ARCHITECTURE SCIENCE, No. 2, pp.35~47, December 2010

Livindex : Situational Energy Awareness for Sustainable Living

Pochun Chen[1*] **Tay-sheng Jeng**[2]

[1] Graduate Student, Institute of Creative Industry Design, National Cheng Kung University, Taiwan

[2] Associate Professor, Department of Architecture, National Cheng Kung University, Taiwan

[*]Corresponding author Email: bootwooo@gmail.com; Tel: +886-6-2757575 ext.54158

(**Received** Oct. 27, 2010; **Accepted** Dec. 23, 2010)

ABSTRACT

Energy is becoming the major issue for creating a sustainable living environment. The lack of awareness of energy consumption becomes the barrier for users who are willing to behave in sustainable way. A number of technologies have been developed to digitalize the energy consumption for both power demand and supply, such as smart meters and smart grids, which are becoming the government policy in numerous countries. However, the existing electric utilities in old buildings are hard to change or upgrade to smart meters. Furthermore, it remains a big barrier for users to measure energy at any time anywhere in individual appliance level.

In this paper, we propose an in-home energy visualization framework, which is featured with three aspects: 1) a non-intrusive way to digitalize the electronic energy use, 2) wire-free energy monitoring to the appliance-level, and 3) an open framework for seamless integration with future service. The major contributions in this paper includes : 1) The energy visualization framework - Livindex suggested an in-home energy awareness system seamlessly integrated with individual appliances and energy awareness tools, 2) The energy data collection method, which the system components currently process, record and output energy data, will become a major breakthrough by which energy information in old buildings can be easily visualized, and 3) Visualization of digitalized energy data has encouraged user awareness of energy consumption. The proposed system has been implemented and tested in a workspace for long-term monitoring energy consumption. The system design and implementation are described and discussed in this paper.

KEYWORDS**:** Energy Awareness, Sustainable Living, Energy Visualization

1 Introduction

In the context of sustainability, reducing energy and enhancing energy efficiency are becoming the fundamental requirement to promote sustainable living. According to the report, buildings are accounted for 48% of all greenhouse emissions around the world (Katz, 2003). In US, the residential sector accounts for 21% of energy usage (US Department of Energy, 2006). In Taiwan, the residential sector accounts for approximately 20% in 2009, and the number is still increasing (Taiwan Bureau of Energy, 2009). The user's energy awareness directly influence the energy usage in buildings and homes. The energy in our living environment is abstract, invisible and untouchable (Fischer, 2008). The lack of energy information becomes the barrier for users who are willing to save the energy. The technologies of smart meters and smart grids are developed to attempt to replace the traditional meters and enhance the energy efficiency in innovative smart grid services. Most of all, some innovative internet services based on smart meter solutions enable users to measure the energy usage in real-time. To date, over ten countries announced their blueprint to deploy and upgrade the current energy systems, including US, EU, Japan, China, Taiwan and etc.

A common approach to energy reduction solutions is to build zero-emission green buildings which integrate with smart meters as the energy infrastructure. However, in some cities, many houses and buildings are quite old and are hardly replaced by new buildings or cannot be installed with new smart meters. Even if it is possible to install smart meters in old buildings, monitoring the power consumption of individual appliances for making energy use decisions is still a challenging problem. Our attempt to tackle these issues is to make the energy consumption of individual appliances available, through which users or occupants can make better decisions on saving energy without losing living quality.

This paper aims to develop an appliance level energy awareness system with an in-home energy visualization framework. Awareness, monitoring, recording and flexibility of integration are the criteria of the energy awareness system. Information about energy use is provided in real-time, directly to the users with a web-based visualization tool. In the following section, we demonstrate the design development, implementation and discussion. The system has been implemented and tested in a workspace for long term monitoring energy consumption.

2 A System Development Framework

In this chapter, we describe our in-home energy visualization framework, which we call it as Livindex. Livindex aims to avoid complex installation and provide high flexibility for seamless integration, with in-home sensors. Furthermore, our system provides the appliance level energy monitoring in real-time.

Livindex is comprising of three major componants (Fig. 1): 1) Sensor Input: the distributed smart outlets gather information on in-home energy usage, 2) Data Process: the server system receives, records and outputs the energy data from smart outlets, and 3) Application Output: the web-based XML format data that generates output for energy visualization tools. The Input and Output are on the user side which directly interact with users. The energy visualization framework is depicted in Fig 1.

