SinBerBEST
Building Efficiency and Sustainability in the Tropics

Plug-load Management Technology for Future Buildings

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National Research Foundation
Prime Minister's Office
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1. Background – Buildings & Plug-Loads
2. Existing Smart-Plug Solutions
3. Smart Electrical Outlet/Socket (**SEOS**)
4. SEOS Features and Case-Study
5. Discussions & Future Work

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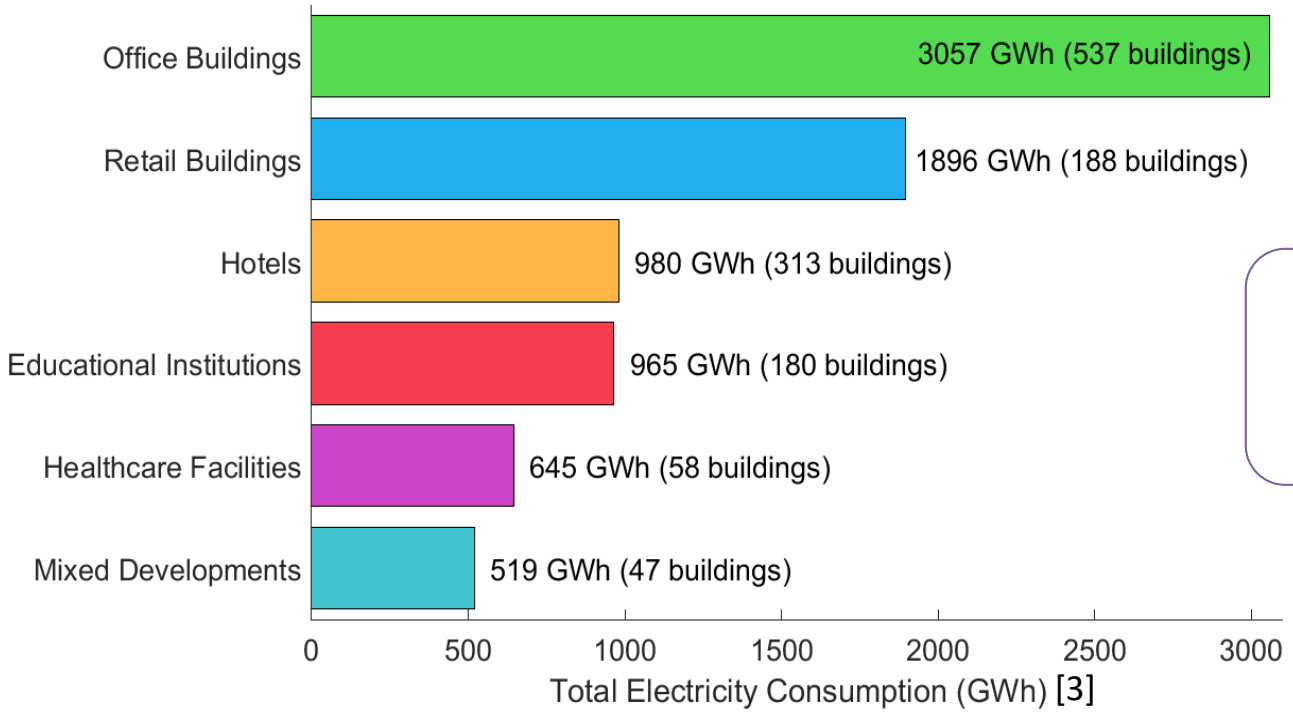
Background – Building Energy

The total electricity consumption in Singapore is nearly 50TWh (or 50 billion kWh units)[1]

Buildings account for more than one-third of the nation's total electricity consumption[2]



Households consumed 7,296 GWh in 2017

Total residential dwellings >1.3 million units

[1] Singapore Energy Statistics (2018), Energy Market Authority (EMA), Singapore. URL: https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Publications/ses/2018/energy-balances/index.html
[2] Super Low Energy Building Technology Roadmap (2018), Building and Construction Authority (BCA), Singapore. URL: https://www.bca.gov.sg/GreenMark/others/SLE_Tech_Roadmap.pdf
[3] Building Energy Benchmarking Report (2017), Building and Construction Authority (BCA), Singapore. URL: https://www.bca.gov.sg/BESS/BenchmarkingReport/BenchmarkingReport.aspx

