Theory, 2008. SSST 2008. 40th Southeastern Symposium on, 2008, pp. 50-53.
[78] Available: http://www.mcgill.ca/sustainability/education-and-research/asr-living-lab
[79] McGill Engineering Inaugurates Benedek Integrated Laboratories in Environmental Engineering. Available: http://www.mcgill.ca/files/engineering/News_Benedek_Rev.pdf
[80] B. Webber, "University of Michigan Field Study of Class II Biological Cabinet Energy Consumption Costs," American Biotechnology Laboratory, 2008.
[81] Government of South Australia. Saving Energy at Home. Available: http://www.sa.gov.au/subject/Water,%20energy%20and%20environment/Energy/Saving%20energy%20at%20home
[82] The University of Vermont. Green Laboratories: Energy Savings and Sustainability. Available: http://www.uvm.edu/safety/lab/green-laboratories-energy-savings-and-sustainability

Appendix A - System Overview

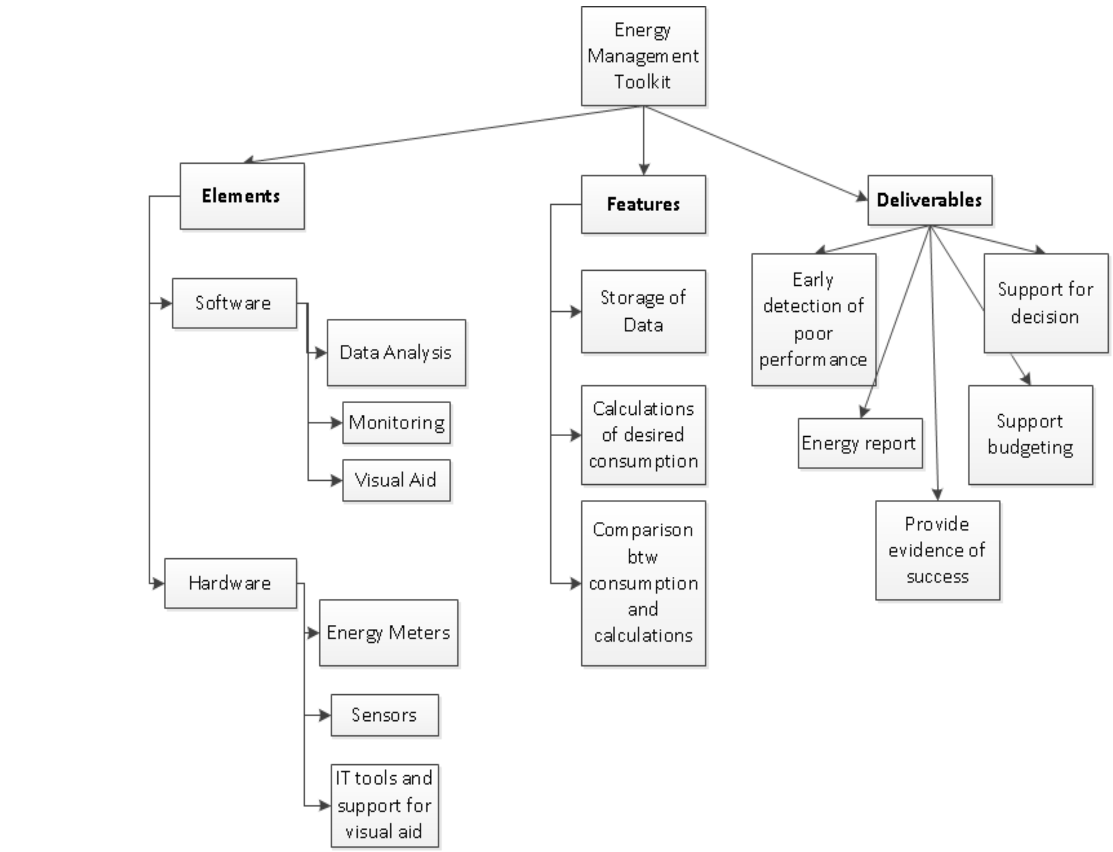

Figure 8 - Elements, Features and Deliverables of an EMIS

Appendix B - Power Monitoring Methods

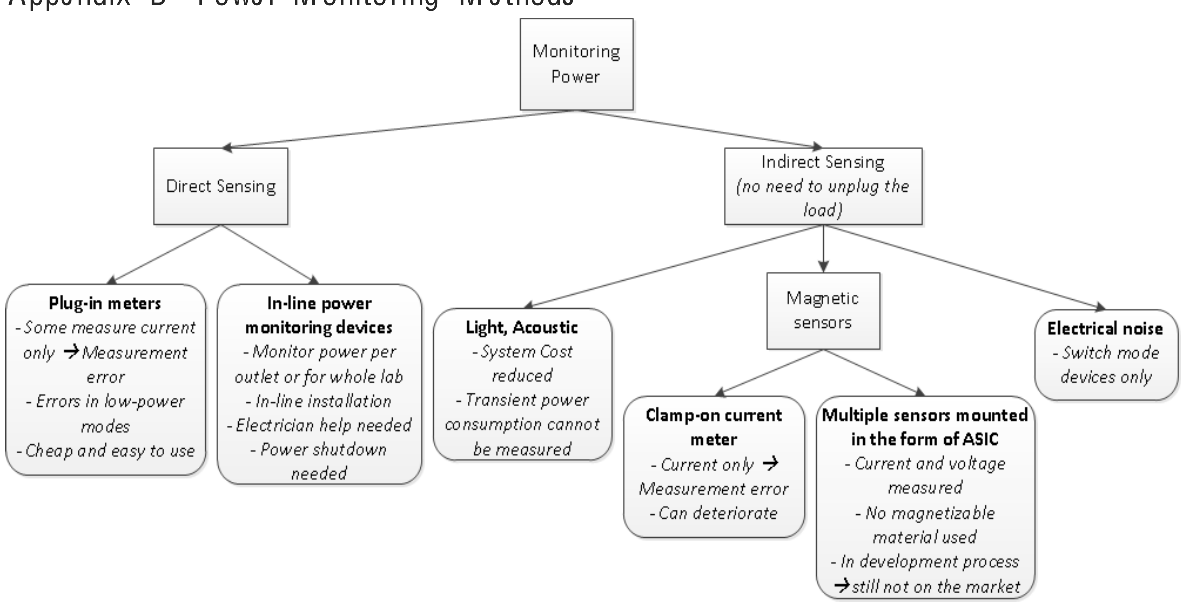

Figure 9 - A Summary of Sensing Method and Devices for Power Monitoring

Appendix C - Current Technology for Data Transmission Methods and Networks

Ethernet and the general packet radio service (GPRS) communication technologies are popular methods [20, 21]. Although the communication module of the DPRS is portable, its signal is too weak to connect the communication bases in distribution rooms, usually underground [11, 22]. A cabled Ethernet communication method is more stable and has lower cost.

Another popular communication technology is the Power Line Carrier (PLC) which uses existing electricity grid and power lines as a data communication medium. Each device plugged into an electrical plug would be able to use the internet services. Power lines are not suitable for high frequency signals and act as antennas introducing harmful interferences. To overcome these issues, an encryption standard on the entire PLC network is implemented. Building VPN can also be considered for that task. The PLC technology constitutes a high-efficient solution to the automation of energy data capture while satisfying the security standards and providing good transmittable range [23].

