Seeing by Degrees: Programming Visualization From Sensor Networks

Da-Wei Huang
Engineer, Building Control Development

Michael Bobker
Director of Technology Strategy

Daniel Harris
Manager, Building Control Development

Association for Energy Affordability
New York, USA
dhuang@aeanyc.org

Abstract: In order to create baseline conditions for building energy performance, make a setting adjustment or determine optimal operating parameters, it is often necessary to view a large series of history data from a building control and management system. However, viewing large amounts of data in tables and charts is not a useful procedure to find significant patterns and information for an energy team. A new approach at AEA adds a programming engineer to the normal energy analysis team who manages data and programs visualization tools to speed analysis. This paper addresses the potential effectiveness of such an addition to the typical building operations (optimization) project team.

The programming engineer confronts issues in two directions. First is the nature of the data as it is captured and stored, which establishes various data processing steps that are necessary to produce an automated acquisition system to the server. For the second direction, the programming engineer must adapt to the needs of the project team: what kinds of questions are the building engineers asking, how does data need to be aggregated, and how can it best be visualized. The paper considers how, in order to produce useful data tools, the programming engineer is confronted with having to learn and appreciate the kinds of questions asked by other disciplines on the project team.

1. INTRODUCTION

1.1 Sites in Operation

The Association for Energy Affordability (AEA) has completed four residential demonstration projects using a retrofitted wireless, web-based energy management system (EMS) in New York City.

- Lambert Houses, an electrically heated complex in the Bronx: 350 apartments in two construction phases electrically heated and window unit air conditioning, the EMS performs thermostat in each apartment and includes advanced functions such as outdoor temperature setback and automated peak demand limiting;
- Aurora, a 99-unit apartments building in mid-town Manhattan, packaged terminal air-conditioner (PTAC) in each room with electric AC and steam heating, the EMS controls steam heating optimization and performs peak demand limiting;
- Ocean Village in Far Rockaway, a 1100-unit electrically heated complex: the EMS performs thermostat function in each apartment and includes the same advanced functions as Lambert;
- Tiffany Mews, 70 apartments building in Brooklyn, individual window unit air conditioner and hydronic central boiler.

1.2 E-Master Energy Management System (EMS) Description

E-master is an energy management system originally designed by the AEA energy team in partnership with Intech21 Inc. A typical EMS installation contains a power meter, relays, switches and measurement sensors to control the AC or heating as necessary. The power meters measure the apartment electrical load, actuate the loads, and wirelessly communicate between each other to create a building wide local area mesh network. Each building has an access point that collects the signals from the power meters and relays it via the normal Wi-Fi building-to-building network to the management office terminal where the data is sent to the internet and a remote database.

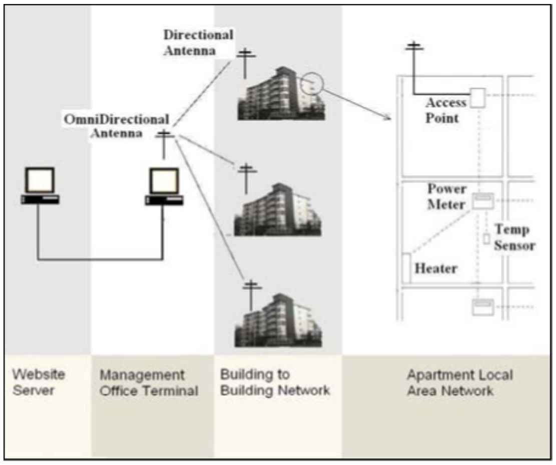


Fig. 1 E-master System Picture Diagram

At the electrically heated buildings, the power meter performs a thermostat function by actuating the heaters to maintain a set point temperature in one or two heating zones. The outdoor temperature setback function in both electrically heated buildings and central steam plant control prevents unnecessary heating during warm days in the shoulder months (May and September). In the summer cooling season, the EMS can control air conditioners based on set point temperature or employ an automated peak demand limiting function, to avoid high demand. In all cases, the management office terminal collects data from the buildings at the site. and stores it in an on-site database in the management office terminal every 15 minutes. The terminal transfers the data to a remote database via the internet via industry standard protocol.

