Interactive Energy Consumption Visualization

Sarah Ward and Nkosinathi Msimango
School of Information and Electrical Engineering
Witwatersrand University
Johannesburg

Dr Dalton Lunga
Council for Scientific and Industrial Research
Meraka Internet of Things Group
Brummeria, Pretoria

Abstract—Interactive data visualization is a transformational technique that can turn raw data into immersive insights extraction. In this study, an interactive dashboard that visualizes raw aggregated data is developed to identify energy usage patterns in an office building environment. The main goal is to highlight high consumptions patterns, estimate costs and savings, and recommend energy saving strategies. In its useful nature, the dashboard can provide valuable information for further programs tied to energy management systems. The dashboard's interface caters for different users that include a building operational manager, and the building occupants. In its demonstration, the visualization interface will show how to incorporate data filtering algorithms or multiple facets to enable multidimensional scales of viewing the same data (i.e. day, week, month, and year). The dashboard successfully highlights high energy usage intervals with bar, line, and heat map charts. In addition, the interface incorporates interactivity to ensure that the display allows for the user to submit instant uncanned queries. For future work, algorithmic approaches that include machine learning will aim to incorporate demographic data to establish human behavioural patterns and activities related to energy usage.

I. INTRODUCTION

Modern technological advances in the building industry continue to champion the design of efficient energy management systems. Although the continual improvement of such systems is yielding promising results for energy saving strategies [1], more is yet to be investigated when seeking to understand the hidden energy consumption patterns and how they differ from context to context. Smart meters are easing the difficulties with the collection of measurements [1]. However, the extraction of meaningful details presents additional challenges as raw energy measurements are often not easily understood, are processed differently for different stakeholders, and even worse, are collected at resolutions that sometimes do not capture instant events changes in device consumption. When various components are connected in a building, it becomes impossible to distinguish one device's energy use from the other by simply looking at the raw data collected at very coarse resolutions [2].

Previous energy consumptions investigations have demonstrated that the bulk of energy usage in households and office buildings are due to air conditioning, heating, and electronic devices [3], [4]. It is common knowledge that such devices are switched on and off in-line with behaviour and needs of the building occupants. As such, energy campaigns, energy labels on products, energy advice through media have been used to encourage people to use energy differently but this has proven to be rather insufficient [5], [6]. This study adapts a different approach that seeks to engage the user and display near real-time interactive visualizations that reflects energy usage patterns. Data visualization can serve as a great method in identifying energy usage patterns and thus can be incorporated in any energy management system. While there has been a one sided focus to energy concerns (which is supply over usage [7]), within focus of energy usage, it has been estimated that a feedback and/or tailored information scheme (that can be used in data visualization) may enable a reduction of upto 30 percent on energy demands [8].

As an application example, this study seeks to design and develop an interactive web-based dashboard that visualizes energy and weather data collected from three office park buildings. The ultimate goal is to contribute a technology that helps individuals, communities, and cities to become smarter energy consumers by keeping them informed of their energy usage at all times. As such, information visualization can only be useful if it is presented to relevant stakeholders in views that are expressive and effective at conveying the details. In order to ensure that the relevant audience (main electricity users) remain the target for energy efficiency [8], the designed dashboard mainly consist of two views, one for a building or site manager, and the other for an office occupant. Both views share a primary goal that seeks to highlight energy usage patterns and effects of temperature, estimate costs and savings, and recommend energy saving strategies which makes the dashboard contextual as opposed to applications that only display energy usages on time-series charts [11]. This study is intended to check the viability of energy monitoring and visualisation as an energy saving strategy.

This paper is organized as follows. In Section II, the problem requirements and domain, existing approaches are discussed. In Section III, a design for the dashboard is proposed including data handling and the views that will be incorporated. In Section IV, the results of the dashboard are presented with accompanying images showing various aspects of the design. Lastly in Section V, the results of the dashboard are discussed and future improvements are proposed for consideration.