In addition to above options, transmission of data between data collectors and a computer can be done using the TCP/IP protocol with data transformation between the field bus interface and TCP/IP network [18]. To have a fully wireless transmission network, [24] the data collector collects data from the metering devices using ZigBee communication. The analog signal of the measuring meter is converted to a digital signal into a Microprocessor Unit of a sensor node and data is transmitted to the data collector of the ZigBee configuration every period of time.

Appendix D - Additional Literature Review on Device Signature

To this date, there is not enough research done on device signature specifically. However, the concept of device signature is pattern recognition, which has been studied extensively in voice recognition.

[35] The EMG (electromyogram)-based ASR (Automatic Speed Recognition) system is modeled by HMM (Hidden Markov Model), the template patterns are represented by their probabilistic models, which are obtained by maximizing the likelihood of the training data. Unlike speech signals, which can be characterized as time-varying random process, energy consumption of individual devices within a certain lab space, is expected to behave within an operating range [33]. Therefore, a probabilistic method is not required. A mapping rule is established, which maps a sequence of EMG signals into a sequence of context words [35]. This concept is particularly useful. Raw data containing certain device signature parameters requires some preliminary data manipulation, before they can be used as feature matching parameters in the individual device signatures.

[36] proposed a multibiometric system, in which multiple pieces of evidence were provided for the same identity. A novel rank-level fusion method is used to consolidate the output from matching multiple pieces. This system yields an improvement in the overall performance, even in the presence of low-quality data. As discussed in previous sections of this paper, a number of measurement can be utilized to measure power consumption. In a multi-sensor EMIS, such a fusion scheme can be used to fully exploit the accuracy potential in recognizing individual devices.