2. HOW IS DATA ACQUIRED?

2.1 The Intech21 Remote Database and Website Intech21 Inc., a partner of AEA, designed a webbased GUI to display the data from each building.. Remote users, like building owners and managers, or the AEA energy team, can use the GUI to examine building conditions, send commands to control units and respond to resident concerns. This GUI is password protected and control functionality is further limited with additional security.

The website prepares a CSV (comma separated values) file for download each day. This file contains individual apartment data such as apartment number, meter reading, and date and time, and temperature. The energy team uses the downloaded file to perform analysis either by parsing the data into a database or a spreadsheet

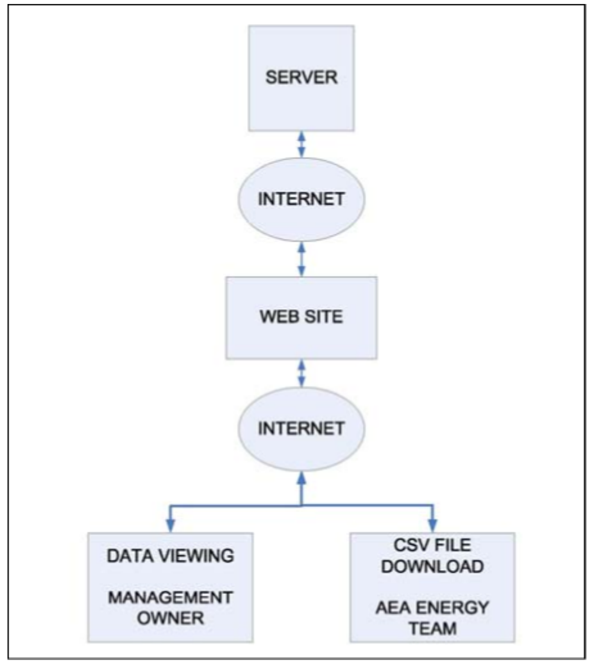


Fig. 2 Intech21 Website diagram

2.2 How is Data Viewed?

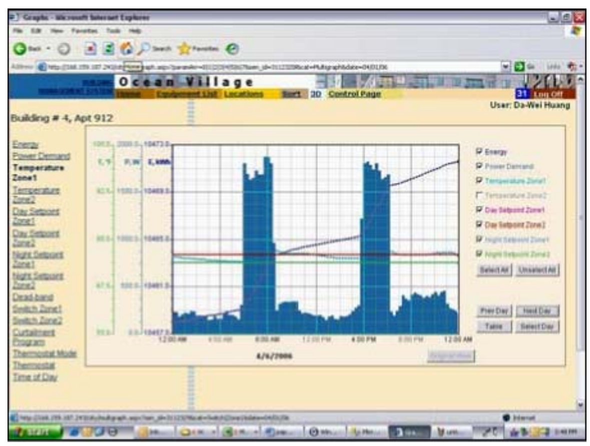


Fig. 3 Graphical User Interface on the Web-site showing the electric heating site

The user may individually inspect all the apartments in each building with the GUI. Data is displayed for a single apartment in graph with a 24-hour window that updates dynamically in Java. The user can display multiple parameters such as energy, demand, and temperatures as necessary to determine the nature of problems or look for ways to improve performance. The buttons marked "previous day" and "next day" allow the user to see data for different days. Other data views include a real-time monitoring page that displays up to date information in a table, a locations screen that shows a simple graphical representation of the apartments, and a 3-D screen that shows a model of the relative spatial orientation of each apartment with color coded parameters. Some simple comparisons can be achieved with these views; e.g. a comparison of the power demand and temperature in each zone with set point can be used to detect unauthorized heaters or other electrical devices as shown in figure 3. For more advanced energy analysis or visualization the energy team needs excel spreadsheets or Microsoft Access tools to process the CSV file data. Using the functions in excel, the energy team sorts the data and makes calculations to get useful analysis and present them in figures, tables, and charts.

