

Its Different: Insight into home energy consumption in India

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Abstract

Across the world, residential buildings contribute significantly to overall energy usage. Residential deployments provide insights into home energy consumption and occupant behavior. Most of the prior work in residential deployments is from developed countries. We present unique aspects of residential deployments in India, based on our experience of extensively instrumenting a home in Delhi, measuring electrical, water and ambient parameters. Most notably, electrical grid and internet are unreliable in India. Owing to these constraints, we present Sense-Local Store-Upload, which is a sensing architecture suited to the context of deployments in developing countries. We also validate the learnings from previous literature involving similar residential deployments.

Categories and Subject Descriptors

H.4 [Information Systems Applications]: Miscellaneous; D.2.8 [Software Engineering]: Metrics—complexity measures, performance measures

General Terms

Delphi theory

Keywords

ACM proceedings, L^AT_EX, text tagging

1 Introduction

Buildings (both residential and commercial) account for 30% of all energy consumption globally [10]. The contribution of buildings to overall energy usage for different countries is as follows- Australia: 20%, China: 34%, India: 47%, Japan: 33% and USA: 29%. In many of these countries residential buildings contribute significantly to overall building energy usage (China: 90%, India: 93%, Australia: 67%) [23, 14, 11, 10, 22].

Residential deployments can provide detailed insights about occupant behavior (specifically activities of daily living (ADLs)) and energy consumption (gas, water and electricity). These deployments also provide data sets which can be leveraged for building simulations. In the recent past, several datasets, such as REDD [17], BLUED [12], Smart* [6], monitoring household electricity and ambient parameters, have been publicly released. These datasets have helped advance the field the field of Non intrusive load monitoring [15].

Most of the previous deployments have been done in the context of developed countries. However, it is equally important to understand building energy consumption in developing countries such as India, where there is electricity deficit and new buildings are being constructed at a rapid rate, adding to electricity demand. The peak demand deficit in India was reported to be 10.3% in the year 2010-2011 [1]. Also, 19 million square meters of residential building space was added in 2004-2005 [10].

We have been involved in such deployments in Indian context for more than an year, whereby, we have until now instrumented - 25 homes with smart meters, a smart campus with sensors for ambient monitoring in a research wing and energy meters in institute dorms. In this paper, we discuss an extensive ongoing deployment in one of the homes in Delhi, India. This home is instrumented with - smart electricity and water meters, plug level load monitoring for major appliances in the home, ambient environment across every room etc. To the best of our knowledge, this is first such extensive deployment outside any developed country. We discuss in detail the unique characteristics of our deployment, such as unreliable nature of grid and internet connectivity. We also discuss common issues in residential deployments, which had been highlighted in previous work and how we tackled them. Our deployment was maintained as an open source project, clearly showing the issues faced and how these were addressed. Unlike many of the past deployments, detailed metadata logs, such as appliance make, mode of operation, etc. are also provided.

2 Related Work

Building deployments have been studied in the recent past with the goal of computational sustainability. Office and campus deployments presented in previous work [4, 2, 8] have shown the scope for significantly reducing HVAC and

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plug load energy consumption in respective settings. Residential deployments have been studied in the past highlighting the unique challenges involved in residential sensing.

In the early 1990s Hart [15] laid the foundations of NILM in his seminal work on the subject. Since then, several residential deployments have specifically targeted residential sensing for NILM and as a consequence home electricity datasets have been released in the public. Kolter et al. [17] performed deployments in 6 homes in Boston (US) in 2011, with collected data spanning upto 19 days in some homes. Their deployment involved monitoring household electricity at the meter, circuit and appliance level using COTS. Their dataset (REDD) has become a pioneer in NILM datasets and to date has been cited 55 times, which clearly suggests the impact such deployments carry. Anderson et al. [12] performed a week long residential deployment, specifically focusing on collecting fully labeled high frequency electrical data at various resolutions and released BLUED dataset. Barker et al. [6] have performed deployments across three homes and have collected information across varying modalities including, but limited to, electricity monitoring, door and motion status, weather monitoring, renewable electricity generation. They have shown the wide variety of applications pertaining to residential deployment, such as: peak demand flattening [7], cost optimization using variable electricity pricing [20], using electricity storage in homes and renewable generation [21]. Further, they have highlighted the value of additional information which can be obtained by correlating across multiple sensing modalities.

Hnat et al. [16] have provided a detailed guide into residential deployments and have provided lessons learnt from residential deployments across multiple homes for several years. They have proposed various applications of such detailed sensing including identifying activities of daily life (ADLs). Previous residential deployments have also led to smarter appliances such as smart thermostat [18], which builds probabilistic models on data collected from door and motion sensors, to build an electricity efficient thermostat.

All of the deployments discussed above are in the context of developed countries. While residential deployments anywhere across the world are challenging, our deployments highlight some unique challenges limited to developing countries. Some of these challenges in our setting include, but are not limited to, unreliable grid, unreliable internet and difficulty in procuring quality COTS.