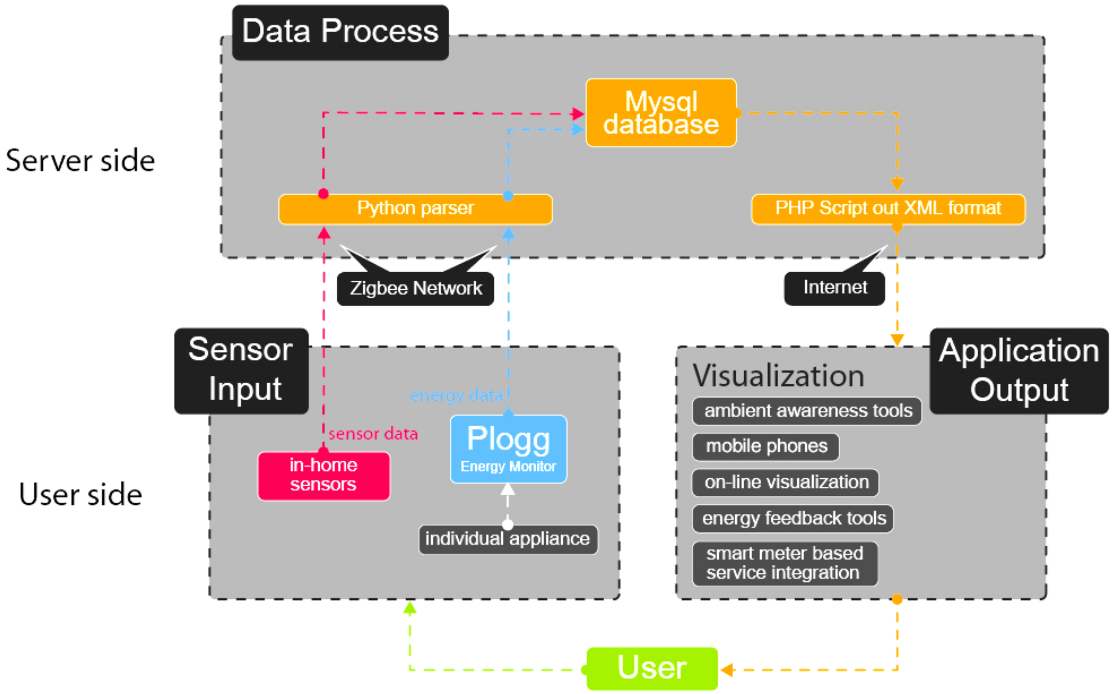


Fig. 1 Livindex system framework

(1) Sensor Input: The smart outlet we used for energy monitoring on individual appliance is Plogg Energy Monitor. The installation can be done by simply plugging the Plogg Energy Monitor on the appliance. Then, energy information will be transmitted through wireless network. The Plogg Energy Monitor has two major features which we considered it as our energy monitor in our framework, wireless network in Zigbee protocol and energy data output as CSV format (Shafranovich, 2005). Zigbee is a short range wireless mesh networking standard communication protocol for small area, such as home and office. It features with low cost, low power usage and high reliability. The low power usage can minimize the extra energy usage on monitored appliances. Also, the high reliability is suitable for long term and accurate monitoring. The CSV format is the most common format for logging information. The simplicity makes it easy to transform and

analyze. However, the data format is not common on smart outlet. We take these two advantages to better connect with the Data Process component.

(2) Data Process: The Data Process component is the core of Livindex framework; it consists of data parser, data record and data output. The process begins with data parser that was written in Python script. The system will immediately parse the CSV format data which Zigbee receiver received from Plogg Energy Monitor. The Python (Python Software Foundation) script is a light-weight and powerful language, suitable for batch working. The various kinds of library also made the Python a high flexible language for fulfilling the different usage. In our framework, we use the CSV parser library as the parse tool and URL library as the tool to post data into our database. Together with data record, we use Apache webserver (Apache Software Foundation), PHP script and MYSQL database (Williams and Lane, 2004) as the recording platform. The PHP script will process the SQL script to record the data while Python script post the information. The overall energy information is recorded and stored in the database and indexed with timeframe. The final part is data output, which is written in XML format. The XML format is a set of rules for encoding data, the tidy structure of data can make it widely used in Internet. In addition, the high compatibility between various platforms makes it become the most common protocol for communication. We use it as our output format which can be flexible used in advanced output applications.

(3) Application Output: As the system framework design, the energy data are dynamically generated in XML format and output to specific applications. With the Internet connection, the energy awareness can be implemented on multiple applications. The barrier that lack of energy data to behave in sustainable way can be reduced and users can make decision of using energy in a more strategic way with detailed energy information. In addition, the gap between smart-meter based services can be reduced.

3 The Implementation

We implemented the Livindex framework in our workspace and tested the system for over five months. The workspace is located in an old building without advanced energy control system. It was also hard to install smart meters without huge spatial modification. We deployed the Livindex framework instead; the high flexibility and none-intrusive installation made us achieve the goal of energy monitoring. The following steps are the process of implementation.