A framework for generating hypotheses is developed, by combining human and machine learning [37]. This approach takes advantage of the vast computing power as well as human's expertise and experience in a certain domain. In addition, this approach respects the human responsibility in modern research, while preventing the user from missing potentially important relations yet to be harvested from the data. This concept can be utilized, in terms of obtaining real-time user feedback during the training phase of the device signature algorithm, in an effort to decrease the training time and to increase the algorithm accuracy.

Appendix E - Additional Literature Review on Occupant Engagement

Rick Diamond et Al. [30] compare the simulated whole building energy consumption with the actual billed energy consumption. It concluded that a LEED-certified commercial building can be designed to be energy efficient, however, in the actual building operation with plugged loads included, a LEED-certified building does not necessarily consume less energy than a non-LEED –certified commercial building. This paper emphasises that ultimately, it is the occupants who can ensure the sustainable operation of a building, by monitoring the usage of plugged loads.

Appendix F - **Recommendations from Shivan Kaul's report on Energy consumption data** Visualisation

Establish an EMIS in a number of labs and setup a system wherein there is a provision for data comparison among the different labs. There could also be a time period across which the results are tabulated, and at the end of each period a winner could be selected. At Harvard, the winning labs of the Shut Your Sash! Campaign got a Wine and Cheese party thrown in its honor; at UBC, a cash prize was awarded (Department of Chemistry, University of British Columbia, ; Harvard Office of Sustainability, 2005). While research shows that incentives are not the reason why comparative feedback works (Siero et al., 1996), it certainly helps to have external, well-defined incentives, if only in the initial stages of the campaign. Another idea could be to tie sustainability awards to performance in these campaigns.
In fact, the results of this paper could be (and are) applied in any similar setup eg: university dorms, (at McGill the Environment Residence Council holds Fight the Power!: a 10 day competition between the residences to see who can reduce their energy consumption by the maximum amount) administrative offices; basically, any setup where the incentives for individual behavior are not explicitly defined.

Appendix G - Summary of Power Meters

Table 4 - Initial Market Research 1 [51 - 57]

Meters/Features	Price	Type	Display
Kill-A-Watt	$33.99	outlet power meter	Watts, Amps, Volts, Hz, VA
Energy Detective TED Model 5000	239.95 + $13 for each additional plug-in filter	breaker panel installation	electricity usage
Belkin	$30	outlet monitor	Watts
Energy Hub	$325	outlet monitor	Watts

PlugWise	$299 for 8-plug monitoring control	outlet monitor	Watts
ThinkEco	$355 for 10-plug monitoring	outlet monitor	Watts
Visible Energy	$99 for four-socket monitoring	outlet monitor	Watts
Black and Decker - Home Power Monitor	$99.99 + $159 for remote data access	outlet monitor	Watts
Blue Line Innovations - PowerCost Monitor	$109 + $159 for remote data access	outlet monitor	Watts
Brultech ECM-1240s	$170 - 600	breaker panel installation/outlet monitor	Watts
CurrentCost Ltd - ENVI	$129 + $69 for remote data access	breaker panel installation	Watts
Efergy - Elite	$138.05	breaker panel installation	Watts

Table 5 - Initial Market Research 2 [51 - 57]

Meters/Features	Communication	Package	Power Supply	Export Data Format
Kill-A-Watt	N/A	N/A	outlet	N/A
Energy Detective TED Model 5000	wireless	one set of CTs, one MTU, and one Gateway embedded with software	outlet	.csv
Belkin	N/A	N/A	outlet	N/A
Energy Hub	Wi-Fi (802.11b/g),ZigBee Home Automation with enhanced security	Home Base, Socket, Strip	outlet	N/A

PlugWise	USB stick for wireless communication, ZigBee	software	outlet	.csv
ThinkEco	USB receiver	monitoring/control software	outlet	N/A
Visible Energy	Wi-Fi	iPhone app	outlet	N/A
Black and Decker - Home Power Monitor	Wireless	N/A	battery-powered	N/A
Blue Line Innovations - PowerCost Monitor	Wireless, ZigBee	iPhone app	battery-powered	N/A
Brultech ECM-1240s	Wireless, ZigBee	N/A	outlet	.csv
CurrentCost Ltd - ENVI	433MHz SRD band, C2 architecture	N/A	display with power supply	N/A
Efergy - Elite	wireless	software	battery-powered	available

Table 6 - Further Market Research 1 [51, 57, 58, 59, 61 - 63]

Meters/Features	TED Pro Energy Monitoring and Control System	Brultech Green Eye Monitor
voltage measuring limit	277V	480V
current measuring limit	200A	1200A
Is the meter installation intended for the electrical power room/ plug outlets/ circuit breaker box?	inside breaker panel, CTs, MTUs (to pick up voltage), gateway (communicate via power line carrier to meter, connects using Ethernet to a router, from there it can connect to a modem to perform wireless communication with laptop)	The monitor itself must be installed outside of the circuit breaker box.