3 Deployment Overview

Over the past year, we have performed extensive sensor deployment for ambient monitoring in research environment and smart meters across more than 25 homes in India. Building upon these experiences, we undertook a detailed deployment, constituting 33 sensors measuring electricity, water and ambient parameters across different resolution, in one of the homes in Delhi, India during June-July 2013. Primary objective for this deployment was to bring forth the differences in the Indian context, as compared to the context of developed countries along the dimensions of - 1. The ecosystem of available sensing options that restrict the possible deployments; 2. Energy and water consumption patterns;

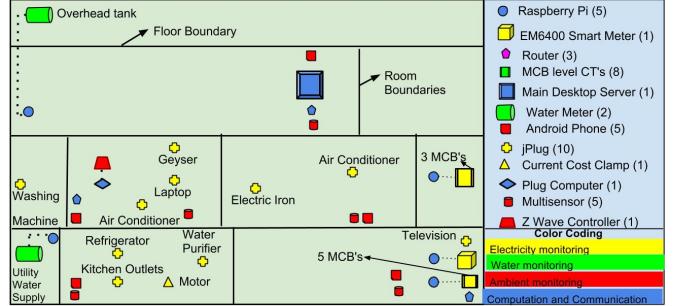


Figure 1: Schematic showing overall home deployment

and 3. Grid and network reliability. We believe that this discussion will enrich the existing research in building energy domain, which has only leveraged deployments and data collection in the context of developed countries, for wider applicability across different contexts. Figure 1 shows the deployment of these sensors in a 3 storey home, together with 5 single board computers and 3 routers for computing and communication. We now provide detailed description for our deployment.

3.1 Sensing Infrastructure

For sensing, we took a “leave no stone unturned” approach, where we chose to monitor as many physical parameters (ambient conditions, electricity usage and water usage) and non-physical parameters (such as network strength and network connectivity, among other). We, however, chose to deploy these sensors in a way that home users can continue their daily routines without getting affected. Many of these sensors were procured from outside India due to limited options available in the Indian context. Detailed description of the sensors used for monitoring various parameters are explained next.

Electricity monitoring: We chose to monitor electricity consumption across different resolutions - electricity meter monitoring the consumption at the home aggregate level, Current Transformers (CTs) monitoring current for Miniature Circuit Breakers (MCBs) (each connected to a combination of appliances) and plug level monitors for consumption monitoring of plug load based appliance (see Figure 4a for illustration).

- Meter level:** Schneider Electric EM6400¹ smart meter is used to instrument the main power supply (see Figure 2a showing EM6400 smart meter deployed in the electricity panel). 30:5 ratio CT was used on the power mains coming from the grid to ensure that the load current is within the permissible limits (5 A) of the meter. All the necessary parameters including voltage, current, frequency, phase angle, and power (apparent, real, reactive) were read at 1 Hz using Modbus over RS485-serial link provided by EM6400. Based on our experience, we believe that the support required for large scale smart metering deployments, exists in the Indian context.

- Circuit level:** Split CTs, clamped to individual MCBs, are used for monitoring circuit level current. Since no commercial solution is easily available in India for

¹www.goo.gl/01edPS

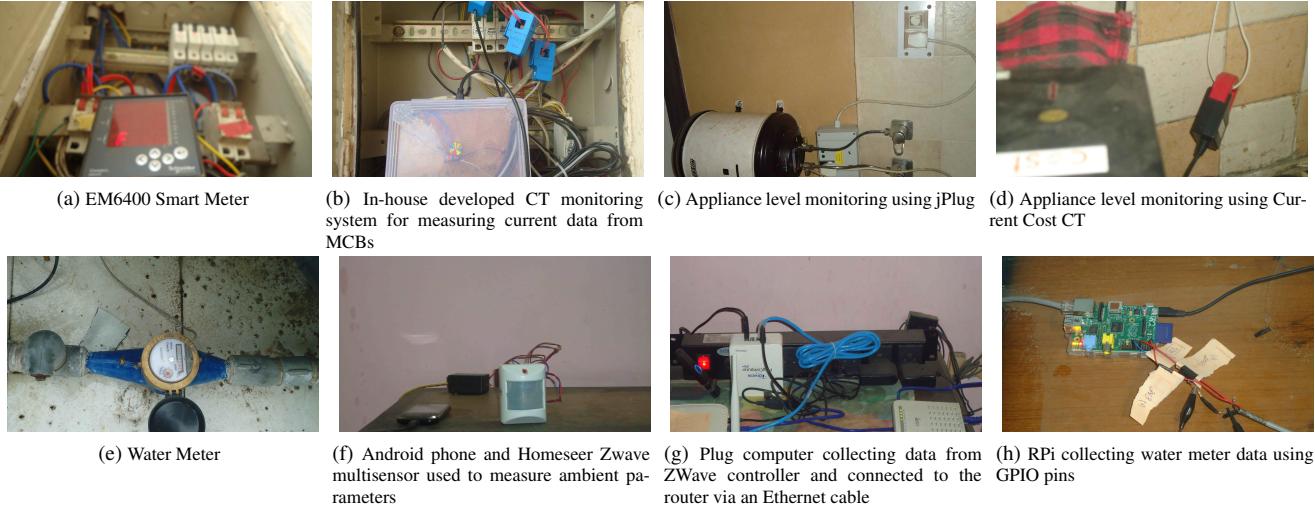


Figure 2: Sensing, computation and communication equipment used for deployment

panel level monitoring, a low cost microcontroller platform is used to collect Analog output from CTs at 125 KHz, calculate the rms value and communicate it over serial UART interface (Figure 2b captures CTs monitoring 3 MCBs on the first floor MCB box).