2.3 Energy Team Shortcomings

The GUI is able to construct data and make a few comparisons for an individual apartment or whole building in 24-hour profiles. However, in order to create a baseline conditions, make a setting adjustment, or verify system performance, it is necessary to view a large set of recorded data. To understand the temperature distribution in the whole building or in certain region of a building, it is necessary to have a temperature analyses for more than one apartment and 24-hours. Unfortunately the website software must be programmed with these functions and this requires customization for each job site. Other data comparisons, such as individual indoor and outdoor temperature comparisons, lower and higher level temperature comparisons, east and west side temperature comparisons are also very important to the building control system. Unfortunately, the necessary data is exhaustive as shown in Figure 4. There is no reporting and visualization tool to handle custom queries about variable time frames or building regions on the current website.

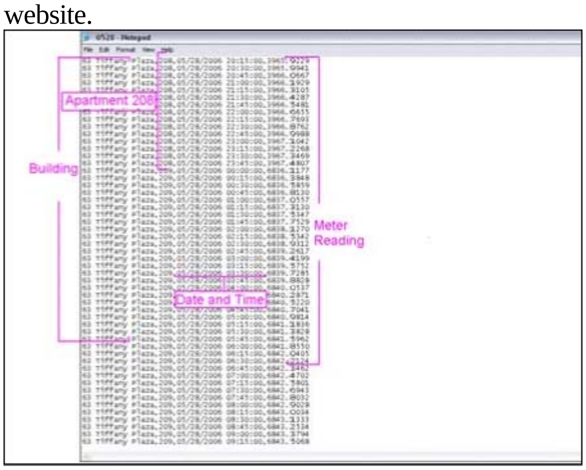


Fig. 4 An Example of Daily CSV Files from Tiffany Mews

Downloading daily CSV files for further analyses might be able to address this situation, but each file only contains a 24-hour period and a month of data for a modest sized building takes about 1 hour to gather. Besides, consider the time to get the needed information from raw data and the time to create proper application to analyze for each building, it is not an efficient procedure.

2.4 Programming Engineer

To address these issues AEA has added a programming engineer to the energy team. The programming engineer confronts issues in two directions. The first direction is how to gather and structure the data. The second direction is to create tools to effectively analyze and visualize the data. The energy team knows what it wants to see from the data but knows little about programming. While the programming engineer is experienced in building applications but does not know what trends or analysis is important. In order to effectively integrate IT into the energy team's view of the building, the programming engineer must understand the structure of the energy management system and its application to the control of the building. What kind of questions would the energy team like to ask? What are the forms in which the data should be presented? How can the data best be visualized?

3. FIRST DIRECTION: GATHER AND STRUCTURE THE DATA

3.1 DTS – Data Transformation Services

For the E-Master EMS projects the remote web server automatically generates each day several CSV files that contain building energy data recorded during the previous day: e.g. temperature and usage for all apartments, outdoor temperature and total building usage from the master meter, alarms and controls statuses. The server places the CSV files on a FTP site

Correspondingly the AEA server downloads the latest CSV files each day from the FTP site This data transfer typically only takes a minute or two for all the data in a 200-unit building. The AEA server automatically transfers the data from CSV files into the E-master SQL database and processes it to remove data gaps, prepare pre-calculations, and set flags. The DTS transfer diagram is shown in Figure 5.

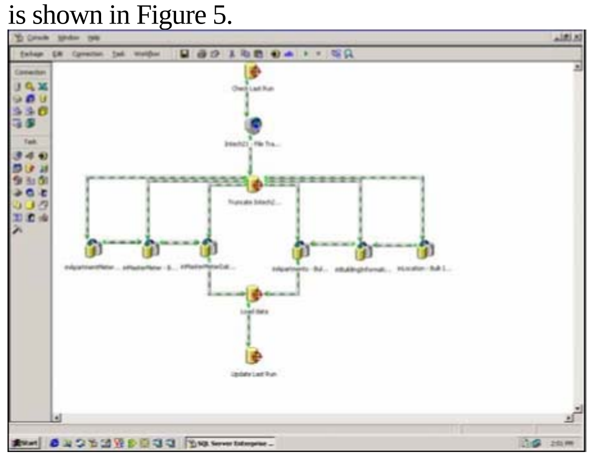


Fig. 5 Data Transformation Services Diagram

3.2 Structure DB

The AEA server gets several files for each building each day. The structure of the database accounts for different sites, buildings within sites, floors, and apartment lines. This pre-preparation of the data ensures that it can be grouped as necessary to look for trends that the energy team may need.