II. RELATED WORK

The management and monitoring of energy usage patterns in both private and commercial environments is a global problem. There has been a growing interest towards the development of effective visualization systems for energy management and

strategic planning. Drawing from the information visualization and the visual analytics fields, the proposed work seeks to present an effective communication alternative with great potential to influence the consumption of energy. In example work, the authors in [9] developed interactive visualization techniques that can be adapted to touch screen appliances that includes tablets. Other work [10], whose focus was on behavioural development of children, demonstrates the benefit of using different views on a dashboard to highlight different features of the same dataset [10]. The results further suggested that human perception turns to absorb more information when presented with multiple dimensions of the same data. There has been work done in relation to energy visualization. For example, in [8] the authors sought to develop a means to visualise energy usage in individual households. Their work focused on tracking energy usage within a household and identifying when each member of the family used electricity, what activities triggered energy use, and who used the most. In their visualizations they made use of stacked bar charts to compare the energy usage of different members of the family as well as activity logs to see what actions were using electricity. In other related work [12], energy usage is studied through use of heat maps. Perhaps of close relation to our investigation is the study undertaken by researchers at the University of Texas [13]. The work involves some level of interactivity and allows a user to navigate along a time chart and view the recorded energy and associated cost in a home environment.

As to be illustrated, this study proposes a unique design with an increased level of interactivity that is intended to take advantage of various filtering mechanisms and also presents an application domain that differs from what has been investigated by existing literature.

III. PROPOSED METHODOLOGY

To reiterate the target audience for the nature of the presented problem, an interactive dashboard was designed to visualise a sample dataset for two types of clients; a site manager and a general office user. The study can be divided into three main sections namely data storage using PostgreSQL [14] database, data handling and processing which was performed using python [18], web server and client development using the Django [15] framework, the creation of dynamic graphs to conform to interactive visualization of the data - all done in D3 [16] and lastly, creating and styling the web page using HTML and CSS. Figure 1 shows a basic schematic of the dashboard development process. Each of these sections is discussed in detail below.

A. Data Storage

Collection of data was handled externally with energy data being collected by PowerWatch [19] and weather data being collected by the South African Weather Service [21]. Due to the different types of data not originaating from the same source there was some disparity between the two data sets. In Particular the weather data covered a shorter time period

Fig. 1. Diagram of process and tools used in developing the dashboard

than the energy data. Compensation was made for this in developing the visualisation dashboard and is demonstrated later when example outputs from the dashboard are discussed. The data was received in excel files containing information about energy usage for three of the buildings on the campus (building 43-CT, building 43-DB and building 26) as well as weather data including temperature, pressure, wind speed and wind direction in the vicinity of the campus, Figure 2 shows a sample of the collected data. Each energy file contained approximately 24000 data points and each weather file contained approximately 16000 data points. The energy data consisted of measurements such as time, apparent power, active power, reactive power, power factor, and maximum energy usage; however only the time and apparent power measurements were used as the other measurements reflect the same trend as that shown in apparent power and thus are redundant for the purposes of this study. All data was migrated to an instance of a PostgreSQL database. PostgreSQL was chosen as the database because it is capable of multi-threading and has a connecting module that makes its communication with python to be user friendly.

Fig. 2. Sample energy (bottom) and weather (top) data used in the study

B. Data Processing

The processing of data is performed before it is forwarded to Django and the web page for viewing to minimise the processing power required on the client side. This includes formatting the time into a more easily readable string (i.e. 2014:03:01 would be displayed as 1 march 2014 etc.), and processing the data to display a statistical summary of the energy usage over a given period. Within the statistics a total energy usage was calculated for each building and then the overall campus energy use was found by adding the total energy use values from each building. In addition the

time and place of maximum energy usage was determined and the overall maximum energy usage and time was found by comparing the maximum usage values for each building. Lastly values that would later be used to plot a heat map were normalised per building(to become a percentage of the maximum). The values were normalised as a result of some of the data being in very different ranges with some buildings having data in the range of thousands of KWh and others having readings in the tens of KWh. Thus an unnormalised heat map may have resulted in a monochromatic rows in the heat map and loss of valuable information due to a lack of resolution.