3. Appliance level: Similar to circuit level monitors, there are no good commercial options for plug level monitors in Indian context as well. Correspondingly, we worked with our collaborators who in-house developed jPlug² to measure individual appliance power consumption. 9 of these jPlugs were used to monitor plug-load type appliances. jPlug sits in between an appliance and the socket and provides multiple parameters (including voltage, current, phase angle and frequency) at 1 Hz resolution. We also used Current Cost based CT to measure the power consumption for electric motor (used to pump water), which is not a plug-load, yet has significant power consumption (approx. 700 Watts). jPlug and Current Cost CT deployment are shown in Figure 2c and Figure 2d respectively. jPlug makes a HTTP POST connection to log measured parameters. Current Cost exposes apparent power data over the USB port.

Water monitoring: There are a few differences in home water distribution in India when compared to developed countries. Due to non availability of 24x7 water supply, overhead water tanks (typically 1000 liters capacity) are used to store water, when available, and supply it for home activities throughout the day. Due to low water pressure, even during the times when the supply is available, electric motors are used to pump the water for storage. Figure 4b illustrates the water flow distribution, together with placement of water meters. One water meter is placed at the inlet (coming from the utility) and another one at the outlet from the water tank (flowing downwards) to capture the incoming (from utility) and outgoing (from tank) water consumption.

Due to prohibitive cost and difficulty in procurement of digital water meters in India, we chose to use Zenner Aquamter's multijet³, a pulse output based water meters.

Output pulse is generated through a 4-20 mA current loop, commonly used for analog signaling in industrial process control instruments. For the water meter connected to the utility, over a 0.5 inch diameter pipe, a pulse is generated for every 1 liter of water consumption. Water meter connected to the outlet of storage tank, with 1.25 inch diameter, generates a pulse every 10 liters of water consumption. Figure 2e shows the water meter deployed inline at the overhead tank.

Ambient conditions monitoring: We used ZWave based HomeSeer HSM100⁴ multisensors for monitoring motion, light and temperature across 5 rooms in the home. Till date, to the best of our knowledge, no commercial ZWave based sensor is available working on Indian frequency (865.2 MHz). We correspondingly imported EU frequency (868.4 MHz) devices and used it for ambient monitoring. For these HSM100, motion is reported in an event-driven manner (i.e. whenever there is change in motion status, a reading is reported) and temperature and light are polled at 1 Hz. We also placed 1 Android phone at a fixed location in each room and ran FunF journal application⁵ to log ambient parameters such as light and sound level every 30 seconds for 5 seconds.

Miscellaneous: Android phones, in addition to measuring ambient conditions, were also used to scan and log Bluetooth, WiFi and GSM networks. All home occupants were requested to keep the Bluetooth on during the duration of the experiment. The network scanning was done every 1 minute and is stored locally on the SD card. External weather conditions, such as temperature, humidity and wind speed, were also logged every 10 minutes using publicly available API's from weather monitoring stations⁶. Additionally, network traffic was sensed to monitor connectivity and signal strength. Such miscellaneous data collection, together with detailed electrical consumption, water consumption and ambient information, can be used for multiple applications including energy-apportionment (i.e. assigning energy usage to different occupants within the home), localization and correlating energy usage with outside temperature.

⁴www.homeseer.com/pdfs/guides/HSM100_Release_Notes.pdf

⁵<http://www.funf.org/journal.html>

⁶Forecast, World Weather, Open Weather Map

²A variant of nPlug [13]

³www.aquametwatermeters.com/multijet.html

Table 1: Sensing Infrastructure

Sensor name	Sensor type	Sampling frequency (Hz)	Resolution	Quantity	Communication	Obved parameters
EM6400	Electric Meter	1	Home	1	RS 485 Serial	Voltage, Current, Frequency, Phase, Power(Active, Reactive and Apparent), Energy
Aquamet multijet	Water Meter	5	Main supply and tank	2	Direct wire connection to GPIO	10 liter events for tank and 1 liter events for main supply
Homeseeer HSM100	Ambient multisensor	Light, temperature: 1 PIR: event based	Room	6	ZWave	Light, temperature and motion
Android phones	Ambient multisensor and network	Audio, light: Reading is taken for 5 seconds, every 30 seconds; Nearby WiFi, cellular, Bluetooth: 1/60	Room	5	Manually transfer files to PC	Audio features, light, nearby Bluetooth, cell-tower, WiFi
Prototype CT	Electricity meter	20	MCB	8	Serial	RMS Current
jPlug	Electricity meter	1	Appliance	10	WiFi	Voltage, Current, Frequency, Power (Active and Apparent), Energy, Phase
Current Cost	Electricity meter	1/6	Appliance	1	Serial	Apparent power

Complete sensing infrastructure is summarized in Table 1.

3.2 Communication and Computation Infrastructure

Multitude of sensing infrastructure, as described in Section 3.1, involves multitude of communication channels as well. Different computing platforms - microcontrollers, Single Board Computers (SBCs) (e.g. Raspberry Pi⁷ (RPi) and Ionics Stratus⁸) and desktops are used for data collection. SBCs served as a good low cost alternative (25 \$) constituting 700 MHz ARM processors, support for Linux based distributions and allow for coding in higher level languages such as Python.