What information does the meter provide? (In order to gather a full device signature, we need real power, pf, RMS current, RMS voltage) Does the meter provide the information with a time stamp?	real power, pf, current, voltage, kW, kWh, energy cost, timestamp	It provides Watts, Amps, and Voltage. Those values can be used to derive power factor, etc.
Is the communication between the meter and the computer wireless or Ethernet? What is the communication protocol?	PLC	The GEM supports Wi-Fi, Serial, and ZigBee.
How does the meter transmit data from the meter to the computer? What is the data format? (.csv?)	excel or pdf	It transmits using various packet formats. You can take a look at our developer manuals at http://www.brultech.fom/software under the GreenEye Monitor section for more information (click the Developer link under Manuals when there). The data format can be HTTP format, which can be extracted to develop custom applications.
Is the data transmission real-time? Or is there a time lag? If so, by how much time?	real time, every 1-2 seconds	Packets are sent at a set interval, from 1-255 seconds.
Price? Do they ship to Canada? Shipping fees? Custom fees? How long is the waiting time or how advance should we order the meter? Method of payment? Any discount?	$399 - 1399, depending on voltage and current limit	Located in Ontario, Canada. $499.99
Does the meter consume power from a plug outlet/ a feeder? Is the meter's power consumption excluded from the meter readings/ measured and displayed separately in the meter readings?	7W, the meter power consumption will be displayed in the exported data	It consumes power from the outlet, very little power however. It would be included in the Main panel readings.
Does the meter measure the voltage of the feeder? Or does it assume the voltage of the feeder?	yes	It measures voltage from a potential transformer.

What is the percentage of error/accuracy of this meter?	0.02	0.01
Refund/ return policy?	0.75	#N/A
Sampling Frequency	The sampling rate is 4000 times per second for power, current, voltage and apparent power. The values are averaged over 1 second and then outputted.	10.4kHz
Instantaneous P(t)/I(t)	Instantaneous power	It provides instantaneous current.

Table 7 - Further Market Research 2 [51, 57, 58, 59, 61 - 63]

Meters/Features	Acuvim Two	Wattsup Smart Circuit 20
voltage measuring limit	690 L-L V	250V
current measuring limit	5A as an input to the meter, can provide Cus for step up/down	15A
Is the meter installation intended for the electrical power room/ plug outlets/ circuit breaker box?	breaker panel	The SC 20 is designed for a panel installation and is hardwire. We also will put the guts of the Watts Up?. Net into a panel if needed. We call these our EMCB (Energy Monitoring Circuit Box). These are typically pre-wired by the vendor; with an internal meter for each circuit to be monitored plug an Ethernet hub/switch - for hook up to the internet.
What information does the meter provide? (In order to gather a full device signature, we need real power, pf, RMS current, RMS voltage) Does the meter provide the information with a time stamp?	DL,EL real power, pf, current, voltage, timestamp	current Watts, minimum watts, maximum watts, power factor, volt amp (apparent PWR), cumulative watt hours, average monthly kwh, elapsed time, duty cycle, frequency (Hz), cumulative cost, average monthly $, line voltage, minimum volts, maximum volts, current amps, minimum amps, maximum amps. Time stamps are provided on every reporting

		interval. All meters are capable to measure all 18 parameters above - down to 1 second interval.
Is the communication between the meter and the computer wireless or Ethernet? What is the communication protocol?	Modbus, Ethernet (2 series)	There are four options for collecting data:1. Use the interval memory in each meter and then download using the vendor's free USB software; 2. Provide connection to Ethernet jack; and stream data to your meter account/membership on the vendor's data farm; 3. Provide connection to the Ethernet jack, readdress IP to local server; and write your own web/server side code (based on the vendor's API) to obtain data on local LAN;4. Connect directly to a computer via USB and use the vendor's RealTime software and collect data live over USB.
How does the meter transmit data from the meter to the computer? What is the data format? (.csv?)	.csv, excel, .txt	Files will be either csv or txtl and can be imported into Excel.
Is the data transmission real-time? Or is there a time lag? If so, by how much time?	real time	The RealTime software is real-time, down to 1 second intervals, no time lag. When sending data over via Ethernet port, the data can lag slightly; and come in as chunks. For example, if you are logging at 1 second intervals, the data may pause for a few seconds and then 4-6 data rows populated at the same time. This is largely dependent on the customer's ISP and traffic condition over the network. The data is being sent over port 80 as raw data string packets, so it does not take any bandwidth itself.
Price? Do they ship to Canada? Shipping fees?	L series DL - 350,L Series EL - 380, 2 Series - 495, in stock, 1	Yes, it can be shipped to Canada. The shipping fee