C. Visualization

To ensure that the data is effectively communicated to the target audience, it was decided that the visualization would be split into two views with each being contained in tabs on a single web page for easy navigation. Each of the views has two drop down filtering tables that enable a client to select the building of interest and the time resolution or period they would like to view the data (e.g. building 43E over the month of February). The querying period can be supplemented by date from which the results should be generated (e.g. 2013:05:05). The visualization framework is made robust by incorporating additional error catching mechanisms for blocking the entering of invalid dates. Each view is discussed in further detail below.

1) General Office User's View: The first view would be for an ordinary office user who would most likely be interested in the energy usage of their particular building. Thus the office user's view contains 4 graphs: a bar graph showing the energy usage for their building over the selected time period, a bar and line graph showing a comparison between current energy usage and the target energy usage over the same period of time, a dual line graph showing energy usage over the selected time period compared to average historical energy usage over a similar time period and lastly a heat map showing a comparison between temperature and energy over the selected time period. In addition a statistics box was included which contains information about when maximum energy usage occurred, what the total energy usage and total target energy usage over the time period was and the estimated costs and hence how much the target was exceeded or undershot by. Lastly the savings or additional expenses relating to the difference between the target usage and actual usage were calculated and displayed. The display of savings or additional expenses is displayed as an incentive to either improve energy usage or maintain good energy saving behaviours. The rates used to calculate costs were obtained from the city of Tshwane municipality [20].

To highlight important features and dimensions of interest on the graphs, different colours were used. For example the bar and line graph (where the bar represents actual energy usage and the line is the target). If actual energy usage is above targeted usage then the bar will highlight red, but if it

is below the target then the bar will highlight blue. Similarly in the statistics block if there is an overshoot for the entire period then the additional expense incurred will be printed in red, but if there is a saving then the text will be green. In addition, hovering over any bar in any of the graphs will cause a box to pop out containing the exact energy reading at that point. These visual cues help a client to more readily take in the information being presented.

2) Site Manager's View: The second view is aimed at a site manager or office park manager who would be interested in comparing energy usage for all buildings within an office park. Many of the features on the site manager's view are similar to those in the office user's view with the exception that they contain more comparisons between buildings and less specific data about any building in particular. Three graphs were selected for the site manager's page, these being: a stacked bar graph showing the energy usage for all buildings simultaneously, a heat map showing the energy usage in each building along with temperature readings, and a bar graph showing the energy usage for a particular building as selected in the drop down menu. The difference in scale for energy measurements caused readings from other buildings to be invisible which prompted the design of a blow-up bar graph that would offer a further zooming-in capability onto each individual building.

As in the office user's view, a priority in producing a visualization for the manager was that the data be easily interpreted at a glance and that the visualization be interactive. Thus all the graphs would pop up additional information upon hovering over a particular point and the individual bar graph would change colour to correspond to the legends on the stacked bar graph based on which building was selected. In addition the stacked bar graph had the ability to be viewed either stacked up so the total energy usage would be apparent or to be viewed grouped with corresponding data for each building to be viewed side by side for easy comparison. The last feature in this view is a block containing statistics similar to the one in the office user's view with the only differences being that the values are totals over all the buildings and the highest energy usage specifies in which building the highest energy usage occured in addition to the time at which the highest energy usage occurred.

IV. DASHBOARD DEMONSTRATION

A. Manager

The main interests of a site or building manager would be to over see all the buildings and be able to compare their energy usages. The managers tab is shown in Figure 3, in which it can be seen to contain the stacked bar graph in Figure 4, individual building bar graph in Figure 6, heat map in Figure 5 and the cost analysis in Figure 7.

