Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference

Expanding Boundaries:
Systems Thinking for the Built Environment

AN INTEGRATED AND INTELLIGENT WAY TOWARDS ENERGY MANAGEMENT- THE COCKPIT

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Abstract

In an increasingly competitive environment, a highly efficient energy management system is of utmost importance. However, despite the research on energy saving methodology and retrofitting analysis, these results and data do not allow different users to focus on what lies inside the management and strategy level. The Cockpit concept emerges as a strategic management system, in near real time, as an attempt to explain and communicate the institutes' energy performance at different levels. With respect to the detailed energy data analysis, it helps in the understanding and visualization of the institutional building energy performance. In addition, the Energy cockpit display interface presented in this study is an essential feature for the integrated energy study. Energy consumption and comparison as well as the different security levels provided, are able to give relevant and critical information for the building developers, owners, occupants, as well as visitors.

Keywords:

Energy management; Cockpit; Energy efficiency; Data analysis

1 INTRODUCTION

Energy is nowadays one of the most challenging sectors because of the rise in prices and the diminution of the energy sources. The impact of the building sector on the energy consumption is even enormous: 40% of the overall energy consumption in Europe [1] and around 30–40% of the world primary energy consumption [2]. Studies have shown that there is a significant potential to reduce energy consumption of 20% [3] and in GHG emissions of 30% [4]. However, to achieve these potential reductions some strategies in energy management are needed [5,6]. Hence, a lot of research studies have been recently focused on energy optimisation [7,8] through different energy management systems [9].

The Cockpit concept emerges as a strategic energy management system in recent time, with the advantages of being able to explain and communicate the energy performance at different levels within an organization or a specified scope. While it can be considered almost absolutely eco-friendly during the operational phase, it is important to evaluate the energy in a visualization way to give relevant and critical information for the building developers, owners, occupants, as well as visitors. In a thorough literature review, it is found that a comprehensive energy cockpit development involving the energy consumed from the data collecting, data cleaning, until usage by the systems of the buildings and the energy data analysis is very limited.

On the other hand, with the rapid development of sensor/meter technology and the installation in building sectors, network and transmission technology and cloud computing, large amounts of energy consumption data is being generated and has been accumulated in several subsystems of a building [10]. To better make use of this data and also better deal with these data challenges, real time cockpit energy data analytics provide new opportunities by achieving integrated and intelligent energy management.

The following paper presents a smart development of energy monitoring cockpit, which is able to perform automated data cleaning to reduce labour cost, and describes smart automation tools which are able to identify energy saving opportunities, hence meeting the

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DOI 10.3218/3774-6_40, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

requirements and dealing with the challenges as described above.

2 COCKPIT DEVELOPMENT

2.1 Energy Information Network (EIN) Infrastructure

The EIN takes National University of Singapore (NUS) campus as a living lab, with the first phase to include 10 buildings to be instrumented an integrated with an energy and environment monitoring and management system so that each building can be communicated with a centralized and monitored Energy Cockpit.

The "Energy Cockpit" is located in the Department of Building. Energy analytics will be used to monitor and manage the performance of these buildings with a goal of reducing energy consumption. This will help determine any discrepancies between benchmarked performance and actual energy usage thereby unlocking energy savings opportunities and identifying areas for improvement or energy efficient upgrades.

2.2 Data Cleaning

Figure 1 shows the potential errors in data, such as outliers, missing values and time stamp issues, which can happen with any data collection system any time randomly, sometimes for no reason. In the energy consumption data collecting system in NUS, more than 5000 errors occurred in one month only for one random building. Although it is possible to spot and correct them by those people with an intimate understanding of the building's functions and usage on a daily basis. The required resources, time and financing, are the main challenges the energy management system faces.

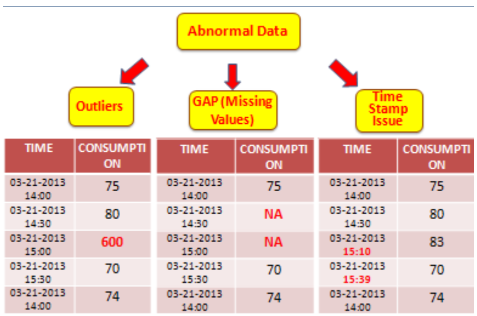

Fig 1: Potential errors in data.

Since the energy consumption data collected is the basis for any data analysis and monitoring, the Cockpit runs a data cleaning methodology in the background to provide the clean data. The methodology involves a K-means clustering approach and data imputation using linear regression with a past five hour input to detect the outliers. The size of the resulting clusters is further analysed into key factors to identify groups of energy consumption so as to observe the outlier that are distinct from the majority of the data. The whole process is applied automatically to provide a clean data set for future research purposes.

Figure 2 is the dashboard of the Cockpit data collection and cleaning status. The green light in the last column shows the smooth data collection with no error currently. The total number of missing data imputed, timestamp issue data and the outliers identified thought the automatic data cleaning process are shown in column 4,5 and 6 respectively.