Custom fees? How long is the waiting time or how advance should we order the meter? Method of payment? Any discount?	week, pay pal, credit card, 10% discount	depends on the order (size and quantity). The custom fee depends on how your facility address important/GST etc. The vendor stocks all standard Watts up meters. If more than 50 are purchased, the customer should notify the vendor ahead of time, in order to check on the stock. EMCB are built to order, 4 weeks will be needed if possible. Credit card is the easiest method of payment. As the OEM, the vendor will match anyone's price.
Does the meter consume power from a plug outlet/ a feeder? Is the meter's power consumption excluded from the meter readings/ measured and displayed separately in the meter readings?	3 W, constant power consumption	The meter's reading does not include any power used by the actual meter. It is calibrated out.
Does the meter measure the voltage of the feeder? Or does it assume the voltage of the feeder?	yes, up to 3 phase voltage	It measures the voltage (true RMS) at 2500 per second.
What is the percentage of error/accuracy of this meter?	0.005	1.5% +/- 3 counts
Refund/ return policy?	no returns allowed	All sales are final, the vendor provides a 1 year warranty.
Sampling Frequency	multiple of seconds, no exact info is known	True RMS voltage and amperage are measured 2500 per second and the instantaneous values are reported.
Instantaneous P(t)/I(t)	Yes, it provides instantaneous power.	The meter's chips are measuring at 2500 per second. However the report out is every 1 second. The min and max of the 2500 times is reported out at the 1 second interval as well - so the spikes can be caught if needed.

Appendix H - Summary of Server-side Web Development Language based on Market Research

Table 8 - Table of Functionality Comparison 1 [46, 47, 48, 49]

Functionality	Ruby	Python
Description	dynamic object-oriented, functional programming, imperative programming, flexible and expressive	dynamic, object-oriented, very high level dynamic data types, extensive standard libraries and third party modules for virtually every task, extensions and modules easily written in C, C++ (or Java for Jython, or .NET languages for IronPython)
Software Architecture	MVC	GoF (Gang of Four) Design Patterns
Open Source?	Yes	Yes
Query Data from a Database?	DBI (Database Independent Interface) - MySQL, Postgre SQL, ADO, ODBC	MySQL, Postgre SQL
Frameworks	Ruby on Rails	Django, Grok, Pylons, TurboGears
Operating Systems	UNIX, Mac OS X, Windows 95/98/Me/NT/2000/XP, DOS, BeOS, OS/2	Windows, Linux/Unix, Mac OS X
Exception Handling Features	Yes	Yes
Mark and Sweep Garbage Collector*	Yes	Yes
Embedding in other softwares	Yes, SWIG Interface	Yes, SWIG Interface

Table 9 - Table of Functionality Comparison 2 [46, 47, 48, 49]

Functionality	PHP	Perl

Description	Interpreted script language, Compilable	Interpreted script language, Compilable into binary executable or platform-compatible Bytecode
Software Architecture	MVC	MVC
Open Source?	Yes	Yes
Query Data from a Database?	MySQL	MySQL, DBI
Frameworks	Prado, Seagull, CakePHP, Akelos	Dancer
Operating Systems	Unix, Windows	Windows, Linux/Unix
Exception Handling Features	Yes	Yes
Mark and Sweep Garbage Collector*	Yes	Yes
Embedding in other softwares	Yes, SWIG Interface	Yes, SWIG Interface

Appendix I - Tables of SQL Databases based on market research

Table 10 - General Comparison of RDBMS [42,44]

	Compatibility	Interface	Max DB size	Licensing
MySQL	Windows, Mac, Linux	SQL	unlimited	Open Source
PostgreSQL	Windows, Mac, Linux	SQL	unlimited	Open Source
SQLite	Unix, Windows, OS/2	GUI, SQL	140 tetra bytes	Public domain

Table 11 - Database Speed Comparison 1 [44]

	1000 INSERTs (s)	25000 INSERTs in a transaction	25000 INSERTs into an indexed table	100 SELECTs without an index
MySQL	0.114	2.184	3.197	2.760
PostgreSQL	4.373	4.900	8.175	3.629
SQLite	13.061	0.914	1.555	2.494
SQLite (nosync)	0.223	0.757	1.402	2.526

Table 12 - Database Speed Comparison 2 [44]

