STUDY PROCEDURE

Data Collection

A partial inventory of the MELs available at the International Institute of Information Technology-Hyderabad Vindya building was prepared. 93 devices were selected to be monitored by random sampling. Devices high in energy consumption and high usage variability were chosen for the study. The devices for the preliminary study belong to the following five categories: Display, Computer, Imaging, Networking and Other appliances. Display category includes different types of LCD, LED and Desktop monitors. Computer category includes different types of laptops, integrated PC and desktop CPUs. All kinds of printers, scanners, copiers, projectors are included in imaging category. Networking category includes devices like routers and switches. All the remaining plug load devices such as ovens, refrigerators, water coolers etc. are in “Others” category. The devices are metered for a period of four months. The metering study of plug loads is still going on. Plug load meters were installed and the data collection from these meters was done manually at periodic intervals. Data collection was done in the evenings with prior permission from users of devices. Some of the key study parameters such as taxonomy of devices, number of devices to be metered, duration of metering, and the sampling intervals were decided by referring to similar studies done at LBNL (Lanzisera et al. 2013).

Energy Meter Selection

For the study, we have built a low cost energy meter to measure the energy data. It uses STPM10 (Anon A) which is a programmable single phase energy metering IC to address a wide range of electricity metering requirements. The STPM10 records the amount of active, reactive, and apparent energy consumed, as well as the RMS and instantaneous voltage and current values at every 10 minute intervals. The device retains the data in the power down mode so that no data gets lost. It was tested with the standard meter before deployment. Fig. 1 shows energy meter attached to the laptop and the design of meter.

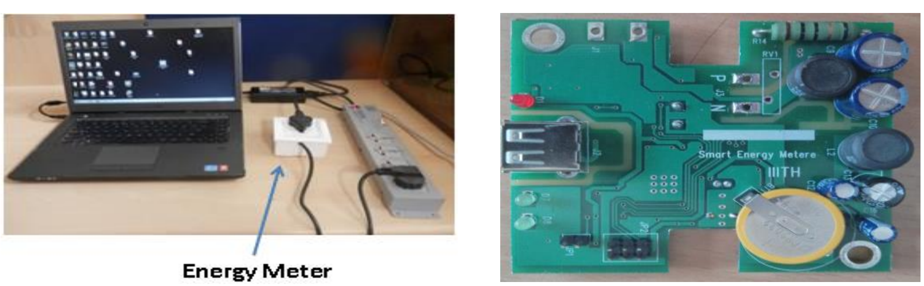

Fig. 1: Design of the connected energy meter

Plug Load Data Analysis

The remainder of this paper presents the analyses performed on the collected data. The following are the main analysis types performed on plug load data:

- Estimation of the annual energy usage of devices of different categories
- Variability in energy usage of devices of similar category

- Average load shapes for different day types (day of week, weekday vs. weekend) hourly and day wise
- Probability of a given device spends "ON" state in any given time interval
- Different device modes analysis, Off, Sleep, Other, and On modes for each category of devices

Device Count and Energy Usage

The energy consumption of the plug load devices was measured. Table 1 shows the count of the devices of different categories and their estimated annual energy consumption per device. Computers and "Others" account for maximum energy consumption. The annual energy consumption for the complete inventory in the building is estimated as well.

Table 1: Category wise count of devices metered and the average annual energy consumption per device

Category	Count	Avg. Annual Consumption/device KWh
Computer	38	140
Display	25	24
Imaging	11	26
Network	5	89
Others	13	339

Different Average Load Shapes

Fig. 2 shows the day wise average energy usage of devices in different categories. It shows that the average energy consumption of Computer category is higher compared to Imaging, Network, and Display category.