(1) Sensor Input: We chose five work areas as our monitor target. We deployed five Plogg Energy Monitors in our workspace and monitored five appliances that belong to each work area (Fig. 2). The five seats are spread out in our workspaces. It is relatively simple and convenient to connect the

energy sensors through wireless network. The Zigbee network between Plogg Energy Monitors was immediately established while the Plogg Energy Monitor was deployed to each appliance. On the Livindex Server, we enabled the Zigbee receiver to join the Zigbee network and began to receive the energy data in CSV format as shown in Fig.3. The CSV format energy data we received is consisted of thirteen different fields, including timestamp, Watts, kWh consumed and etc. The detailed information has been precisely logged.

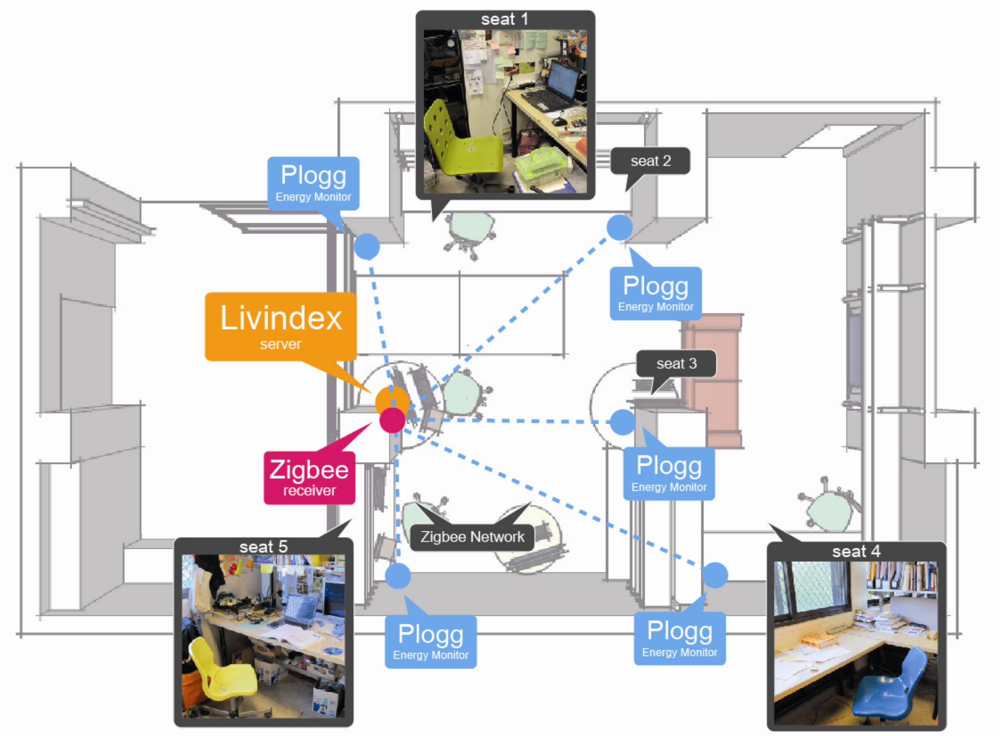


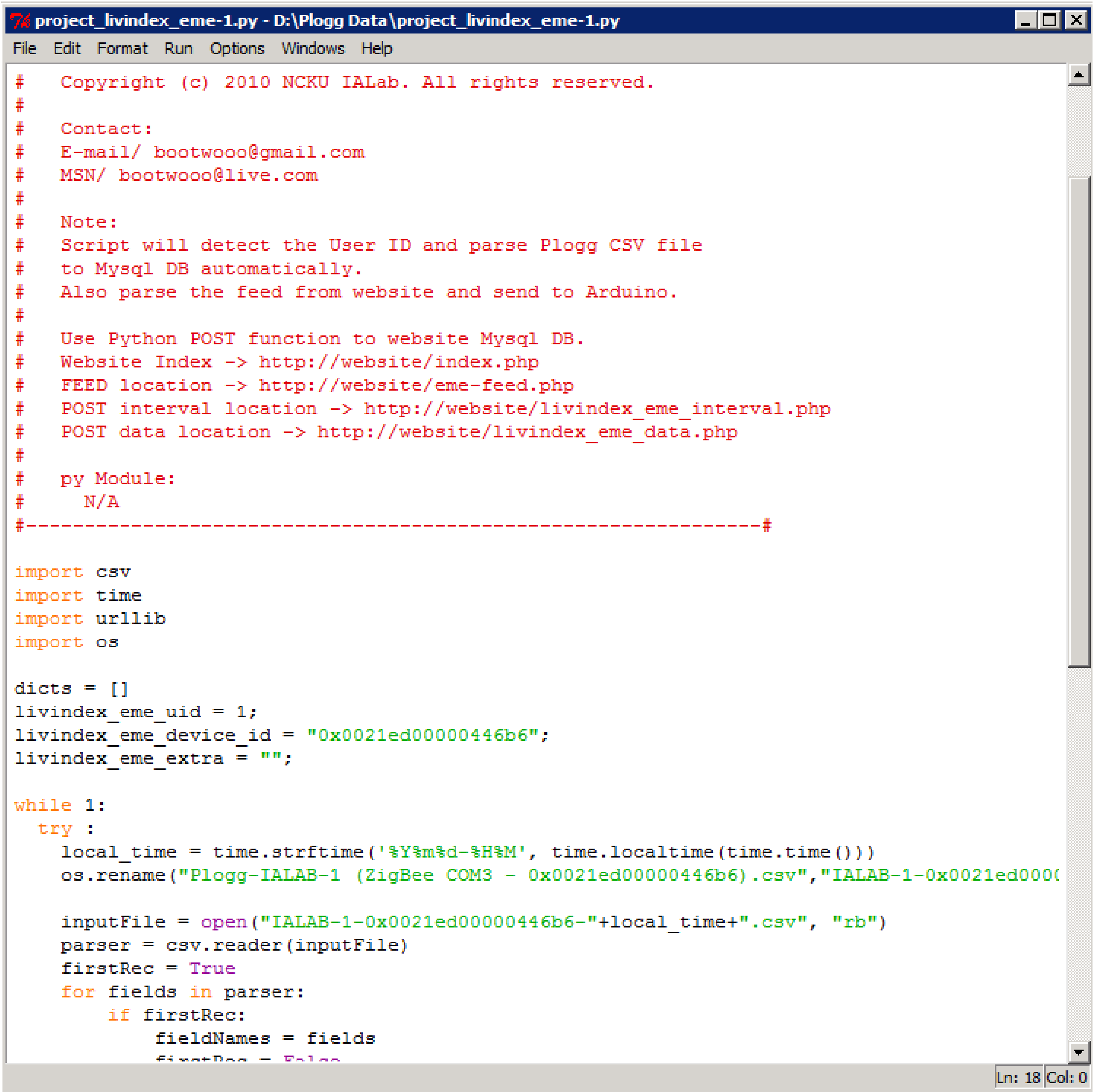
Fig. 2 Spatial mapping of Livindex implementation

A1 | Device Time

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Device Time	Watts	kWh Gene	kWh Consu	Frequency	RMS Volta	RMS Curre	Plogg Upti	Reactive Po	VARh Gen	VARh Con	Phase Angl	Equip On Time	
2	1/14/2010 18:04	36.32	0	0.0453	59.9	108.2	0.34	0 days 00:1	-5.62	0.0053	0	354	0 days 00:15.52	
3	1/14/2010 18:09	51.51	0	0.0484	59.9	108.2	0.479	0 days 00:2	-5.62	0.0058	0	355	0 days 00:20.52	