For this particular example, which shows the average usages per day, observations made were that considerable energy usages started at 8:30 am till 4:30 pm which corresponds to working hours. The selected building which was building 26
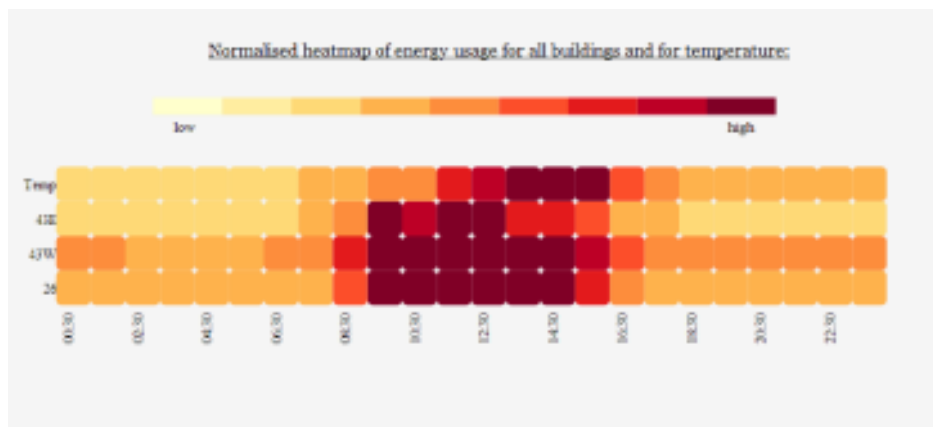
Fig. 5. Heat map illustrating building energy use in comparison to environmental temperature data.
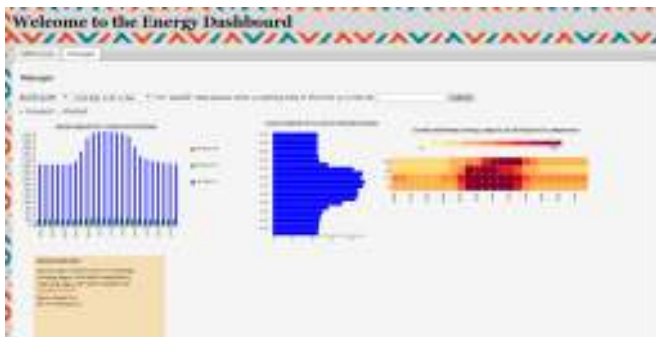

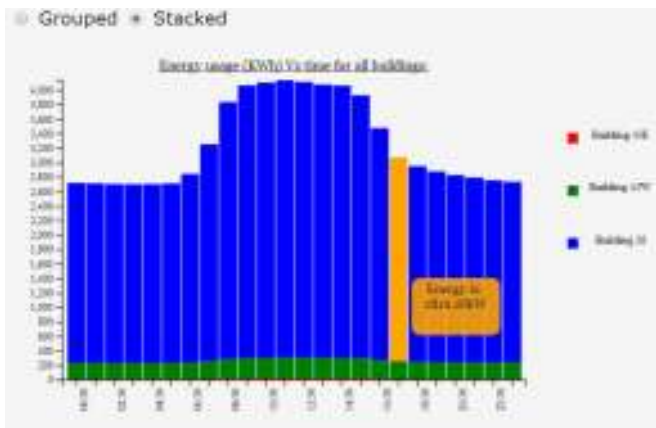Fig. 3. Managers Energy consumption view

Fig. 4. Stacked bar graph with transition ability
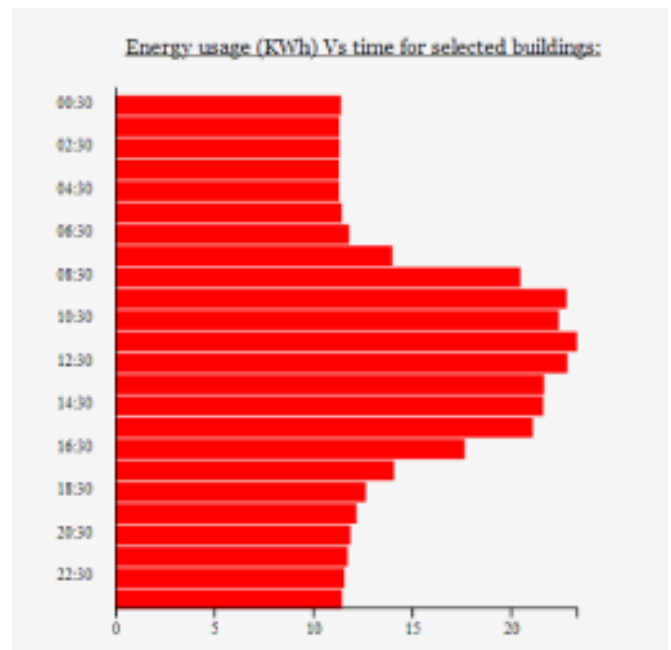