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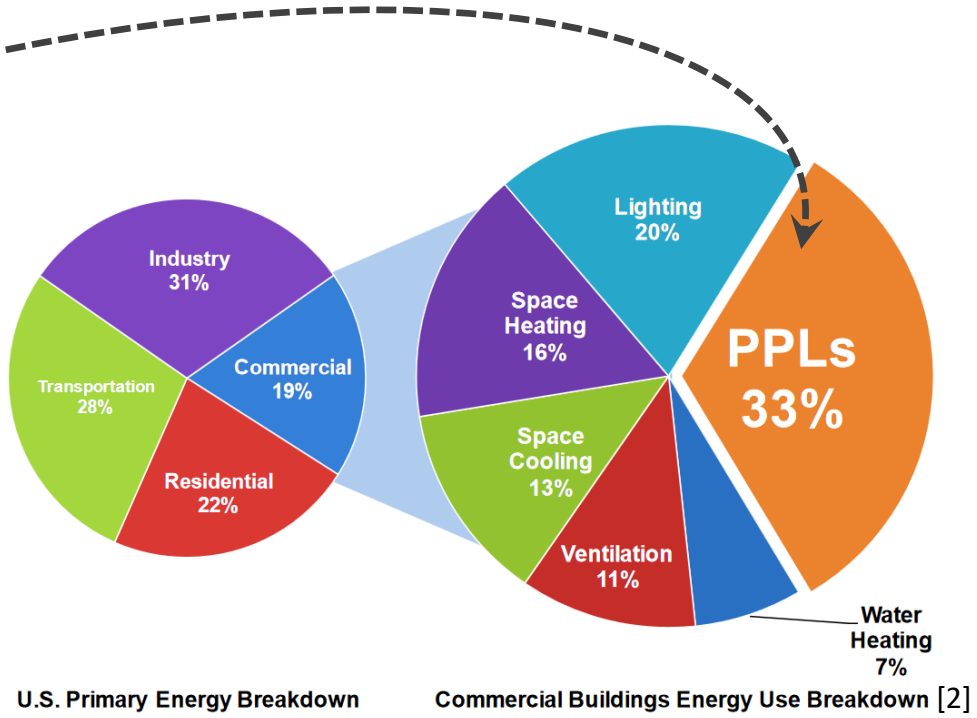
Background – Plug-Load Energy

Plug-loads are small, diverse, and scattered throughout buildings.

Difficult to manage!

Modern buildings spend around 25%-50% energy on plug-loads[1]



U.S. Primary Energy Breakdown

Commercial Buildings Energy Use Breakdown [2]

Example of Impact

Every year California's office plug-loads account for

- 3,000 GWh , $400 million
- 700,000 tonnes of CO_2
- ~= **140,000 cars**!

Plug and process loads (**PPLs**) account for 33% of U.S. commercial building electricity consumption.

[1] Bloom, Michael. "Plug Load Frequently Asked Questions (FAQ)", U.S. General Services Administration.
URL: https://www.gsa.gov/about-us/organization/office-of-governmentwide-policy/office-of-federal-highperformance-buildings/resource-library/energy-water/plug-load-frequently-asked-questions-faq#6

[2] Sheppy, M., C. Lobat, S. Pless, L. P. Gentile, and P. Torcellini. "Assessing and reducing plug and process loads in retail buildings." National Renewable Energy Laboratory (NREL) (2013).

