Accurate Real-Time Occupant Energy-Footprinting in Commercial Buildings

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Introduction

An accurate accounting of individual occupants' energy expenditure in real-time is still a missing piece in the building energy system area. In this paper:

- We first present a model that enables real-time accounting of appliances with delay characteristics.
- We introduce a complete system that fairly attributes energy usages of shared resources, and reveals per-person energy footprint information.
- Our system has several ways to analyze and visualize individuals' energy footprint.
- We present the deployment experience at an office building.

Background

Devices consume energy in different ways, we define the two terms as follows:

- **State-less** – Total energy consumed is simply the sum of energy consumed from users' active usage
- **Memory-less** – Energy consumed directly and fully reflects the current usage in time

Figure 1 shows the energy trace of a typical fridge in a public kitchenette. We have some challenges that our work takes the first step in solving.

- The fridge has the energy consumption delay feature
- We need user feedback in real time

To address this problem, we propose an appliance model that considers the following two parameters:

- **Base** power – The operational power that an appliance must consume to be able to function, regardless of usage
- **Per-use** power – The additional power consumed for a single use, which reflects the power consumption due to a particular user

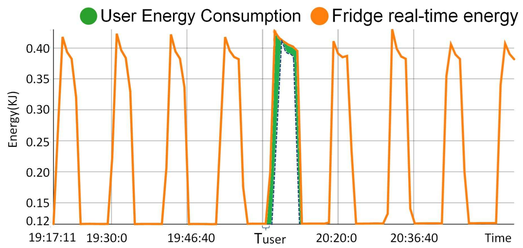

Figure 1. Fridge exhibits the memory property

Appliance Base Model - I

Suppose the current time is T_c and a time window T_w before T_c, we have the following equation.

$$E = P * T + B \tag{1}$$

E is the device's real energy usage during the time window (but may be measured with a delay ΔT from the current T_w), P is the per-use power, T is the total device usage time during the time window, and B is the base energy. With simple regression analysis, we can compute the parameters P and B. The System updates P and B with the time going on.

Appliance Base Model - II

After updating the parameters, we can use the following equation to allocate the energy of device k to user i.

$$E_{i,k} = P * T_{i,k} + \frac{B}{N}\frac{T'_w}{T_w} \tag{2}$$

For each user, we can compute the real-time energy consumption (or energy footprint) by summing all individual usages over all devices M, as below.

$$E_i = \sum_{k=1}^{M} E_{i,k} \tag{3}$$

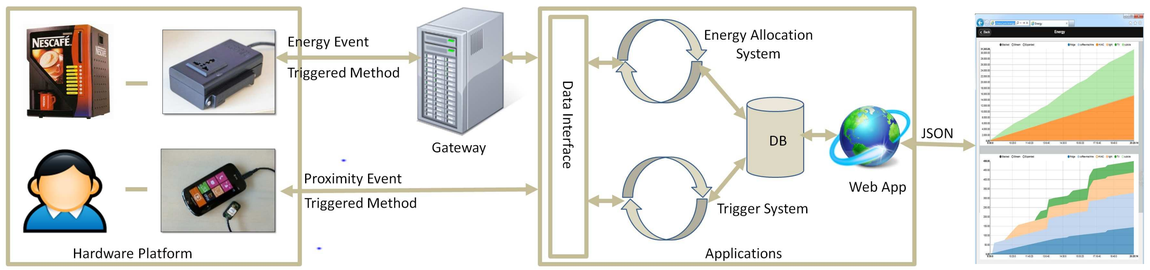

Figure 2. System architecture

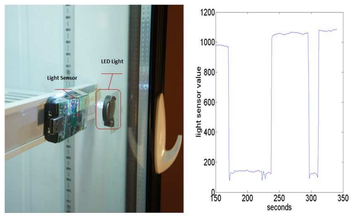

Figure 3. Resource Accounting Example

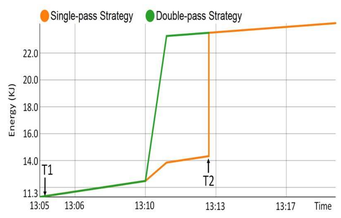

Figure 5. Accuracy difference of two strategies

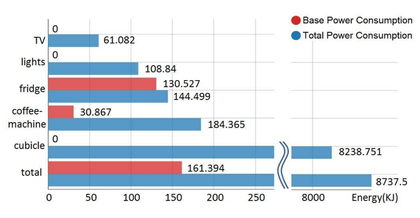

Figure 7. User-view energy consumption

Figure 4. Localization Module

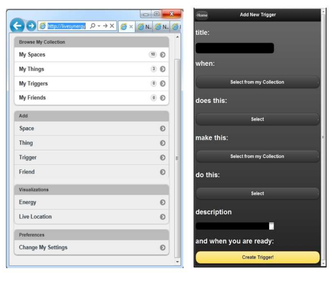

Figure 6. Web portal

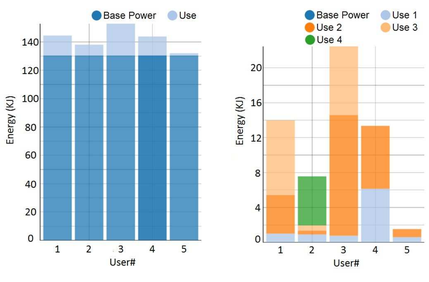

Figure 8. Device-view energy consumption

Architecture and Implementation

Figure 2 depicts the system architecture, and it highlights four components: *resource accounting*, *localization inference*, *data analysis*, and *event triggering*.

Data Analysis and Visualization

Figure 5 depicts the accuracy difference with energy traces from the fridge. Figure 6 is the web portal. Figure 7 and 8 are User-View and Device-View.

Sensitivity Analysis

We evaluate the effectiveness of the model with the fridge's data sets.

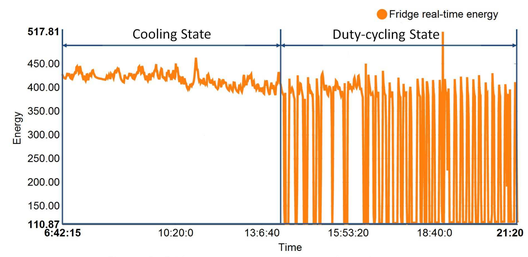

Figure 9. Fridge energy consumption and running state

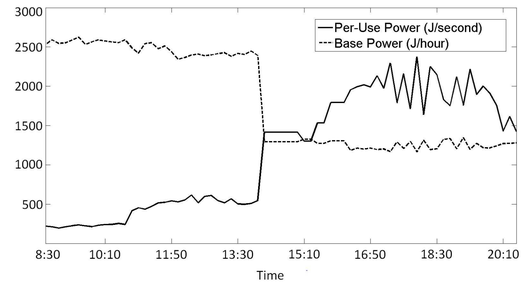

Figure 10. P and B changes during one day of the fridge

Triggers

Some interesting triggers:

1. If the fridge door has been opened for a long time, then the user receives a SMS alert.
2. If users leave the cubicle without turning off the monitor, then they receive a SMS alert.
3. If users leave the cubicle, then the certain devices are turned off automatically.
4. If users have been consuming more energy than the predefined threshold, then they receive a SMS alert.
5. The system generates energy usage report according to predefined time settings.

The following table is the impact of recurring and real-time reminders crated by triggers on reducing energy waste.

	Avg pwr consumption (KJ)		
	Without triggers	**With triggers**	**Energy savings (%)**
Fridge	685.2	405.5	40.8
Computers	1019.7	372.9	63.4

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