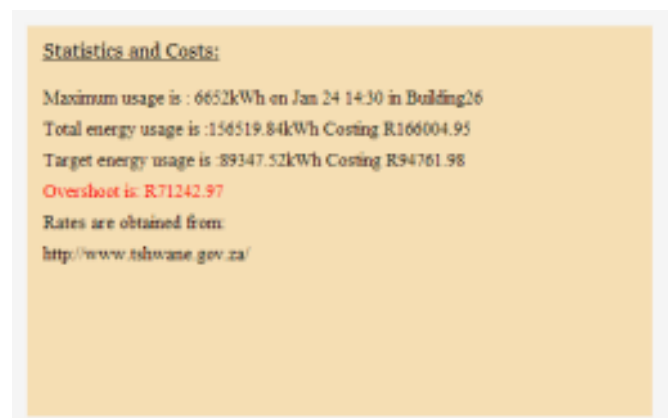Fig. 6. A pop-up view of selected building in site manager's view

Fig. 7. Summary of energy consumption cost analysis

uses very high energy compared to the other two buildings, and it was later found that this is where the campus power substation is housed. Another useful observation is that about R71 242.95 was lost on average. The heat map shows both the temperature and energy usage being high towards noon for all buildings, which may suggest that building occupants use air conditioners to counteract the high temperature. When considereing all the available data temperature was found to have a large effect on energy readings. When temperatures

were either very high or very low there a spike in energy usage is apparent corresponding to air conditioners and heaters respectively. This may suggest that one way to save energy would be to improve the insulation of the building thus reducing the need for airconditioners and heaters. This is precisely the kind of insight that the dashboard is designed to help highlight. Lastly it is clear that there is relatively high energy usage at night with peak energy usage being less than double night time usage. This suggests that in developing an energy management plan it may be of value to investigate what machinery is being left switched on at night resulting in such high off peak energy usage.

B. Office User

Figure 9 is an office users tab which shows information pertaining to only a specific building. The example shown is for a standard week and shows a single bar graph as seen in Figure 10. It can be seen from the current versus target energy graph in Figure 11, that the current energy usage is sometimes lower and sometimes higher than the target usage. Conditional colouring of the graph helps make this more visible. Figure 13 shows that the data for the selected time frame matches historical data fairly accurately and that there are no abnormal occurrences within the week. From the cost analysis in Figure 12 a loss of R161.05 was incurred on the corresponding day and is highlighted red to make it instantly apparent and raise a prompt attention to the user. As shown in the heat map in Figure 8, error catching functionality is demonstrated by notifying the user that there is no available temperature data for the selected day, the lack of temperature measurements that overlap with the available energy data is the root cause for this error.