4	1/14/2010 18:14	1.24	0	0.0491	60	108.7	0.019	0 days 00:2	-1.76	0.006	0	305	0 days 00:25.52	
5	1/14/2010 18:19	1.24	0	0.0492	59.9	108.5	0.019	0 days 00:3	-1.76	0.0061	0	304	0 days 00:30.52	
6	1/14/2010 18:24	1.24	0	0.0493	60	108.5	0.02	0 days 00:3	-1.87	0.0063	0	304	0 days 00:35.52	
7	1/14/2010 18:29	1.24	0	0.0495	60	108.4	0.02	0 days 00:4	-1.87	0.0064	0	305	0 days 00:40.52	
8	1/14/2010 18:34	1.24	0	0.0496	59.9	108.6	0.02	0 days 00:4	-1.87	0.0066	0	305	0 days 00:45.52	
9	1/14/2010 18:39	1.24	0	0.0497	60	108.8	0.02	0 days 00:5	-1.87	0.0068	0	304	0 days 00:50.52	
10	1/14/2010 18:44	1.24	0	0.0498	60	108.9	0.02	0 days 00:5	-1.87	0.0069	0	304	0 days 00:55.52	
11	1/14/2010 18:49	1.35	0	0.0499	60	108.7	0.02	0 days 01:0	-1.76	0.0071	0	308	0 days 01:00.52	
12	1/14/2010 19:09	1.24	0	0.0503	60	109.4	0.02	0 days 01:2	-1.87	0.0077	0	304	0 days 01:20.52	
13	1/14/2010 19:14	1.24	0	0.0504	59.9	109.4	0.02	0 days 01:2	-1.87	0.0079	0	305	0 days 01:25.52	
14	1/14/2010 19:19	1.24	0	0.0505	60.2	109.4	0.02	0 days 01:3	-1.87	0.008	0	305	0 days 01:30.52	
15	1/14/2010 19:24	1.24	0	0.0507	59.9	109.3	0.02	0 days 01:3	-1.87	0.0082	0	305	0 days 01:35.52	
16	1/14/2010 19:29	1.24	0	0.0508	60	109.3	0.02	0 days 01:4	-1.87	0.0083	0	305	0 days 01:40.52	
17	1/14/2010 19:34	1.24	0	0.0509	60.1	109.4	0.02	0 days 01:4	-1.87	0.0085	0	304	0 days 01:45.52	