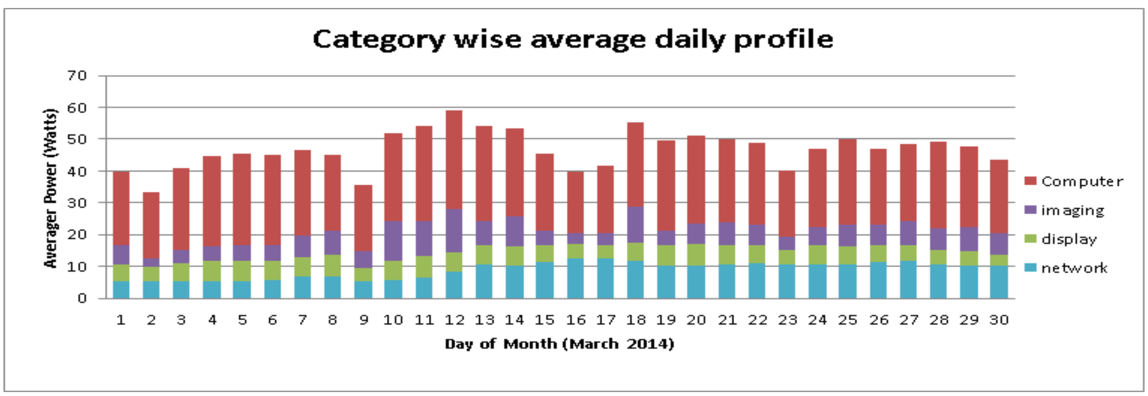

Fig. 2: Day wise average energy consumption over a period of 1 month

Average load shapes help us to understand the energy consumption pattern of the device. This data can be used appropriately in load prediction and demand response planning at peak time. Fig. 3 shows the average load shapes of the devices of different categories during weekend and weekdays respectively. The Computer category consumption is lesser on weekends.

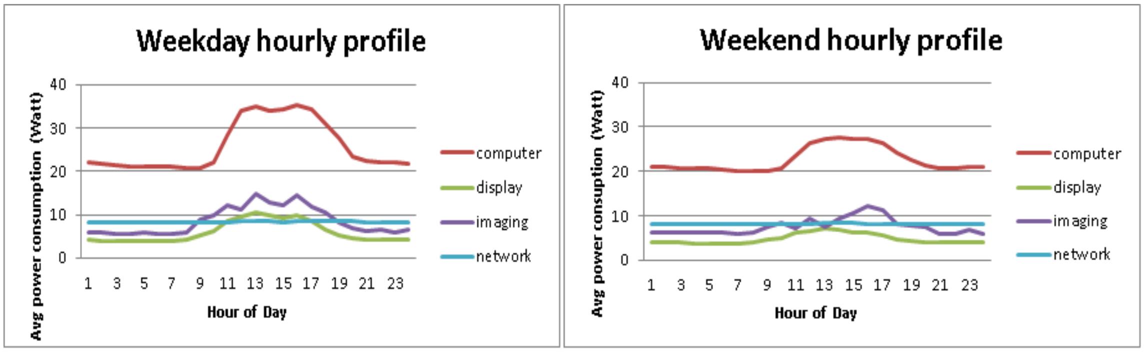

Fig. 3: Category wise average hourly power consumption over Weekdays and Weekends

Plug Load ON State Analysis

The average probability of being in the ON state for Computers, Displays and Imaging is shown in Fig. 4. Sixty percent of the computers are in ON state during peak hours and forty percent are in ON state during off peak hours. This indicates the probability of computers left in ON state after working hours and the ones switched off.

Displays are in ON state of time during peak hours and are in off state in off peak time. Imaging is not in ON state most of the time.

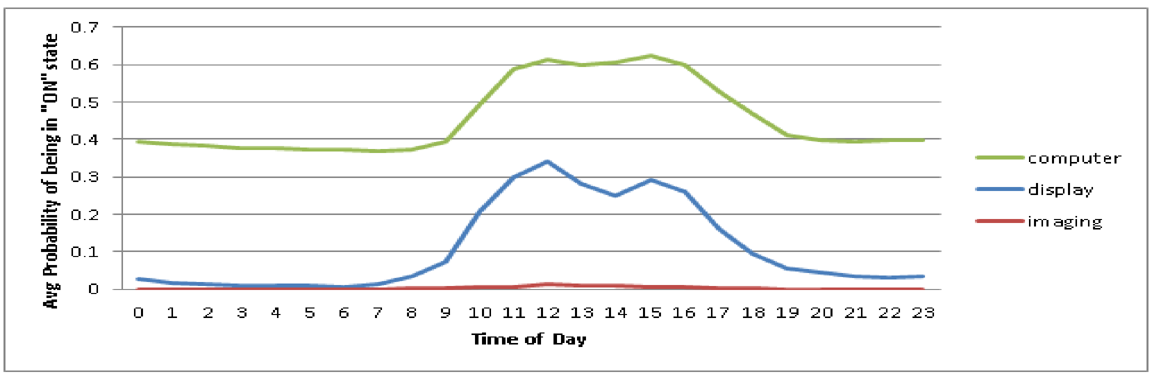

Fig. 4: Average probability of being in the "On" state for computers, displays and imaging equipment

Fig. 5 shows how many computers were in ON state for a given fraction of time.