V. DISCUSSION AND FUTURE IMPROVEMENTS

The dashboard results and its accompanying demo (which was performed in front of a panel by the authors) did demonstrate that through information visualization and visual analytics techniques, mechanisms for curbing excessive use of energy can be devised and incentives introduced to encourage energy saving. Furthermore, the dashboard could be visualised on a tablet although the hovering features of the dashboard were only visible by tapping on the graphs and further improvements are required for the dashboard to be accessed on a mobile phone. Overall the dashboard is still at its early stages and some immediate improvements that can be made include adding more interactivity to visualize the data. The resolution of the graphs is currently pre-set in program, so an advanced options panel to select the frequency of averaging the data could be beneficial in pattern identification. If the correct data could be obtained, a graph of the number of people or machines turned on (from number of people logged on to their computers) versus energy could be included to visualize the effect that the number of people in the building has on energy usage. A big improvement will be the ability to predict future energy usages based on an energy usage model determined by using machine learning algorithms that include
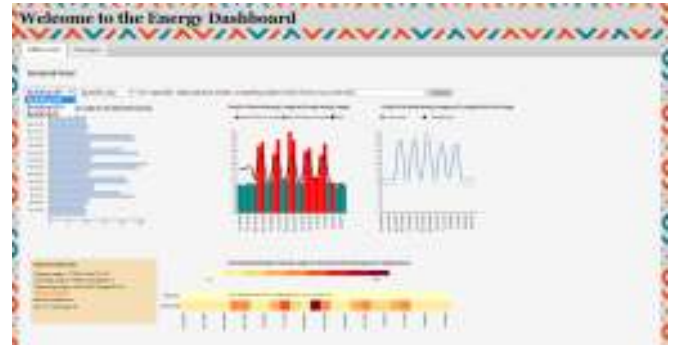

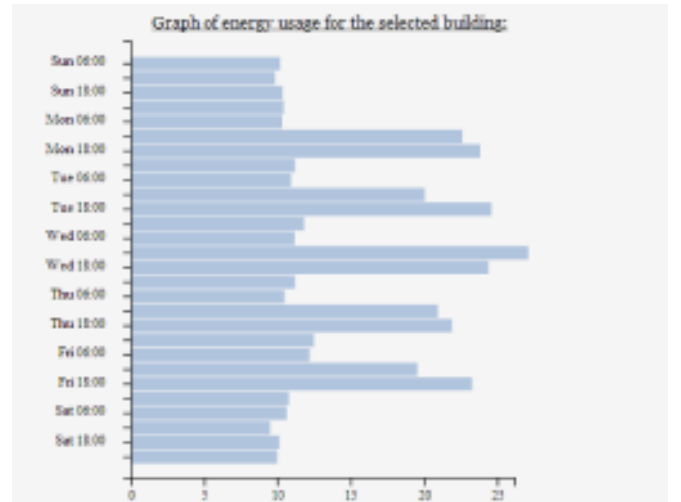Fig. 9. Office user Energy consumption view

Fig. 10. Bar graph illustrating energy usage in selected building

parameters such as the number of people in the building, temperature, date, and time of the day. The visualization could also be improved by incorporating a wide range of energy sources so that it can properly visualize big data from multiple sources for use by a large corporation such as Eskom. Even though the specified requirements were fulfilled the deluge of more energy data points could cause a potential bottleneck to filtering algorithms. As such, with the growing volumes of energy data, some due to collecting reading at finer time intervals, our future attempts will look at adapting Big Data platforms for increased real-time interactive on gigabytes and even terrabytes of energy data points. This would open doors for research in large scale visualization of energy data. In addition, modifications that allow individual households to monitor their energy usage could be beneficial. Lastly the dashboard would benefit from increasing compatibility on mobile phones so that the data can easily be accessed via GSM networks.

VI. CONCLUSION

An energy visualization dashboard has been design and developed, the dashboard is interactive and provides information on energy consumption for a site or building manager and also information for an office user. The dashboard presents
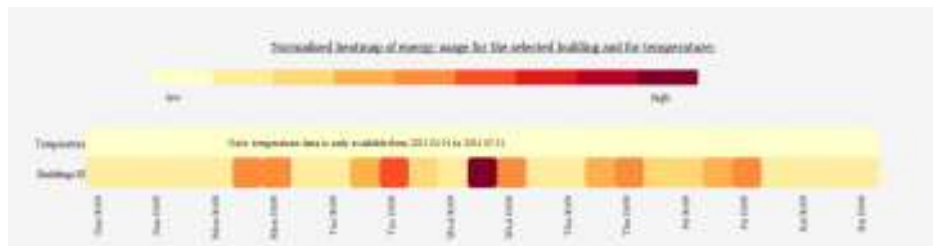
Fig. 8. Illustrating error catching functionality on Heat map view

comparison graphs for the manager while it shows specific building graphs for the office user. Its interactivity includes time scale filtering, tool tips showing more information on hover, energy costs/savings statistics, and selective colouring to highlight important features. As a preliminary investigation into the effectiveness of visual analytics in energy management the study showed promise and sucessfully identified certain energy usage patterns that could be used to improve the way in which energy is utilised.