Fig. 3 Screenshot of energy data in CSV format

(2) Data Process: We use Python parser as the automation tool to decompose the fields into single variable line by line (Fig. 4). While the decomposed process is finished, the variables are automatically upload into our database. We created a database structured with the existing field in CSV format energy data (Fig. 5). Thus, the variables that are uploaded by Python will be line by line stored in the database (Fig. 6). The overall data are indexed with unique identify number and timeframe, which can easily trace back the energy usage with argument.




```
#   Copyright (c) 2010 NCKU IALab. All rights reserved.
#
#   Contact:
#   E-mail/ bootwooo@gmail.com
#   MSN/ bootwooo@live.com
#
#   Note:
#   Script will detect the User ID and parse Plogg CSV file
#   to Mysql DB automatically.
#   Also parse the feed from website and send to Arduino.
#
#   Use Python POST function to website Mysql DB.
#   Website Index -> http://website/index.php
#   FEED location -> http://website/eme-feed.php
#   POST interval location -> http://website/livindex_eme_interval.php
#   POST data location -> http://website/livindex_eme_data.php
#
#   py Module:
#     N/A
#----------------------------------------------------------------#

import csv
import time
import urllib
import os

dicts = []
livindex_eme_uid = 1;
livindex_eme_device_id = "0x0021ed00000446b6";
livindex_eme_extra = "";

while 1:
  try :
    local_time = time.strftime('%Y%m%d-%H%M', time.localtime(time.time()))
    os.rename("Plogg-IALAB-1 (ZigBee COM3 - 0x0021ed00000446b6).csv","IALAB-1-0x0021ed000

    inputFile = open("IALAB-1-0x0021ed00000446b6-"+local_time+".csv", "rb")
    parser = csv.reader(inputFile)
    firstRec = True
    for fields in parser:
        if firstRec:
            fieldNames = fields
```

Fig. 4 Screenshot of Python parser

Server: localhost ▸ Database: livindex-db ▸ Table: livindex_eme_db_data

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Drop

Field	Type	Collation	Attributes	Null	Default	Extra
id	int(20)			No		auto_incremen
uid	varchar(20)	utf8_unicode_ci		No		
eme_device_id	varchar(40)	utf8_unicode_ci		No		
eme_device_time	varchar(30)	utf8_unicode_ci		No		
eme_watts	double			No		
eme_kwh_generated	double			No		
eme_kwh_consumed	double			No		
eme_frequency	double			No		
eme_rms_voltage	double			No		
eme_rms_current	double			No		
eme_plogg_uptime	varchar(30)	utf8_unicode_ci		No		
eme_reactive_power	double			No		
eme_varh_generated	double			No		
eme_varh_consumed	double			No		
eme_phase_angle	double			No		
eme_equip_on_time	varchar(30)	utf8_unicode_ci		No		
eme_extra	varchar(50)	utf8_unicode_ci		No		

Fig. 5 Screenshot of Livindex MYSQL database field

id	uid	eme_device_id	eme_device_time	eme_watts	eme_kwh_generated	eme_kwh_consumed
1	1	0x0021ed00000446b6	10:58:48 25 MAR 2010	1.35	0	9.5269
2	1	0x0021ed00000446b6	11:03:48 25 MAR 2010	1.45	0	9.527
3	1	0x0021ed00000446b6	11:08:47 25 MAR 2010	1.35	0	9.5272
4	1	0x0021ed00000446b6	11:13:48 25 MAR 2010	1.45	0	9.5273
5	1	0x0021ed00000446b6	11:18:48 25 MAR 2010	1.45	0	9.5274
6	1	0x0021ed00000446b6	11:23:48 25 MAR 2010	1.45	0	9.5275
7	1	0x0021ed00000446b6	11:28:48 25 MAR 2010	1.35	0	9.5277
8	1	0x0021ed00000446b6	11:33:48 25 MAR 2010	1.45	0	9.5278
9	1	0x0021ed00000446b6	11:38:48 25 MAR 2010	1.45	0	9.5279
10	1	0x0021ed00000446b6	11:43:48 25 MAR 2010	1.45	0	9.528
11	1	0x0021ed00000446b6	11:48:48 25 MAR 2010	1.35	0	9.5281
12	1	0x0021ed00000446b6	11:53:48 25 MAR 2010	1.35	0	9.5283

Fig. 6 Screenshot of Livindex MYSQL database

(3) Application Output: The energy data output from Livindex server are in XML format, and dynamically generated by PHP script. With specific argument input, the demand information would

display in range (Fig. 7). The feed can be adapted to various platforms and create the energy related applications. To make energy data visible to users, we integrate the feed with visualization tool (Fig. 8). The X axis is the time dimension. The Y axis is energy consumption using Watts as units. By layering the weekly energy usage, we can clearly recognize the relation between user activities and energy usage. Applications and issues are discussed in the next section.