	100 SELECTs on a string comparison	Creating an index	1000 UPDATEs without an index	5000 SELECTs with an index
MySQL	4.640	0.318	8.410	1.270
PostgreSQL	13.409	0.381	1.739	4.614
SQLite	3.362	0.777	0.637	1.121
SQLite (nosync)	3.372	0.659	0.638	1.162

Table 13 - Database Speed Comparison 3 [44]

	25000 UPDATEs with an index	25000 text UPDATEs with an index	INSERTs from a SELECT	DELETE without an index
MySQL	8.134	6.982	1.537	0.975
PostgreSQL	18.797	48.133	61.364	1.509
SQLite	3.520	2.408	2.787	4.004
SQLite (nosync)	3.104	1.725	1.599	0.560

Table 14 - Database Speed Comparison 4 [44]

	DELETE with an index	A big INSERT after a big DELETE	A big DELETE followed by many small INSERTs	
MySQL	2.262	1.815	1.704	0.015
PostgreSQL	1.316	13.168	4.556	0.135
SQLite	2.068	3.210	0.618	0.939
SQLite (nosync)	0.752	1.485	0.406	0.254

Note that there are two times reported for SQLite. One is in its default configuration with full disk synchronization, and the other one is with synchronization turned off.

Table 15 - Database Functionality Comparison [45]

Functionality	MySQL	PostgreSQL	SQLite
Description	Widely used open source RDBMS	Based on the object relational DBMS Postgres	Widely used in-process RDBMS
Implementation Language	C and C++	C	C
APIs and other access methods	ADO.NET JDBC ODBC	native C library ADO.NET JDBC ODBC	ADO.NET JDBC ODBC
Server-side scripts	yes	user defined functions	no
Partitioning methods	horizontal partitioning in MySQL Cluster	no, but can be realized	none
Replication Methods	Master-master Master-slave MySQL Cluster	Master-slave	none
Foreign Keys	yes	yes	yes
Concurrency	yes	yes	yes
User concepts	Users with fine-grained authorization concept	Users with fine-grained authorization concept	no

Appendix J - User Interface

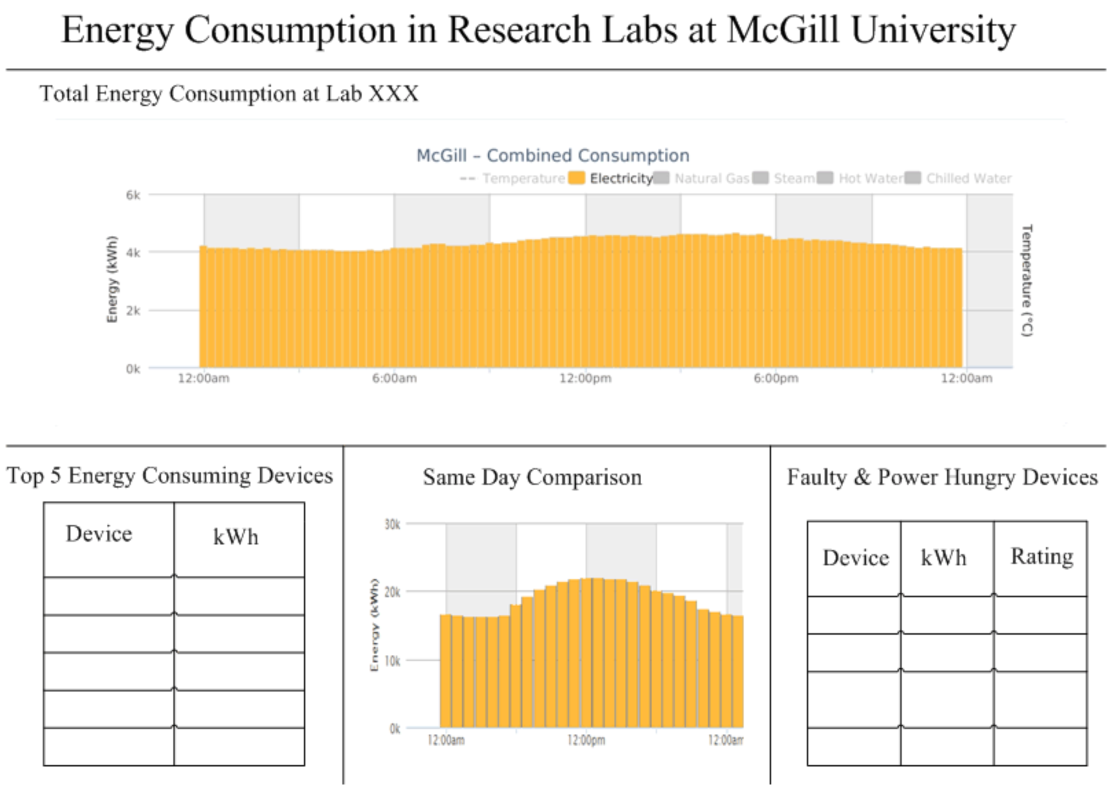

Figure 10 - User Interface Concept Image

Appendix K - Budget

The monetary budget of the implemented system in the pilot laboratory in MacDonald Engineering Building 571-574.