REFERENCES

[1] J.F. Martins, J.A. Oliveira-Lima, V. Delgado-Gomes, R. Lopes, D. Silva, S. Vieira, and C. Lima, "Smart Homes and Smart buildings," CTS/UNINOVA-DEE-FCT Univ. Nova Lisboa, Lisbon, Portugal, Electronics Conference (BEC), 2012 13th Biennial Baltic, Pages 27-38, 2012.

[2] R. Fontugne, J. Ortiz, N. Tremblay, P. Borgnat, P. Flandrin, K. Fukuda, D. Culler, and H. Esaki, Univ. of Tokyo, Tokyo, Japan, "Strip, Bind, and Search: A method for identifying abnormal energy consumption in buildings," Information Processing in Sensor Networks (IPSN), 2013 ACM/IEEE International Conference, Pages 129-140.

[3] K. Karlsson, J. Widen. "Hushallens Elanvandningsmonster Identifierade i Vardagens Aktiviteter," Tema T Working Paper; Linkoping University, Linkoping, Sweden; 2008

[4] J. Widen, and E Wckelgard, "A high-resolution stochastic model of domestic activity patterns and electricity demand," Appl Energy, Volume 87, Pages 18801892, 2010.

[5] P. Gyberg, and J. Palm, "Influencing households energy behavior: how is this done and on what premises?" Energy Policy Volume 37, Pages 28072813, 2009.

[6] K. Ek, and P. Soderholm, "The devil is in the details: household electricity saving behavior and the role of information," Energy Policy Volume 38, Pages 15781587, 2010.

[7] IPCC, "Summary for policymakers"; 2007 http://www.ipcc-wg2.org/ index.html last accessed August 2014.

[8] K. Ellagard and J. Palm, "Visualizing energy consumption activities as a tool for making everyday life more sustainable," Department of Thematic Studies Technology and Social Change, Linkoping University, 581 83 Linkoping, Sweden

[9] R. Sadana and J. Stasko, "Designing and Implementing an Interactive Scatterplot Visualization for a Tablet Computer, International Working Conference on Advanced Visual Interfaces," Pages 265-272, 2014.

[10] Y. Han, A. Rozga, J. Stasko and G. D. Abowd, "Visual Exploration of Common Behaviors for Developmental Health," Visual Analytics in Healthcare, 2013.

[11] M. Masoodian, B. Endrass, R. Buhling, P. Ermolin, and E. Andre, "Time-Pie visualization: Providing Contextual Information for Energy Consumption Data," 17th IEEE international Conference On Information Visualisation , Pages 102-107, 2013.

[12] Y.S. Jeong, Y.J. Chung, J.H. Park, "Visualisation of efficiency coverage and energy consumption of sensors in wireless sensor networks using heat map," IET Communications, Volume 5, no.8, Pages 1129-1137, 2011.

[13] G. Ghidini and S. K. Das, "Improving Home Energy Efficiency with E2Home: A Web-based Application for Integrated Electricity Consumption and Contextual Information Visualization," IEEE SmartGridComm Symposium At University of Texas 2012.

[14] The PostgreSQL Global Development Group, PostgreSQL, http://www.postgresql.org/ last accessed August 2014.

[15] The Django Software Foundation, Django, https://www.djangoproject.com/, last accessed August 2014.

[16] M. Bostock, Data-Driven Documents,2013, http://d3js.org/, last accessed July 2014.

[17] Appcelerator Inc, Aptana Studio 3, 2011, http://www.aptana.com/, last accessed June 2014.

[18] Continuum Analytics, Anaconda, https://store.continuum.io/cshop/anaconda/, last accessed June 2014.

[19] Energy Cybernetics (PTY) LTD., PowerWatch, http://www.cpowerwatch.com/, last accessed September 2014.