4. SECOND DIRECTION: VISUALIZATION AND REPORTING TOOLS

4.1 Temperature Distributions

There are many variables that can affect temperature distribution within a building. For example, sunlight in the morning on east facade of a building results in higher temperatures due to solar gain in east facing spaces than south and than west facade,. Depending on the building construction material, impact of the solar gain can influence temperature long after sunset. Figure 6 shows a temperature graph where the east façade apartment temperatures and west façade temperatures at Tiffany Mews were compared over time. The solar gain is clearly evident beginning in the morning each day.

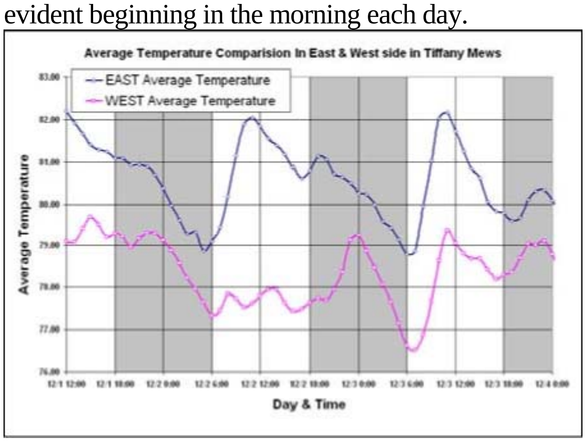


Fig. 6 East and West side average temperature

In the heating season, a heat distribution system has great impact on indoor temperature. Many heat distribution systems are unbalanced and result in the lower levels of the building receiving heat faster than the upper levels. So when upper levels finally receive heat, the lower levels of the building are already overheated.

Other conditions, such as stack effect, have a similar influence on temperature in the building. Stack effect causes hot air to rise inside an apartment building in a poorly compartmentalized building air movement within the building results in hot air from the lower levels migrating upwards and cooling the lower levels which draw infiltration air from outside. This phenomenon causes higher temperatures in the upper floors even when the heat output from the radiators in the upper floors is lower or slower compared to the heat output from the radiators in the lower floors.

A visualization application designed by the AEA energy team using Lab View is shown in Figure 7. The application is able to transfer static data from a CSV file or database into a dynamic 3-D graph with color indicating relative temperature. Reds indicates a high temperature, green indicates a low temperature while blue indicates no data. The rate of change in the temperatures can be speed up or slowed down (or reversed) so that users can easily see temperature differences among apartments on different floors or sides of the building as they develop and persist over time.