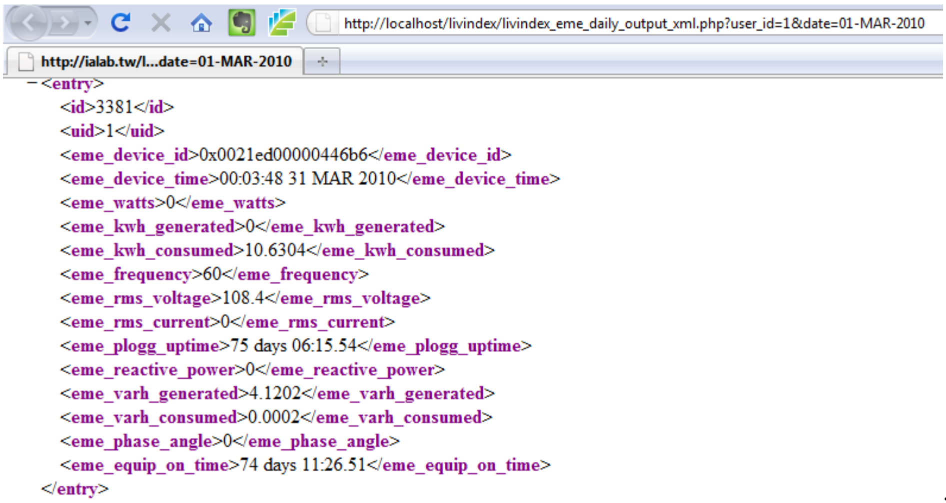


Fig. 7 Livindex energy data output in XML format

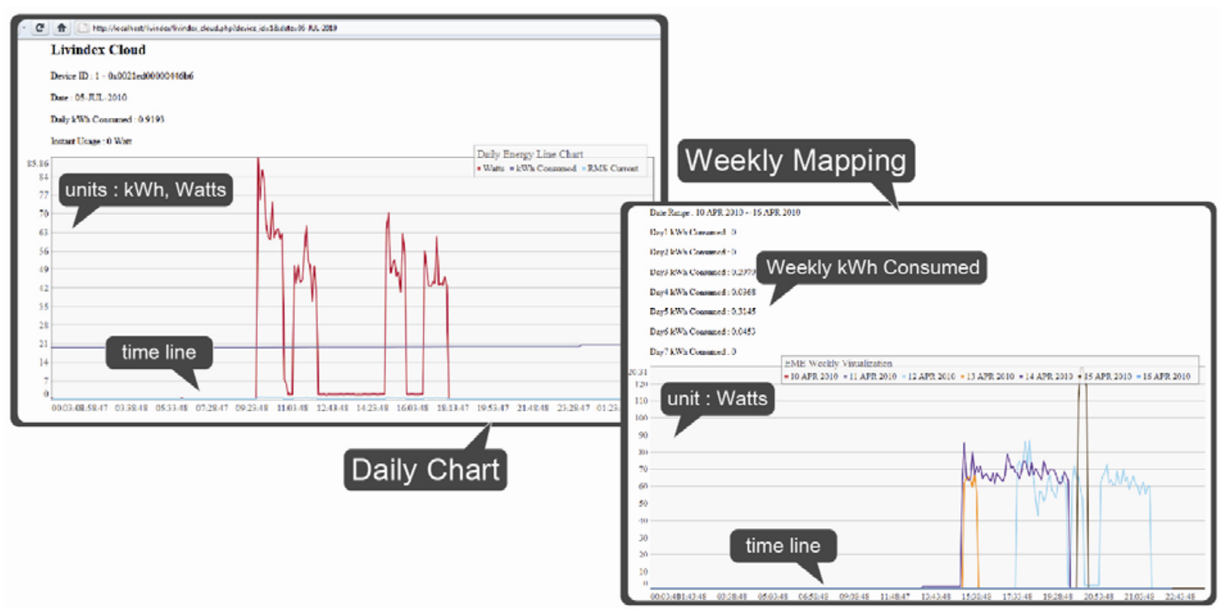


Fig. 8 Livindex XML output integrate with visualization tool

4 Discussion

The implementation result inspired us in multiple ways of achieving sustainable living. Different from smart meter based services, the Livindex framework can make the energy monitoring in an intuitive way. The framework successfully gathered over 150,000 energy consumption data in five months. The flexibility extends our observation between human behavior and energy usage. We explored several applications and issues based on the data we gathered.