Table 16 - Estimated Budget

Item	Dollar Amount
Power Meter	$300 - $500 per meter (3 to 4 meters for the MacDonald Eng 571-574 Laboratories
Adapter + Gateway	$200 per bundle (3 to 4).
Server Space (Device Cloud)	$48/per device (3 to 4 devices)
McGill Electricians' Invoice	1000$
Protection Box	5000$/box (1 to 4 boxes for the MacDonald Eng 571-574 Laboratories).
Total	7644$ - 23992$ *

*The range will be narrowed down after pending responses from Steve Lajoie and Victor Black or Stephane Dudemaine. According to Hubert Marcil, it is most likely that 3 meters and 1 protection box are needed which will result in 7644$.

Appendix L - Lab Visits

Table 17 - Summary on First Round of Lab Visits

Lab	Equipment	Equipment Ratings	Usage Frequency
Chromosome Lab McIntyre 815	Centrifuge	250 W	always on, sleep mode, easy to start
	PCR Machine/DNA amplifier	120V* 8A = 960W	on when needed
	Digital Heatblock	115V * 0.8A = 92W	always on, restarting takes time
	Fume Hood	125V * 15A = 1875 W	always on
	Heatblock	770 VA	always on
	Thermo Scientific Freezer	110V * 5A = 550 W	always on
	Sequencing Machine * 3	110V * 0.5 A = 55W	on when needed
	Incubator *2	115V * 3.6A = 414 W	always on
	Thermo Scientific Freezer ULT2186-6-A *2	746 W	always on
Shockwave Physics Lab Macdonald Engineering B30 & B32	Blast Chamber Control	125V * 5A = 725 W	20 mins / day
	Fume Hood	230 VAC * 20A = 4600 W	always on
	Direct Current Permanent Magnet Motor	90 V * 3.5 A = 315 W	10 mins/day
	Thermo Scientific Furnace	1450 W	5-6 hrs/day

	Tumbler * 2	115 V * 0.54 A = 62.1 W	running continuously for half of the month on average
Mineral Processing Lab Wong Bldg Room 2470	Mozley MKII gravity separation table	1800 W	15 hours / month
	Knelson 3" lab model centrifugal gravity separator	1980W	20 hours/month
	Walkabout Spiral gravity concentrator	150 W	30 hours / month
	Marcy 4*6 Model 3340 jaw crusher	18000W	40 hours/year
	Marcy 10" reduction gy-roll cone crusher	18000W	60 hours/year
	Bico Braun Model 395-5 ball mill	18000W	40 hours/year
	Research Hardware Type L-1 rod mill	18000W	40 hours/year
	Sweco vibro-energy 18" separator	18000W	40 hours/year
	W.S.Tyler Model b Ro-Tap * 2	506 W	30 hours / month
	Desert Lab Prosplitter M12 rotary sample divider	57.5 W	10 hours / month
	Dust Collector	4180 W	40 hours / week
	Drying Oven	4000 W	always on
	Drill Press	1375 W	10 hours / week

Table 18 - Summary on Second Round of Lab Visits

Lab	Comment
October 4, 2013 8:30 AM Bellini Building Lab 356 (Immunology)	The research student, Connor, is very motivated and interested in sustainability

	Bellini is a LEED GOLD building, which is more energy efficient than other buildings, such as McIntyre. Most freezers are energy efficient, but frosted. Freezers cannot be shut down.
October 16, 2013 10:30 AM McConnell Engineering Building Room 008 (Prof Mi's Lab)	Molecular beam epitaxy (MBE) used to produce single crystal semiconductor consumes the most electricity in this lab. The electricity consumption of MBE is monitored through a DC panel in the lab. Other research equipment needs to be metered by the design team. MBE needs to be on all the time. If it is shut down for 15 minutes, it will take approximately 2 – 3 days to return to its vacuumed state. Possible way to be more energy efficient is to coordinate with students in the lab, so that all the samples are placed into the MBE chamber at the same time and new samples are placed into the MBE chamber when the previous batch of samples are taken out of chamber. Incentive for the aforementioned solution is that it is a time saving solution.
October 16, 2013 2:30 PM Otto-Maass Chemistry Building Room 340 (Lumb Lab)	Gas chromatography-mass spectrometry needs to be on 24/7. Pressure chamber [Braun] is always on. Oven is almost always on. Vacuum pumps consume a lot of energy. A rubber band should be placed to seal the interconnection. Devices can be shut down, but it takes time for devices to come back to its normal operation.
October 24, 2013 4:00 PM Macdonald Engineering Building Room 571 - 574 (Prof Gehr's Lab, the Benedek Integrated Laboratories in Environmental Engineering)	The entire lab is equivalent to four lab spaces. An area is commissioned for construction and electrical installation within the next few months All the devices can be shut down for 15 minutes, but coordination with Prof Gehr should be well ahead of time. There is a cold room in the lab, and other major equipment includes: a. Mini clean rooms b. Ovens c. Incubators d. Freezers (incl. -80 freezers) e. Centrifuges f. Microscopes g. Gas Spectrometers h. Gas Chromatographer