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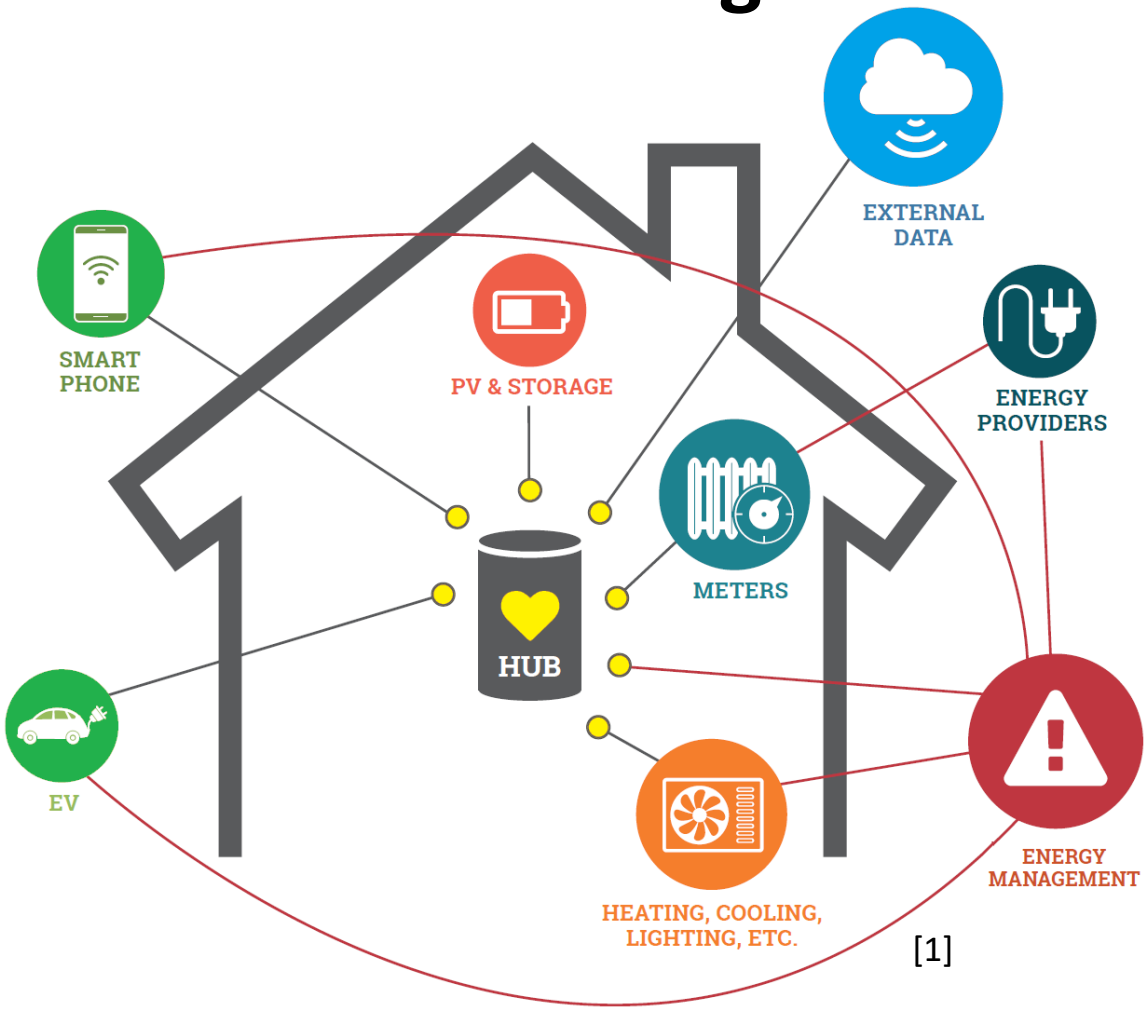
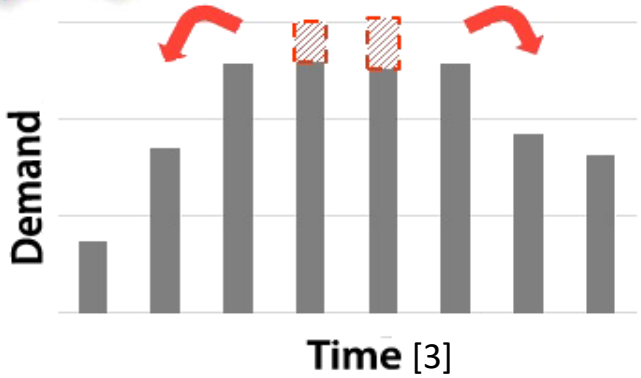
Background – Smart Grid & OEM



[1]

open electricity market | The Power to Choose

[2]



[3]

How to?