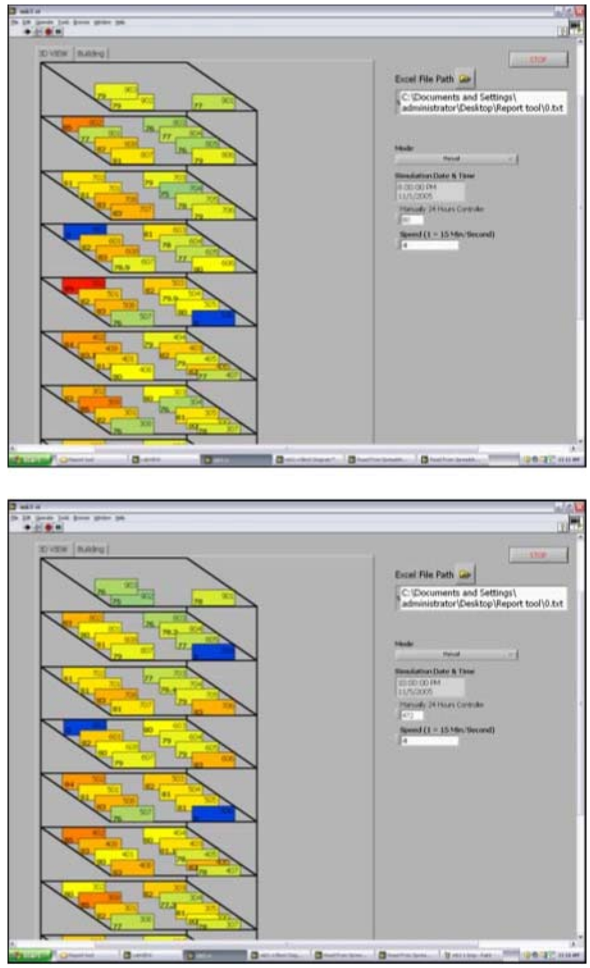


Fig. 7 Lab VIEW Graphical User Interface

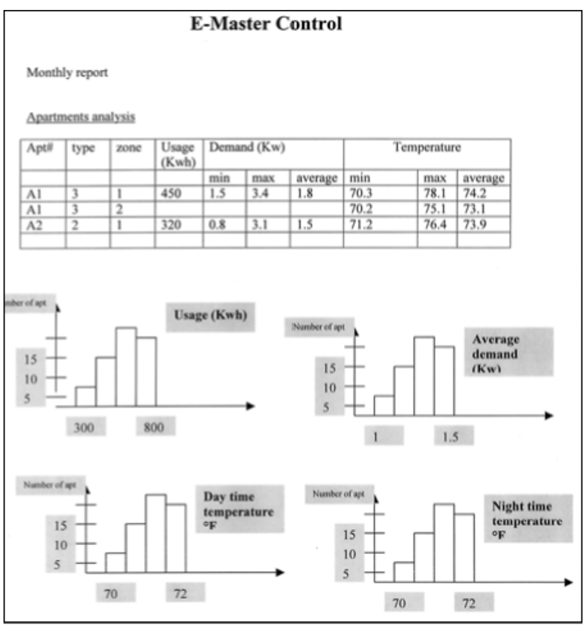
Referring to the custom application note that the east side apartments (left side) has a slightly higher temperature than apartments in west side. This application has multiple uses, for example to investigate unauthorized space heater use in electrically heated buildings where space heaters are not permitted. The blue color indicates "no data" caused by communications errors which is a disadvantage to a completely wireless based EMS

4.2 Boiler Graphical User Interface

In the AEA Bronx Training center, there are two operative boilers that serve as hands-on training aids in steam heating systems. Instructors operate the boilers to teach students how to operate, diagnose, and maintain equipment. Students can also learn how boilers work as well. For a boiler to start cold and heat up to make steam takes at least 30 minutes. The boiler lab instrumentation and visualization system records data during operation and can be played back for students. This allows the students to “watch” the boiler operate in a simulation without having to operate the boiler itself. The boiler GUI is shown in figure 8.

Fig. 8 Lab VIEW Boiler GUI

4.3 E-Master Report tools



Apt#	type	zone	Usage (Kwh)	Demand (Kw)			Temperature		
				min	max	average	min	max	average
A1	3	1	450	1.5	3.4	1.8	70.3	78.1	74.2
A1	3	2					70.2	75.1	73.1
A2	2	1	320	0.8	3.1	1.5	71.2	76.4	73.9

Fig. 8 EMS Reporting Tool Graphics

The E-Master reporting tool generates summary energy reports for an AEA Energy Management System (EMS). The purpose of this tool was to provide a report of the effectiveness of the EMS to building managers as part of AEA monitoring services. The building manager is too busy to inspect large tables or graphs of data and only needs to know the bottom line performance. The Energy team developed a GUI to create queries and reports by integrating the AEA database and a report generation tool knows as Crystal Reports. The application can be installed on any desktop that is on the AEA LAN and AEA created a CDRom for multiple installations. Figure 8 shows some concepts and examples from this tool. The user can choose between two sets of reports: one set at the building level (master meter), and one at the apartment level (apartment temperature, usage). Each set of reports has its own list of report options so that the use can examine any combination of building, floor, apartment line, or site. Printable reports appear on screen in the forms of charts, lists and tables with titles and axes automatically scaled for the query set. Accessing the data and generating the report could take between a few seconds and several minutes based on the period of time and the number of the apartments included

4.3 Time Sensitive Electric Pricing on an hourly Real-Time Rate

AEA database development and methods can also contribute to another project, time sensitive electric rates and electrical demand response. TSDR is a new project that enables residents to take advantage of the natural of Day-Ahead-Market hourly rate to save money in electricity. In the dayahead-market, the higher electricity hourly rates usually occur between 1 PM and 5 PM due to business and industry activity. This is the period that residential buildings usually have the lowest usages.