We used 5 RPi and 1 Ionics Stratus plug computer in our deployment. We used a 2 GHz Desktop PC running Linux, as the main server where all the data was stored. One RPi was connected to EM6400 using RS485-USB converter. We developed a custom Python program based on pyModbus⁹ to collect the desired parameters. All the collected parameters, together with the UTC timestamp is stored in a local CSV file. A new CSV was created every 15 minutes. A background program would periodically try to upload CSV files older than 15 minutes, to the main server, where the data is pushed in MySQL database. This architecture for data collection - creating a new CSV periodically, uploading older CSV periodically to main server where the data is then pushed into MySQL, is used for all of our sensors connected to SBCs. We call this model Sense-Local Store-Upload and describe it in more details in section Section 3.3. On similar lines, USB output from Current Cost (providing data in xml format) is received on another RPi and goes through the Sense-Local Store-Upload architecture for data collection. Although Current Cost has its own cloud based API's, we chose to collect data from it locally, in order to avoid data losses occurring due to network failures.

Two RPi were used to connect to the microcontroller

based circuit monitor to read the data over the serial port and process it further using Sense-Local Store-Upload. One of the RPi connected to the meter was used for circuit monitoring as well for the CTs used in the same panel. GPIO headers on two more RPis were used to interface with each water meter respectively for collecting pulse output over the 4-20 mA current loop interface. We initially wrote an interrupt driven program in Python to detect 10 liter and 1 liter events for the tank and supply water meters respectively. We observed that noise introduced in the circuit due to long cable lengths led to a lot of false events. Correspondingly, we modified our program and polled at a frequency of 5 Hz to obtain GPIO status and further processed this data using Sense-Local Store-Upload.

Data from jPlugs (using the HTTP post request every second) is directly collected on the server machine where a web daemon listened to requests from jPlug and dumped them in MySQL. Ionics Plug Computer is used to collect data from all ZWave based sensors. We wrote custom wrappers around OpenZWave¹⁰ to collect temperature and light information on per second basis, and motion information based on events. A ZWave controller was connected over USB with Ionics and the data was processed further using Sense-Local Store-Upload. Figure 2g shows the plug computer collecting ambient sensor data from ZWave controller. A manual dump of locally collected data on each Android phone was performed every 15 days. Electricity failure and unreliable internet are well known problems in India and are highlighted in Section 4. Owing to these problems, we chose to collect weather data from 3 different weather stations, in one of the servers hosted by our collaborators in the USA.

A lot of issues, pertaining to SBCs, were observed in our deployment. As an example, the OpenZWave program that we used created log files for its own diagnostics, that eventually consumed the 512 MB flash drive space on the plug computer. This was fixed eventually by deleting older logs. Such problems encouraged us to develop soft-sensor

⁷www.raspberrypi.org

⁸www.ionics-ems.com/plugtop/stratus.html

⁹www.github.com/bashwork/pymodbus

¹⁰www.code.google.com/p/open-zwave

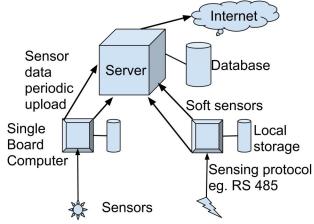
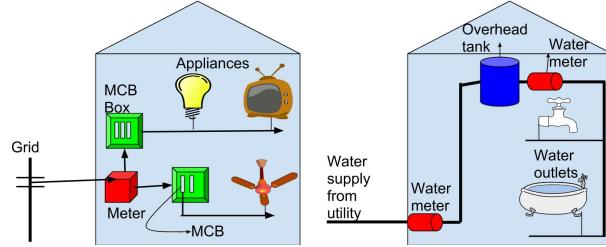


Figure 3: Sense-Local Store-Upload



(a) Different resolutions of measuring electricity consumption in home: meter, circuit and appliance
(b) Different resolutions of measuring water consumption in home: inlet supply from utility, outlet supply from tank

Figure 4: Electricity and water flow inside a home and different resolutions at which these parameters can be monitored

streams, whereby we collected hard disk space, ping success, CPU utilized, remaining RAM space and temperature of the processor, for all the computing devices including the server at regular intervals. These soft-sensor streams can be used for offline analysis as well as for real time alerting and fault diagnosis. Similar soft-sensor streams have also been used in the previous work [16] for raising alerts.

Similar to prior research, reporting WiFi discontinuity in homes in the USA [16], we also observed that one WiFi router will not suffice for our 3 storey home. We thus used 3 Netgear JNR1010¹¹ routers, where the router on the first floor acted as the host and the routers on the ground and the second floor were bridged to it. More details regarding the need of multiple routers and network availability in homes is described in Section 4 and Section 5.

3.3 System Architecture

Middleware systems such as sMAP [9], BuildingDepot [3] and SensorAct [5] have been proposed in the past for sensor data collection. However, we found that they are not fine tuned to our needs arising from faulty internet, power failures, etc. Based on our experience and previous work [16], where importance of simplifying the architecture are proposed, we propose Sense-Local Store-Upload. Sense-Local Store-Upload involves two main ideas- local storage (on SBCs) and periodic data upload (from SBC to server, and from server to cloud). Data collected from sensors was **locally stored** in form of comma separated value files (CSV), in SBCs and **periodically uploaded** to the main desktop server. In case the upload failed, it was retried the next time again. Each SBC had sufficient flash based local storage to accommodate sensor data for a few days, in case there was persistent upload failure.