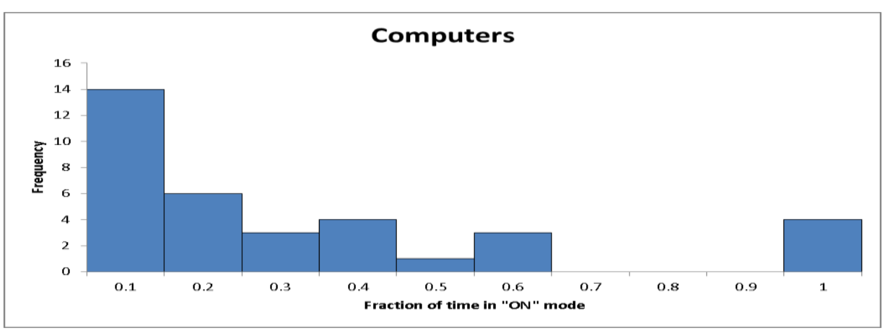

Fig. 5: Fraction of time in "On" mode for computers

Variability Among Device Energy Usage

Histogram of device energy use for a category shows the variability in energy use within a given category. As an example, Fig. 6 shows histograms for computers and displays.

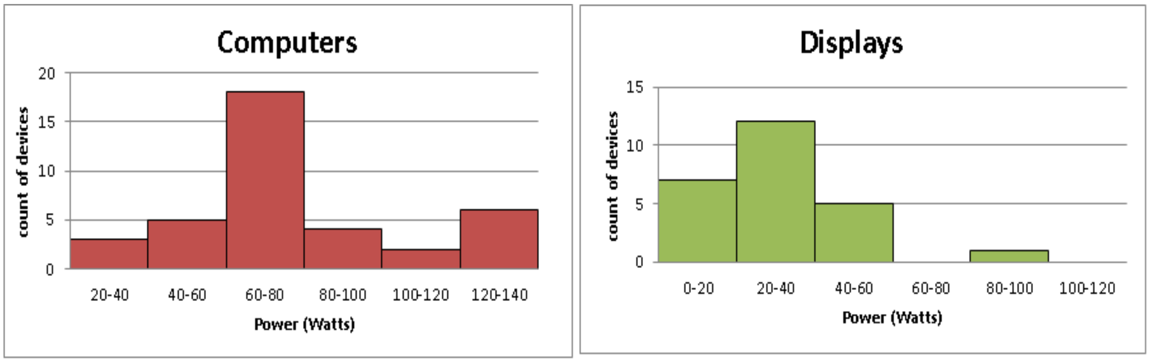

Fig. 6: Energy consumption variability among different computer and display models

Device Energy Consumption in Different Modes

Fig. 7 shows that for computer category there are a high frequency of samples in idle/sleep state which accounts for significant power wastage.

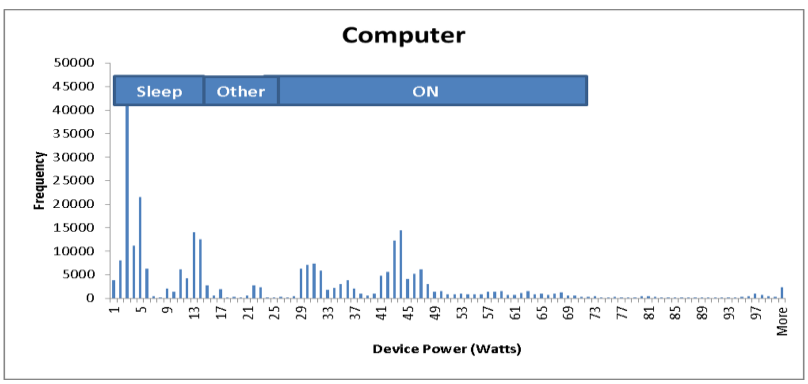

Fig. 7: Energy consumption of computers with the representation of idle mode, on, and other modes. X-axis represents the instantaneous energy in watts and Y-axis represents the number of samples.