(1) Events mapping: By observing the energy consumption in the first month, we found the energy usage was highly related to users' events. Most users were highly relying on the standby functionality that could automatically turn off the electric devices while they were leaving. However, it took time for the standby functionality to determine whether the user was present or not. The most unnecessary energy usage was wasted during this moment. We initiated two different approaches as our future work. One is to add additional sensor to detect user's presence (Fig. 9), and provide active feedback tools to users. Another approach is to integrate with web-based calendar services, such as Google calendar, which will not only display the daily energy usage layered with events, but will also provide awareness of both the coming event and energy saving with reminder coupled with the Google Calendar.

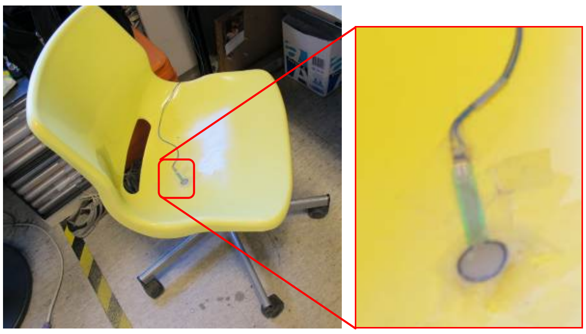


Fig. 9 The sensor used to detect the user's presence

Ambient Device Awareness: Another approach is based on a tangible plug connected with Zigbee energy network. The ambient design can enable the energy awareness without interrupting user. The idea can also be found on numerous energy feedback tools, such as Wattson ambient display, Onzo, Power Cost Monitor and etc, providing low band-width information (Froehlich, 2009). However, without a framework as the backend service, the awareness functionality is limited. We initiated experiment of the interface on the ambient devices, including color change, level bar and numbers (Fig. 10). The interface changed dynamically with the energy usage.

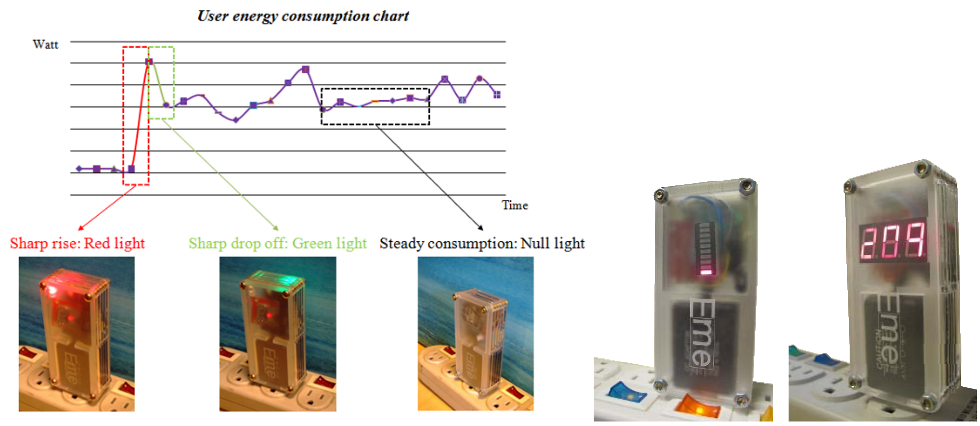


Fig. 10 Ambient Awareness Devices : The devices which awaring the energy usage with different LED lights color, level bar and numbers.

(2) Mobile Approach: The mobile phones are becoming a power handheld device. As the daily outfit by users, various research work also considered it as the mobile energy awareness tool, such as BeAware and Emeter (Jacucci *et al*., 2009). They enabled the remote control and visualization interface design on mobile phones. We considered the multiple mapping between locations, events, appliances and energy usage could raise user's awareness in daily life. We initiated a concept prototype which used augmented reality techniques to superimpose energy information on a real-world appliance (Fig. 11). Through the augmented reality display on a mobile phone, we turn the energy into a playful tangible cube and appropriate the mobile phone we already carry with us every day as an augmentation device and Tangible User Interface. The conceptual prototype is called Energy Cube – the virtual objects visualized with the energy usage level are augmented on the devices that energy consumption is monitored by our system. By holding the mobile phones, users can intuitively manipulate the Energy Cube with hands to adjust the energy usage level. The integration of tangible interaction and visual feedback is undertaken to let users perceive the realistic sensation with energy change in physical world.