- Schedule your plug-loads
- Save energy & money
- Be electrically safe
- Be operationally secure

Demand Management for Smart Building-Grids

[1] Energy Efficiency Policy Brief (2018), International Energy Agency (IEA) URL: https://www.iea-4e.org/document/418/policy-brief-intelligent-efficiency-smart-homes
[2] Open Electricity Market. URL: https://www.openelectricitymarket.sg/home
[3] Demand Side Management, Energy Market Authority (EMA). URL: https://www.ema.gov.sg/Demand_Side_Management.aspx

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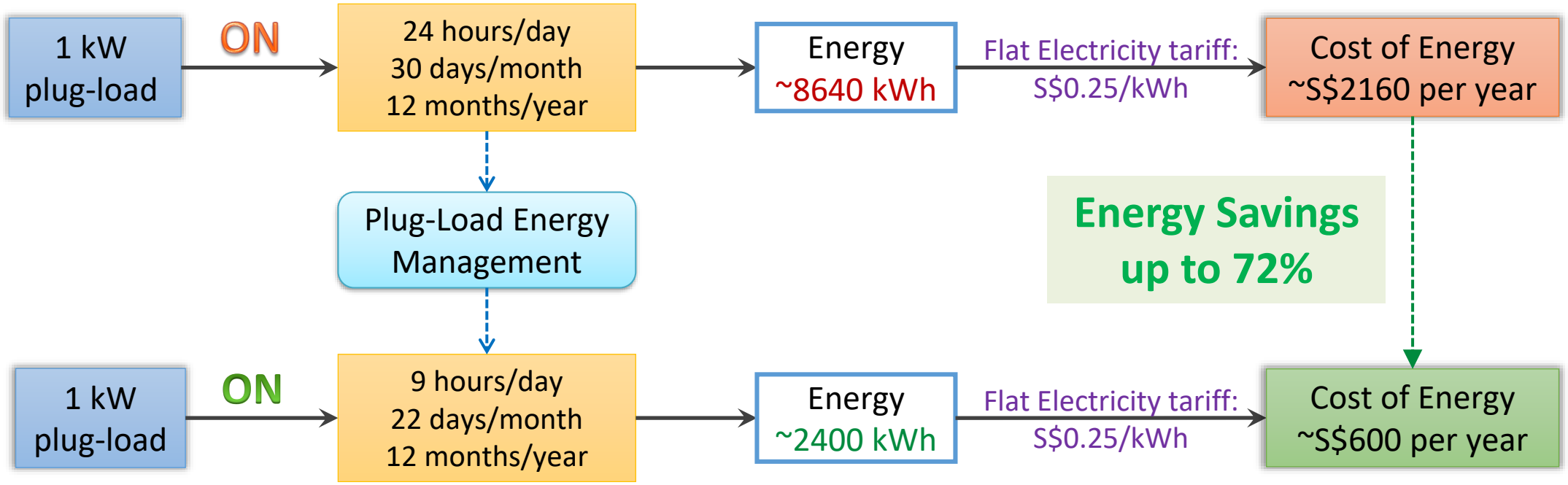
Potential Energy & Cost Savings

In an office space or an educational campus or commercial building, many plug-loads are always ON.
Ex: vending machines, water coolers, plugged-in refrigeration, packaged terminal air conditioners,…



Max. Cost Savings Potential could be **>72%**,
considering Demand Management and Open Electricity Market (OEM).

(OEM ⇒ Energy plans with varying rates for electricity)

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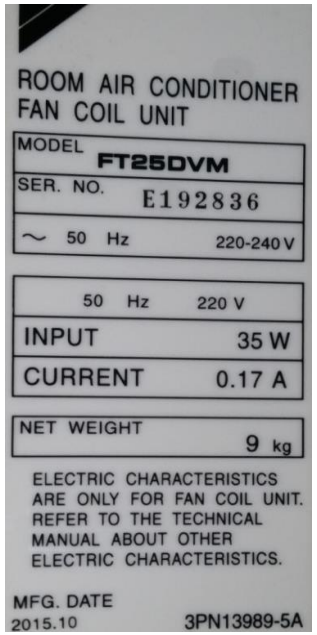
Plug-Loads & Smart-Plugs