[20] City of Tshwane, Supply of Electricity, 2014, http://www.tshwane.gov.za/AboutTshwane/CityManagement/CityDepartments/Financial

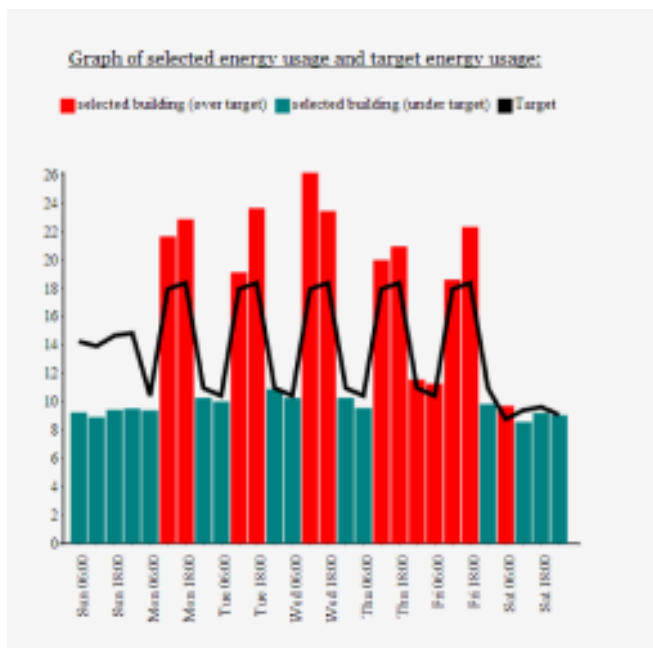[21] South African Weather Service, http://www.weathersa.co.za/, March 2014.

Fig. 11. Bar and line graph illustrating showing target energy usage in selected building and selective highlighting feature
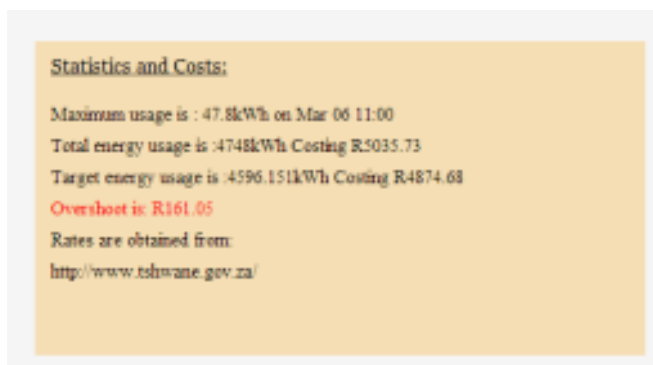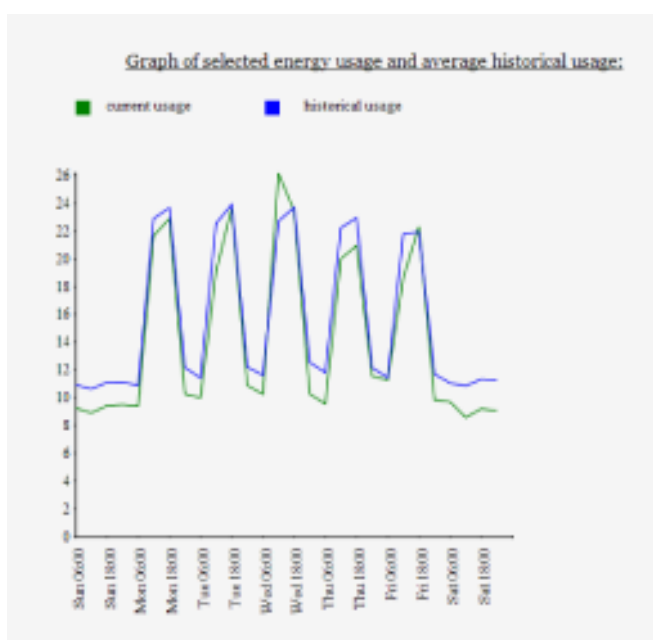

Fig. 12. Cost analysis

Fig. 13. Dual line graph showing a comparison with historical data