Web applications running on the server allowed a home user to locally visualize her data from multiple sensing

streams. Further, data from the server can be copied to cloud servers, allowing outside users and specifically researchers to remotely keep an eye on the deployment. Figure 3 explains Sense-Local Store-Upload architecture. The salient features of our architecture are as follows:

- **Decoupled sensing and data uploading:** This ensures that an error in data uploading does not have an impact on sensing and vice versa. Thus, there is no data loss owing to internet failure. The design choice of decoupling comes from the well established principles of software engineering.
- **Minimal internet requirement:** Internet is required **only** when outside researchers wish to view and analyze collected data in near realtime. Internet failure does not have any impact on sensor data collection. Also, the periodic nature of our uploads ensures that whenever internet is back, data would be uploaded. Further, there is no data loss even if the server goes down for some time, due to local storage.
- **Reduced load on server:** Since data is uploaded periodically in larger chunks rather than sending data for each sensor packet, computation and bandwidth requirements on SBCs and server are reduced. Though this comes at the cost of increased storage requirements on SBCs, we found that for all practical purposes, we did not need to provision for more than 1 GB.

4 How is this deployment different?

In this section we discuss some of the key unique aspects brought forward from our deployment, which are as follows:

Unreliable grid is commonplace: Load shedding or rolling blackout are common in developing countries, owing to several reasons such as improper infrastructure management, high demand and low electricity production. In India, power outages are common in summers when load is high due to usage of air conditioners. As a result, voltage fluctuations or brownouts are also common.

We collected various statistics from our deployment which illustrate these aspects. Figure 5b shows power outages in number of hours per day during June-July 2013. Power outage for upto 12 hours has been reported on some days. Figure 5b shows the duration in minutes of power outages. A total of 107 power outages were reported in the 61 day period. While the average power outage lasted about 1 hour, there were outages lasting upto 9 hours. Figure 5c shows the power outage distribution by hour of the day showing maximum outages around 10 AM in the morning and around midnight. These times correspond to office time and night time when air conditioners in most homes are on and there is excess demand on the grid. Figure 5d shows the voltage fluctuations in a typical day, where we observe voltage to fluctuate between 180 and 250 Volts. We can observe that voltage drops during peak load hours. Figure 5f shows that voltage just before power outage in night hours (10 PM to 1 AM), when load is expected to be maximum. We observe that voltage is well below rated voltage of 230 V. This is in coherence with previous work [13], which hypothesized that frequency and voltage indicate load on the grid. Figure 5e

¹¹www.support.netgear.com/product/JNR1010

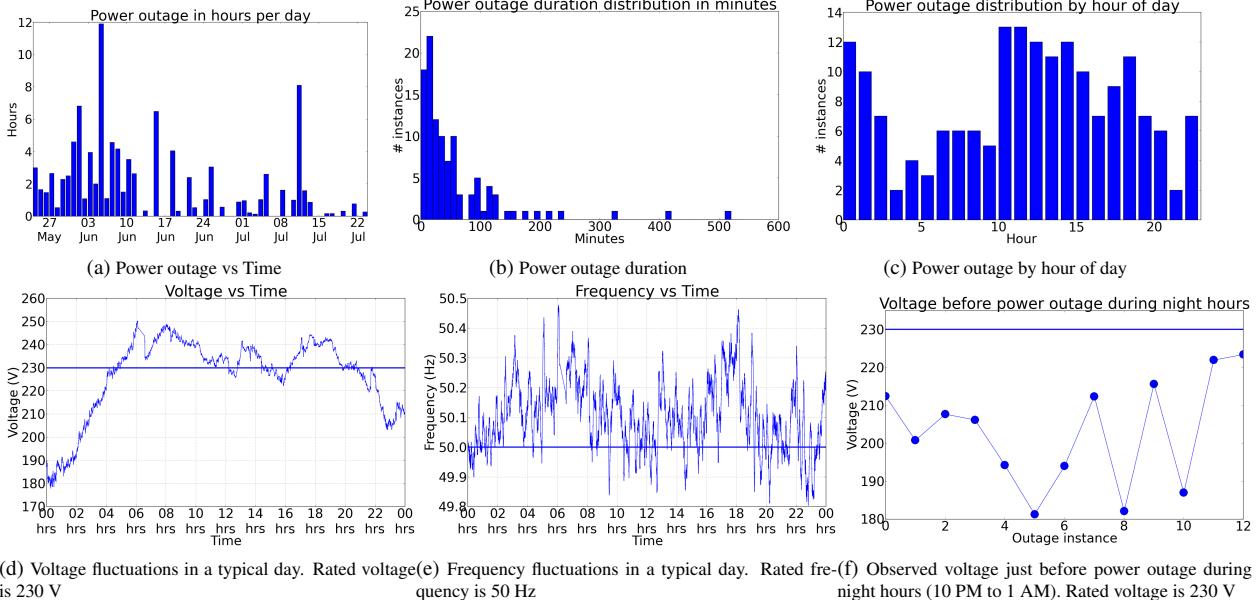


Figure 5: Unreliable grid

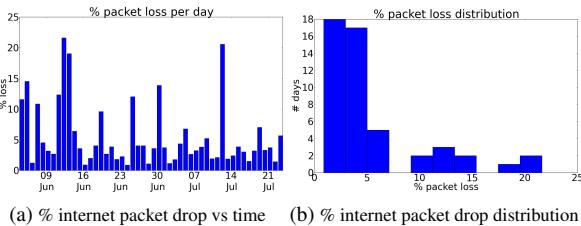


Figure 6: Unreliable internet

shows fluctuation in frequency in a typical day.