Appendix M - Detailed Timeline for Next Semester

Table 19 - Detailed Timeline for Phase 2 of Project

Date	Device Signature Algorithm (9 hours per week)	SQL Database (6 hours per week)	Ruby UI (9 hours per week)	Meters (3 hours per week for the first month)
06/01 /2014	Collect device signature & Generate a training set for the ANN algorithm based on the entire lab	Identify project requirements on the database	Identify project require ments on the UI	Order meters, device cloud, adapter s, etc.
13/01 /2014	Develop the difference algorithm for a 3-device system	Design SQL database to store device signatures	Learn Ruby	Play with meters
20/01 /2014	Test the difference algorithm for a 3-device system	Device signature device database online		Install meters
27/01 /2014	Design data pre-processing using MATLAB	Design SQL database to store raw data from the main power meter	Learn Ruby	Compl ete the data transmi ssion system integrat ion
03/02 /2014	Test data pre-processing using main power meter data	Database for raw meter data online		

10/02 /2014	ANN algorithm using MATLAB (Design & Machine Learning Phase)	Design SQL database to store pre-processed data	Learn Ruby	
17/02 /2014		Database for pre-processed data online		
24/02 /2014	Test ANN algorithm	Design SQL database to store the output of difference algorithm into device signature database and implement online		
03/03 /2014	Study Break			
10/03 /2014	1. Embed device signature algorithm into Ruby 2. Contingencies & Delay	Design SQL database to store output of ANN algorithm	Create client-side UI	
17/03 /2014		Database for ANN algorithm output online		
24/03 /2014		Contingency & Delay	Create client-side UI	
31/03 /2014			Create client-side UI	

Appendix N - Energy Conservation Measures

Table 20 - Energy Conservation Measures

Equipment	Notes	Recommendations
Autoclaves	- The start-up (steam- generating) period is the most energy consuming. - The units consumes energy even when they are not running.	- Switch off the units when they are not in use.

Biosafety Cabinets		- An energy saving technology which is based on a brushless direct current (BLDC) permanent magnet design improves performance and offers greater efficiencies than the ones with alternating current (AC) motors. These BLDC motors can save up to 80% of the energy consumption [80].
Centrifuges		- Turn off the power when the centrifuges are not in use. [70] - Put refrigerated centrifuges away from all sources of heat such as ovens and direct sunlight.
Freezers / Refrigerators	- Some freezers defrost automatically. Others require manual defrost. The frost in the freezers acts as an insulator around the evaporator coils, preventing the cold from getting to the inside. Furthermore, "sensors would not shut off the compressors at the set points." [70] - Frost free-freezers require more energy to maintain low temperature in their compartments. Extra energy is also needed to run their fan. [70] - Chest freezers are also more energy efficient than upright units. Cold air and moisture can easily flow down when the door opens in upright models. - Dust covered on the condenser can also hinder the exchange of heat.	- Defrost the ice when it has reached a thickness of 5mm. [70] - Manual defrost refrigerators are a better choice. - Discard outdated and unneeded samples. - Consolidate sample boxes within and among labs to reduce the total number of running freezers. [82] - Use chest freezers primarily if possible. - Remove dust on a regular basis (at least once a year). A clearance of at least 8 cm between the condenser coils at the back of the refrigerator and the wall allows good ventilation. [81] - Doors should also be sealed properly so cold air will not leak out preventing warm air and moisture seeping into the freezers [81].
Incubators		- Share incubators if possible.
Shakers	- It is more convenient to keep shakers on all the time so they are always ready to use.	- If shakers are not used on a daily basis, consider switching on the units an hour earlier to warm up or cool down the temperature. - If used daily, they should still be switched off at the end of the day, which can result in up to 50% savings. [70]