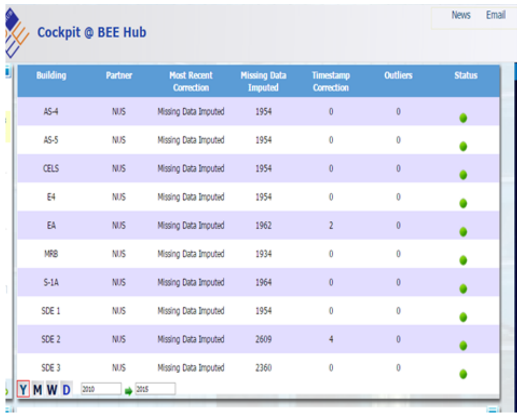

Fig 2: Data collection and data cleaning tool.

2.3 Energy Monitoring

The cockpit consists of three main parts for an integrated and intelligent energy management.

The first part is the energy monitoring. The key data for each building is shown, including gross floor area, building category, age of building, operating hours, occupancy per square meter as well as the EUI for the past 12 months and the chiller plant efficiency. Then energy consumption of the Air-conditioning part, electrical part and the total energy consumption part are monitored simultaneously. It is also possible for the users to choose the shown time period at the bottom left so that the data can be shown on a yearly basis (y), monthly basis (m), weekly basis (w) or daily basis (d) as shown in figure 3.

A comparison of energy consumption is also possible for up to 4 buildings as showing in figure 4. This comparison is a way of indicating the different pattern of energy consumption, and also bring opportunities to look into operational efficiency and cost control [11], system stability and reliability [12], as well as energy efficiency and environmental issues [13].

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Fig 3: Energy monitoring interface with single building.

Fig 4: Energy monitoring and comparison between buildings.

2.4 Energy Analysis

The second part of the cockpit presents a simple but clear user-friendly energy data analysis by using the cleaned real time data to monitor energy while linking consumption with real time period events.

As shown in figure 5, the energy consumption data was compared between day and night (day is the working hour of the corresponding building); weekday and weekends. The facility budget can be keyed in by the facility manager to see how the energy consumption meets the budget line. The aim of this energy analysis part is to formulate a link between energy usage and the actual physical activities consuming that energy. This is because the campus buildings energy consumption is highly related to semester schedules and vacation time [14] so this kind of energy data analysis can be used to generate a rough image of a physical activity profile of the building in a specified time period. The energy profile for weekends during semester time, vacation time, and exam period time, can be identified as an occupancy independent part, so that the energy profile of the occupancy dependent part during working days can be illustrated while highlighting the levels of occupancy influence on the energy consumption.

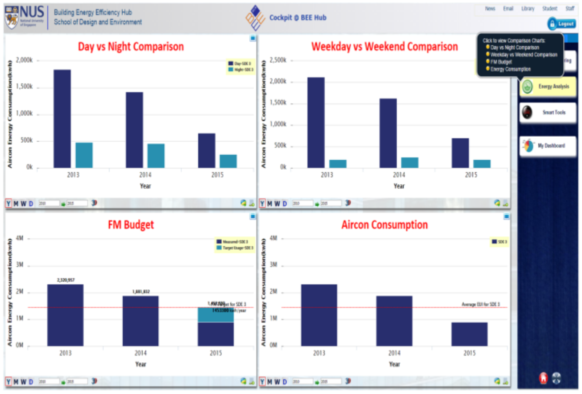

Fig 5: Energy analysis interface.

2.5 Smart Tool

In the third stage, smart tools with novel methodologies are implemented to provide an intelligent profile for the building facility manager and the users.

Figure 6 shows the first smart tool: Energy Forecasting. The methodology can be easily applied to different buildings because it reduces the degree of variation by dividing the energy consumption data into classes [15]. These class numbers are then taken as inputs for the forecasting model using Artificial Neural Networks (ANN). The model development along with the ANN architecture are run in the cockpit background with the high accuracy of R^2 of more than 0.94 when forecasting the energy consumption for the next twenty days.

In the cockpit, the Forecasting tool predicts the electrical energy consumption and the air-con thermal energy prediction consumption of a building for the next two weeks. With the development of a forecasting model based on machine learning techniques and historical energy consumption data only, a set of boundary conditions can be provided and targets for the building facility managers and owners within which the building's energy consumption should ideally fall (daily, weekly, monthly, and annual targets). In addition, the forecasting algorithm can also be clubbed with smart sensors and control systems and equip them for future scenarios. It can also be combined with other simulation models like EnergyPlus and can be used to derive other operational factors like occupancy etc. Meanwhile, as the forecasting tool learns from previous energy consumption usage patterns, a gradual increase in the forecasted energy consumption values over a period of time may also notify the facility managers on the maintenance aspects of the building.