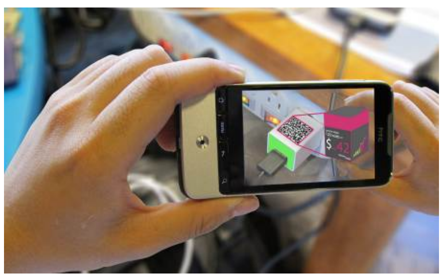


Fig. 11 Augmented-Reality energy awareness on mobile phones

5 Conclusion

In the context of sustainability, encouraging sustainable behavior is becoming the ultimate goal in energy awareness design. In this paper we have presented a novel technological framework for visualization of energy consumption awareness. The major contributions in this paper include:

(1) The energy visualization framework - Livindex suggested an in-home energy awareness system seamlessly integrated with individual appliances and energy awareness tools;

(2) The energy data collection method, which the system components currently process, record and output energy data, will become a major breakthrough by which energy information in old buildings can be easily visualized;

(3) Visualization of digitalized energy data has encouraged user awareness of energy consumption.

Based on the smart outlet that deployed in space, Livindex transformed energy data into consumption information which is web-based, real-time, and individual appliance leveled. It provided us insights on the design and requirements of the future in-home energy awareness tools. Livindex seeks to continue scaling energy awareness from the entire home service to an individual appliance by adding networked ambient devices throughout the visualization interface. We have implemented Livindex framework and tested for a long term energy monitoring. Our future work will focus on implementing user interface visualization techniques and collecting user feedback from usability evaluation.

Acknowledgements

This work is supported by the Taiwan National Science Council, grant No. NSC 99-2218-E-006 -001.

REFERENCES

Apache Software Foundation, http://www.apache.org.

Fischer, C. (2008) Feedback on household electricity consumption: a tool for saving energy?, *Energy Efficiency*, 1:79-104.

Froehlich, J. (2009) Promoting Energy Efficient Behavior in the Home through Feedback: The Role of Human-Computer Interaction, *HCIC '09 Workshop*.

Jacucci, G. , Spagnolli, A. , Gamberini, L. , Chalambalakis, A. , Björksog, C. , Bertoncini, M. , Torstensson, C. and Monti, P (2009) Designing Effective feedback of Electricity Consumption for Mobile User Interfaces, *PsychNology Journal*, 7(3), 265-289.

Katz, G. (2003) The Cost and Financial benefits of Green Building: A Report to California's Sustainable Building Task Force, http://www.usgbc.org/Docs/Resources/CA_report_GBbenefits.pdf.

Python Software Foundation, http://www.python.org.

Shafranovich, Y. (2005) Common Format and MIME Type for Comma-Separated Values (CSV) File, http://tools.ietf.org/pdf/rfc4180.pdf

Taiwan Bureau of Energy (2009) Electricity Consumption Statistic http://www.moeaboe.gov.tw/Download/opengovinfo/Plan/all/energy_year/main/files/03/table-2-34.xls

US Department of Energy (2006) Residential New Construction: An Overview of Energy Use and Energy Efficiency Opportunities, http://www.energystar.gov/ia/business/challenge/learn_more/ResidentialNewConstruction.pdf.

Williams, H.E. and Lane, D. (2004) Web Database Applications with PHP & MySQL, O'Reilly & Associates, Inc.

居家生活資料庫：永續生活的環境能源感知

陳柏均 [1*]　　鄭泰昇 [2]

[1] 台灣成功大學創意產業設計研究所碩士

[2] 台灣成功大學建築學系助理教授

[*]通訊作者 Email: bootwooo@gmail.com; 電話: +886-6-2757575 ext.54158

(2010 年 10 月 27 日投稿，2010 年 12 月 23 日通過)

摘 要

能源已經成爲創造永續生活環境的主要議題。缺少能源消耗的感知已經成爲使用者永續生活的阻礙。現今有諸多將能源消耗數位化的技術，如智慧電錶跟智慧電網，已成爲許多國家的能源政策。然而，在現今舊建築中的電力設備不易修改或升級爲數位電錶。再者，要隨時隨地測量單一設備的能源使用，對使用者來說是一大阻礙。

本研究欲提出居家能源視覺化的框架，具備以下三項特色：1) 使用非侵入的方式將能源數位化，2)無線監控單一裝置的能源消耗，3) 一個開放式的框架，無縫的整合未來服務。本研究的主要貢獻包含：1) 一個能源視覺化的框架 – 居家生活資料庫，提供居家的能源感知系統，與單一電器及感知工具無接縫的整合，2) 能源資料收集的方法，包含目前系統元件運行、記錄與輸出能源資料將會是在舊有建築中視覺化能源資訊的重要突破，3) 視覺化的能源資訊將提高使用者對能源消耗的感知。本研究所提出的系統已經在生活場域中實作且　經過長時間的測試。本報告將描述並討論此系統的設計與執行。

關鍵詞：能源感知，永續生活，能源視覺化