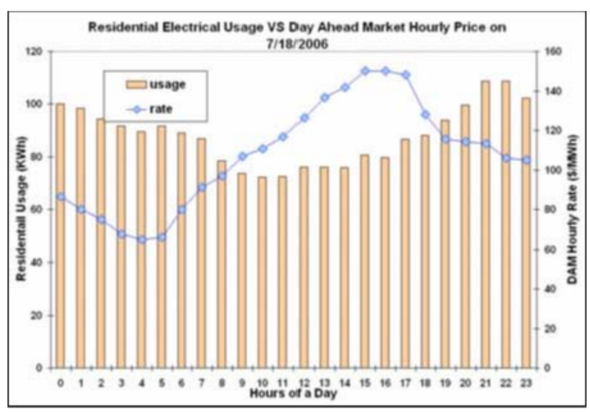


Fig. 9 Residential Electrical Usage versus Day Ahead Market Rate

Figure 9 shows the demand peak in a residential building that occurs at around 7 and 8 PM while the rate is still at a high level. If residents can reduce their energy using during the higher period and shift consumption to lower rate periods, they will be able to save extra money.

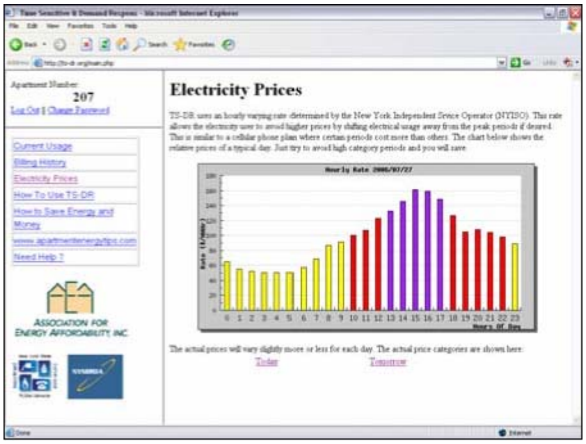


Fig. 10 TS-DR Website

TS-DR utilizes the AEA database to gather building information, such as apartments' energy usages and building energy usage. Using this data, the TS-DR website publishes information for subscribing residents about their current usage and historical billing into tables. Residents have access to their current usage since the last bill and estimated total of their next bill. They also can find the comparison between using flat rate and time sensitive rate. TS-DR provides several web services to the building and residents. The Day-Ahead-Market hourly rates are downloaded to TSDR website's database automatically when a resident logs on their account. With the functionality created in the PHP and MySQL, the website can query the downloaded data and present data in the form of graphs and tables. In this regard, residents are able to clearly capture the current day and following day hourly price, as well as plan how to shift usage and save money.

Security issues are a concern and currently the TSDR website database is not linked to the AEA database. The TS-DR website database updates are scheduled to become automatic with the next revision of the program. AEA is planning more web services such as an automatic billing system and temperature forecast report to enhance the ability to predict costs for residents.

5. CONCLUSION

A new approach at AEA adds a programming engineer to the normal energy analysis team who manages data and programs visualization tools to speed analysis. Using the data available from the E-Master EMS, one can see that enhanced visualization and analysis tools aid the energy team to find answers that previously took many hours of careful data review.

An effective programming engineer will handle the retrieval and structuring of data and databases as well as the effective design of applications and tools to enhance the value of an energy team

REFERENCES

[1] Gregory Cmar. 2006. Reinventing facilities operations (and Culture) through advanced use of data.

[2] Michael Bobker, Da-Wei Huang and Daniel Harris.2006. The parable of the frogs: Introducing new temperature regimes in multifamily housing

[3] Oliver Baumann. 2005. Enhanced building operation using 'operation diagnostics' – a case study. ICEBO – international conference for enhanced building operations, October 11-13, 2005 Pittsburgh, PA, USA