Due to unreliable nature of grid, we ensured that all our systems were capable of automatically starting after a power outage. We put our scripts for data collection and upload in Linux startup script. This provided us another advantage. If we observed that a system was down, we could just ask the home occupant to repower the system. This ensured that there was minimal data loss till the time our researchers could visit the site and repair the fault.

Unreliable internet connectivity: While India has one of the fastest growing internet population, only 11% of the total population is connected to internet, the corresponding figure in USA is 78% [19]. Average connection speed in India is 1.3 Mbps, the corresponding numbers in developed countries are in excess of 10 Mbps [24]. Even though the condition of internet has vastly improved in the previous few years, from practical experience, we have found it to be unreliable. We found internet would be unavailable several times during the day and sometimes it would be too slow. This was a prime motivation behind local storage and periodic data upload, which we have proposed in Sense-Local Store-Upload. Using Sense-Local Store-Upload all the data eventually gets synced up to the main server and from there to the cloud over the internet. We, thus, believe that for deployments where internet is unreliable, architectures such as Sense-Local Store-Upload should be adopted.

To illustrate the need for Sense-Local Store-Upload, we collected network statistics from our deployments. We sent a packet consisting of 15 internet ping requests every 15 seconds and reported packet drop. Figure 6a shows that packet drop of upto 25% was observed on certain days. The average packet drop was around 6% per day. Figure 6b shows a histogram plot of % packet drop. It can be seen that on 1/6 fraction of total days, % packet loss is greater than 10%.

Importance of meta data collection: We collected metadata associated with electrical appliances throughout our deployment. We collected parameters such as appliance name, age, mode of usage (eg. air conditioner set temperature). We believe this detailed metadata can enhance NILM and can provide useful insights for conserving electricity. The home refrigerator was sent for repairing on 2nd July. Figure 7a and Figure 7b show the active power consumption before and after repair. We found that after repair the refrigerator was configured in coolest mode (lowest temperature), while before repairing, it was configured in least coolest mode (highest temperature). After repair the refrigerator was found to be consuming 1KWh more per day (which is 140% above normal). Moreover, its duty cycle pattern was modified significantly. This metadata can be useful to NILM approaches which model duration of appliance usage.

Load specifics: Electrical load setting in India are different from that in the USA and Europe. There are no automated loads and HVAC systems are decentralized. Thus, air

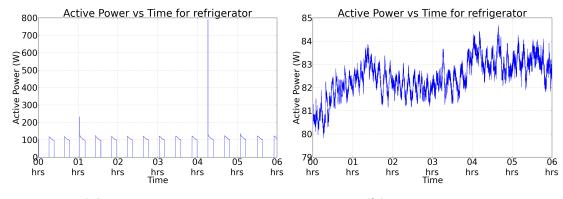


Figure 7: Refrigerator power consumption

conditioning is at room level and water heating is done using geysers at bathroom level. From our deployments, we observed that air conditioners and geysers account for upto 70% and 50% of overall home electricity in summers and winters respectively. Thus, any small improvement in efficiency of these two appliance can significantly lower the home electricity consumption.

Water pumping and filtering are two activities whose scope varies across both water and electricity dimensions. Water motor, described in section Section 3.1, is used to pump water upto water tank on roof. We observed that to fill 1 liter of water into the tank, it took 8 seconds without the motor and 4 seconds when motor was used. The power consumption of the electric motor is around 700 W. To fill an empty water tank it would take 8000 seconds(2 hours 12 mins) without motor and 4000 seconds (1 hours 6 mins) with motor. An additional 770 Wh energy would be consumed if motor is used. Thus, there is a fine balance between electricity consumption and time taken to fill the tank. We found that motor is typically used for 10 minutes in a day.

Reverse Osmosis(RO) based water filters are commonly used to filter the drinking water. We found water filter takes about 1 minute to filter 1 liter of water and consumes 40 W in the process. Thus, the water filter would consume 20 Wh energy for filtering 30 liters of water (typical drinking water usage). Another interesting distinction is that our loads are not always on and there is a switch with each plug socket. We found that the jPlugs attached to kitchen appliances such as microwave and mixer, when used for less than 1 minute, did not report power readings. This was due to the fact that jPlug takes some time to reach steady state and before it could do so, the appliance was turned off. From our survey with the home occupants, we found that their typical microwave and mixer usage was less than 2 minutes.

Lack of quality measurement devices commonly found in USA and Europe: As reported earlier in Section 3.1, ZWave sensors for Indian frequency (865.2 MHz) are not readily available in the market. Thus, we imported European frequency (868.4 MHz) based ZWave multisensors and plug load monitors. Import duty and shipment delays make them an expensive choice. As explained above, our loads are not always on and are controlled via plug sockets. Thus, we could not use ZWave based plug load monitors in our deployments as they had to be manually turned on after a power outage, which is common. Also, solutions for panel level monitoring are not easily available in India. Thus, we had to resort to prototype solutions for appliance and circuit level monitoring.