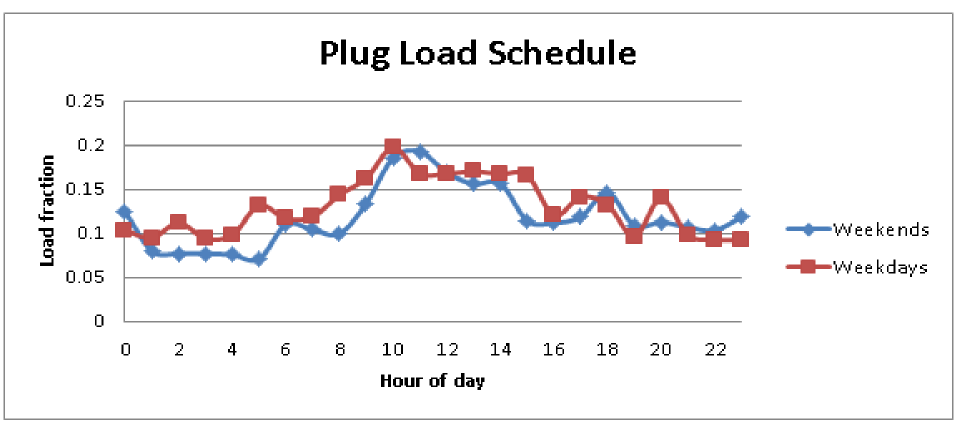

Fig. 8: Plug load schedule for weekdays and weekends

In Fig. 8 the plug load schedule for weekdays and weekends is plotted. The load fraction is the ratio of average to peak load of all the connected plug loads. This graph shows that weekends load increases at 11 am as students come even on weekends to work.
There can be many more kinds of analysis that can be performed on the collected data. The above analysis gives us a general idea on the working of the plug loads inside a building.

The key findings from this study are:

- Most computers, displays, and imaging devices consumed energy in sleep mode as they were not turned off.
- Phantom loads of different devices were measured
- Comparative study of different categories shows that “others” are highly consuming devices followed by computers.
- Identified efficient devices in each category. Under the computer category, integrated PC’s are highly efficient compared to desktops
- Obtained plug load schedules, showed that the load fraction does not go beyond 20%

The following strategies were recommended for reducing power consumption of plug load in the institute:

- Replace inefficient equipment with comparable, high efficiency devices. For example, replacing desktop with low power integrated PCs. Install power management utilities for reducing power consumption in devices.
- Switch off devices using smart plug strip and timers especially when they are in idle mode, standby mode, or during off-hours to reduce phantom load.
- Suggested high energy consumption appliances to be used during off-peak hours.
- Use flyers to create energy conservation awareness.

These are some of the issues identified during the plug load study. The device storage was limited, data had to be collected every 20 days and devices memory cleared for reuse. It was required to ensure that mobile devices such as laptops were plugged into the same energy meter every time.

FUTURE WORK

We plan to use the learning from this study to find solutions to problems faced during the study. Some of the proposed improvements include:

- Conduct a larger plug load monitoring study for 500 devices with wireless monitoring. Wireless plug load meters would help reduce human effort in collecting data. Real-time data analysis would be possible.
- Provide longer on-board memory storage to avoid data loss during communication failure.
- Use a mechanical or electronic seal to ensure that the same device is metered and prevent device detachment from the meter.
- Design a smart plug load strip with load sensing capabilities to reduce device phantom load for devices that are left unattended or go into sleep mode.

- Analyze effectiveness of plug load controls, such as smart plug strip for saving energy

CONCLUSION

In this study, 93 energy meters were deployed on a sample of plug load devices used in an academic institute. Metering data was collected for 4 months at ten-minute intervals for each metered device. The plug load data analysis has provided us with valuable insights about the MELs inventory, usage patterns, and device energy consumption. Plug loads accounted for a significant amount of energy usage in the academic institute. Phantom loads of devices were also measured.

The high power consuming and inefficient plug loads were identified and strategies for reducing plug load consumption were suggested. The study provides us with the plug load data which can be used for building smart plug strips with load sensing feature. Findings from the study would also help in preparing better plug load schedules for simulations

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