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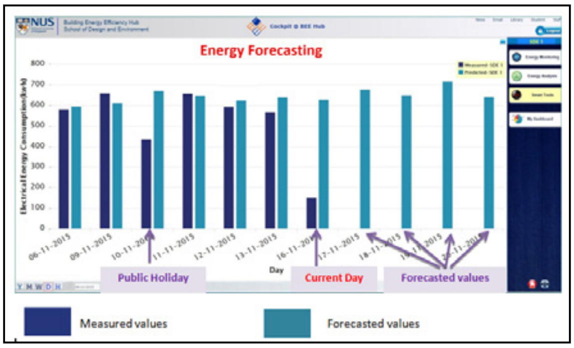

Fig 6: The forecasting tool updates itself every Saturday (12:00 am) and forecasts the energy consumption values for the next two weeks.

The second smart tool implemented in the cockpit is called Identification Tool. It is developed in order to learn the building energy consumption characteristics as well as get the knowledge of dynamic energy budget interrelationships by using the available data [16].

As shown in figure 7, the Identification tool identified three factors influencing the cooling load consumption. In the user interface, there are Four lines: the dark blue is the measured data; the light blue is the simulated cooling load based on function 1, Where function 1 is the daily variable based on the interrelationship between PLUG LOAD and HVAC LOAD (Basic occupancy in a building which will influence both), the red line is the simulated cooling load based on function 1 plus function 2, Where function 2 is the daily variable taking into account the difference between PLUG LOAD and HVAC LOAD (Occupancy variation which will influence the cooling load much more than the way it will influence the plug load), and finally the orange line, which is the simulated cooling load based on function 1 + function 2 + function 3, where function 3 is the daily variable, taking into account the daily outdoor air temperature variation.

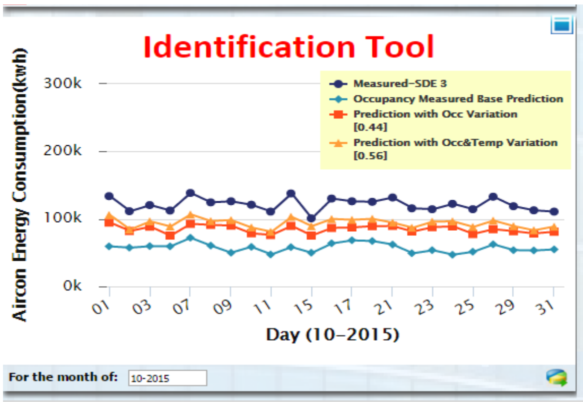

Fig 7: The Identification tool substitutes different parameters to identify energy consumption characteristics.

The identification tool's results are able to provide information to the facility management on how the three factors' results in the cooling load consumption vary daily. Meanwhile, the identification tool can be further used as an input into OCCUPANCY SCHEDULE of the ENERGY PLUS simulation software to achieve a higher simulation accuracy [14], which is the next phase of smart tool development.

The third smart tool is Clustering, which is the bottom level analysis of energy usage among a large group of buildings, in some cases done purely at the building type or at ground floor area, only identifying the one aspect of building characteristics. The cockpit clusters the campus buildings (60 at the first phase) into three groups based on the EUI as shown in figure 8. The clustering tool gives an overview of the energy consumption in a district campus level so that the next step zoom in analysis with the previous two smart tools can be applied.

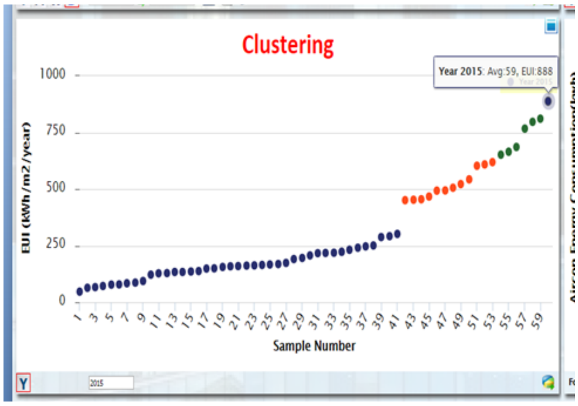

Fig 8: Clustering tool.

3 SUMMARY

An integrated and intelligent Energy cockpit not only includes the massive smart meter reading data, but also the huge story hidden behind the amount of data, such as building characteristics, occupancy activity pattern and the knowledge of dynamic energy budget interrelationships. It assists building energy management with data cleaning, data monitoring, data analysis and smart tool analysis with 4 horizontal dimensions (comparison up to four buildings) and 4 longitudinal dimensions (yearly, monthly, weekly and daily).

With the development of the Energy Cockpit prototype, a log in page with different levels of access is designed which meets the identified data security for data controlling. Hence, it provides different end users different levels of energy related figures with a more straightforward way. Discussions on the smart tool energy data management model development indicates, that the Cockpit strikes a new path when it comes to energy simulation and prediction on a research level.

In the end, in most organizations, facility managers are designated as main users of the Cockpit. However, some managers might not be able to work in a complicated web software interface. This Energy Cockpit, with its simple and clear user interface, provides a quick but comprehensive, accurate and whole energy consumption picture to the user.

4 ACKNOWLEDGMENTS

The project is funded by National University of Singapore under CiBEST (BEE Hub).

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