5 Hitchhiker's guide revisited

In this section, we discuss similarities between our deployment and previous work, most specifically- "The Hitchhikers Guide to Successful Residential Sensing Deployments" [16]. Some prominent similarities are:

Homes are hazardous environments: We observed that one of our multisensors would fail after power outage. Initially, we felt that the sensor was faulty, but other multisensors also showed the same behavior in the same location. We figured that this behavior was due to the fact that this multi-

sensor was put on inverter point (battery backup) and would not go down even on power outage. Thus, when power resumed, ZWave controller was not able to add this multisensor to its network. We resolved this by putting the multisensor at a non-inverter point. We also observed that one of the multisensor would always indicate motion. Initially we solved this problem by replacing its power supply. However, within a week, this problem resurfaced. We believe it is due to faulty power supply in that room. The home occupants did not allow a thorough investigation of that electrical socket and we had to do away with that data.

Although we used zip-ties extensively throughout the deployment to prevent hanging wires, we observed data loss in one of our multisensor and Android phone, which went out of power due to wire snag (shown in Figure 9b). Even after 1 month rigorous testing in lab, we raised 60 new issues (service complaints), when we moved the deployment to this home. This is a testimony that homes present unique challenges which can not be exactly emulated in laboratory settings.

Aesthetics matter: As stated in previous work, sensor LED's can be bothersome to home occupants, particularly in the night. Our 33 sensor deployment had introduced 63 LEDs in the home. Figure 9a shows our sensor LEDs blinking in the night. Choosing appropriate sensor location sufficed for our present deployment. However, for future such deployments, we intend to build better sensor casing to ensure that home occupants are not disturbed. Also, the home occupants complained of buzz like sound coming from the desktop that we had installed. This noise was due to dust clogging in desktop's CPU. This is a unique aspect introduced in the Indian setting. Thus, we believe that any long lived deployment should have routine maintenance.

Homes are not designed for sensing: We observed that the data collected from our ground floor MCBs (5 in number) was noisy. This was due to the fact that these MCBs are close (shown in Figure 9c) to each other causing interference in our CT monitoring circuit. However, on the 3 MCBs on the first floor, there was adequate gap amongst MCBs and data was of good quality. We, thus, believe that homes are not designed for sensing and one may not be able to sense desired parameters.

Redundancy-Accounting for sensor failure: During our deployment 3 jPlugs and 1 multisensor stopped functioning properly. We had accounted for such failure and had kept reserve sensors ready. We believe that one should beforehand account for sensor failure in residential deployments.

Homes have poor connectivity: During the preliminary phase of our deployment, we tried to connect our sensors to the existing networking infrastructure in the home. Already existing WiFi router was on the first floor and we observed poor signal strength on ground and second floor. We used Ekahu Heat Mapper¹² to generate WiFi signal strength heatmaps. Figure 8a and Figure 8c show the WiFi heatmap produced wrt the router placed on first floor. We observed that a lot of regions inside the home show poor signal strength. We bridged an additional router on the ground and

¹²www.ekahu.com/products/heatmapper/overview.html

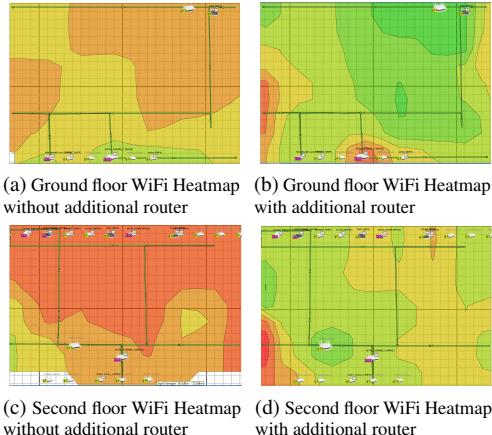


Figure 8: WiFi signal without placing additional routers on different floors is poor. The greener the region, the better the signal strength for the heatmap.



Figure 9: Common problems in residential deployments

the second floor with the existing first floor router. Figure 8b and Figure 8d show the corresponding WiFi heatmaps produced wrt newly introduced bridged routers. We can observe the improvement in signal strength with the introduction of additional routers.

Another important facet of deployments is that additional sensors introduced inside a home may choke up the network bandwidth. We observed this when we tried using imported WiFi based microcontrollers for sensing ambient conditions in our research wing. Research wing occupants complained of low network bandwidth available for their personal usage. Thus, we decided to use ZWave based multisensors for measuring ambient parameters for home deployment. Since ZWave based sensors worked on a different frequency (868.4 MHz) as WiFi(2.4 GHz), they did not cause interference. We believe that a careful mix of sensors working on different frequencies can be used to avoid interference issues.

6 Conclusions and Future Work

In this paper, we present our experiences in an extensive residential deployment monitoring electrical, water and ambient parameters in Delhi, India. To the best of our knowledge, this is the first extensive residential deployment in a developing country. We present key differences between developing and developed countries, in terms of residential deployments. Some of these key differences are: unreliable nature of electrical grid, unreliable internet, different set and nature of electrical loads, concept of overhead water tanks. We verify residential deployments learnings presented in previous literature, such as poor wireless connectivity in homes and the importance of aesthetics.

Frequent power outages and unreliable internet motivated us to develop our sensing architecture: Sense-Local Store-

Upload , which accounts for these pitfalls by introducing local storage and periodic upload. Such architectures can be of particular importance in context of developing countries.

We are in the process of installing our sensors across multiple faculty residences in our institute. We plan to carry out longer duration deployments which capture seasonal variations and after that we wish to release our data set in the public. We plan to perform NILM and provide the home occupants with detailed electricity consumption breakdown.

7 References

- [1] India energy book 2012. page 59, 2012.
- [2] Y. Agarwal, B. Balaji, S. Dutta, R. K. Gupta, and T. Weng. Duty-cycling buildings aggressively: The next frontier in hvac control. In *Information Processing in Sensor Networks (IPSN), 2011 10th International Conference on*, pages 246–257. IEEE, 2011.
- [3] Y. Agarwal, R. Gupta, D. Komaki, and T. Weng. Buildingdepot: an extensible and distributed architecture for building data storage, access and sharing. In *Proceedings of the Fourth ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings*, pages 64–71. ACM, 2012.
- [4] Y. Agarwal, T. Weng, and R. K. Gupta. The energy dashboard: improving the visibility of energy consumption at a campus-wide scale. In *Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings*, pages 55–60. ACM, 2009.
- [5] P. Arjunan, N. Batra, H. Choi, A. Singh, P. Singh, and M. B. Srivastava. SensorAct: A Privacy and Security Aware Federated Middleware for Building Management. In *Fourth ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings, BuildSys 2012*, 2012.
- [6] S. Barker, A. Mishra, D. Irwin, E. Cecchet, P. Shenoy, and J. Albrecht. Smart*: An open data set and tools for enabling research in sustainable homes. In *The 1st KDD Workshop on Data Mining Applications in Sustainability (SustKDD)*, 2011.
- [7] S. Barker, A. Mishra, D. Irwin, P. Shenoy, and J. Albrecht. Smartcap: Flattening peak electricity demand in smart homes. In *Pervasive Computing and Communications (PerCom), 2012 IEEE International Conference on*, pages 67–75. IEEE, 2012.
- [8] N. Batra, P. Arjunan, A. Singh, and P. Singh. Experiences with occupancy based building management systems. In *Intelligent Sensors, Sensor Networks and Information Processing, 2013 IEEE Eighth International Conference on*, pages 153–158, 2013.
- [9] S. Dawson-Haggerty, X. Jiang, G. Tolle, J. Ortiz, and D. Culler. smap: a simple measurement and actuation profile for physical information. In *Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems*, pages 197–210. ACM, 2010.
- [10] M. Evans, B. Shui, and S. Somasundaram. *Country Report on Building Energy Codes in India*. Pacific Northwest National Laboratory, 2009.
- [11] M. Evans, B. Shui, and T. Takagi. Country report on building energy codes in japan. *Pacific Northwest National Laboratory*, 2009.
- [12] A. Filip. Blued: A fully labeled public dataset for event-based non-intrusive load monitoring research.
- [13] T. Ganu, D. P. Seetharam, V. Arya, R. Kunzath, J. Hazra, S. A. Hussain, L. C. De Silva, and S. Kalyanaraman. nplug: a smart plug for alleviating peak loads. In *Proceedings of the 3rd International Conference on Future Energy Systems: Where Energy, Computing and Communication Meet*, page 30. ACM, 2012.
- [14] M. A. Halverson, B. Shui, and M. Evans. Country report on building energy codes in the united states. *Pacific Northwest National Laboratory*, 2009.
- [15] G. W. Hart. Nonintrusive appliance load monitoring. *Proceedings of the IEEE*, 80(12):1870–1891, 1992.
- [16] T. W. Hnat, V. Srinivasan, J. Lu, T. I. Sookoor, R. Dawson, J. Stankovic, and K. Whitehouse. The hitchhiker’s guide to successful residential sensing deployments. In *Proceedings of the 9th ACM Conference on Embedded Networked Sensor Systems*, pages 232–245. ACM, 2011.

- [17] J. Z. Kolter and M. J. Johnson. Redd: A public data set for energy disaggregation research. In *proceedings of the SustKDD workshop on Data Mining Applications in Sustainability*, pages 1–6, 2011.
- [18] J. Lu, T. Sookoor, V. Srinivasan, G. Gao, B. Holben, J. Stankovic, E. Field, and K. Whitehouse. The smart thermostat: using occupancy sensors to save energy in homes. In *Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems*, pages 211–224. ACM, 2010.
- [19] M. Meeker. Internet trends at stanford bases. KPCB, 2012.
- [20] A. Mishra, D. Irwin, P. Shenoy, J. Kurose, and T. Zhu. Smartcharge: cutting the electricity bill in smart homes with energy storage. In *Proceedings of the 3rd International Conference on Future Energy Systems: Where Energy, Computing and Communication Meet*, page 29.
- [21] N. Sharma, J. Gummesson, D. Irwin, and P. Shenoy. Cloudy computing: Leveraging weather forecasts in energy harvesting sensor systems. In *Sensor Mesh and Ad Hoc Communications and Networks (SECON), 2010 7th Annual IEEE Communications Society Conference on*, pages 1–9. IEEE, 2010.
- [22] B. Shui, M. Evans, H. Lin, W. Jiang, B. Liu, B. Song, and S. Somasundaram. *Country Report on Building Energy Codes in China*. Pacific Northwest National Laboratory, 2009.
- [23] B. Shui, M. Evans, and S. Somasundaram. *Country Report on Building Energy Codes in Australia*. Pacific Northwest National Laboratory, 2009.
- [24] A. Solutions. The state of the internet. Akamai Solutions, 2013.