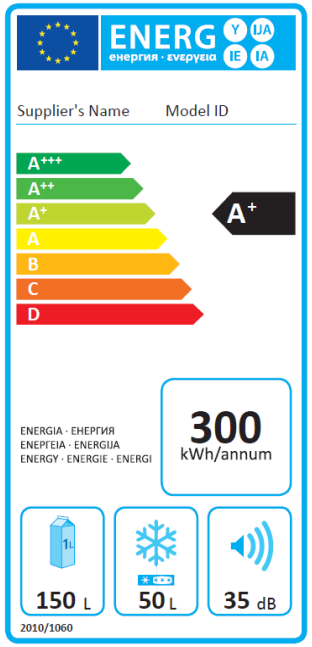


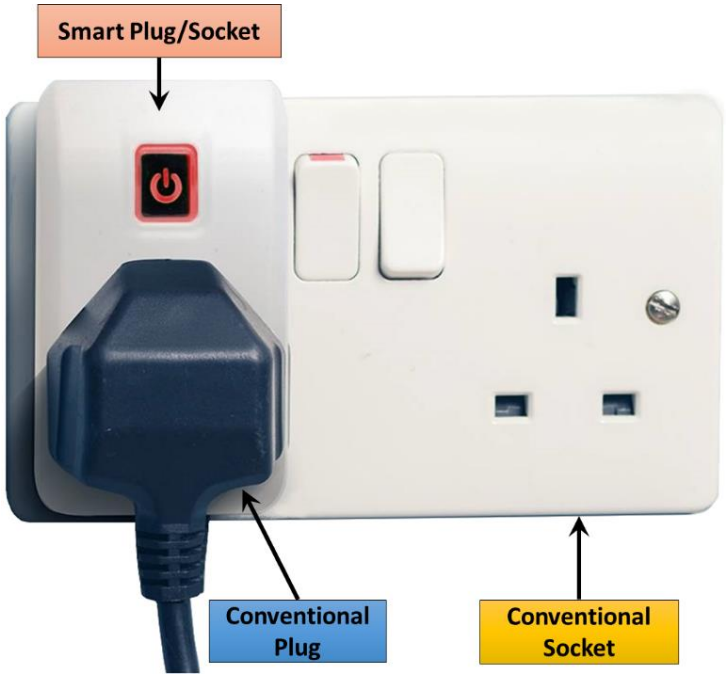
Plug-loads' Metadata

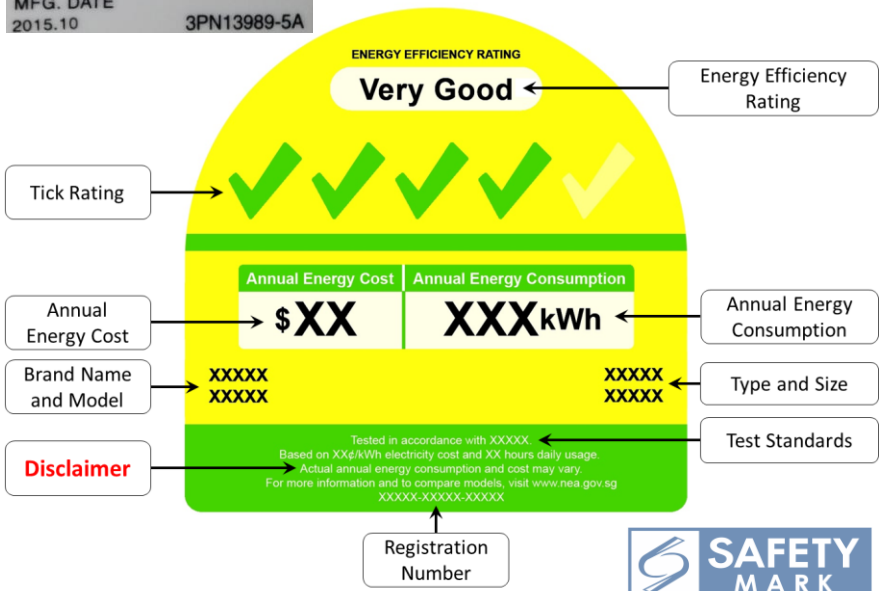
- Appliance Type
- Electrical Ratings
- Energy Label
- Ownership, Location
- Cost, Warranty
- Safety Mark, …

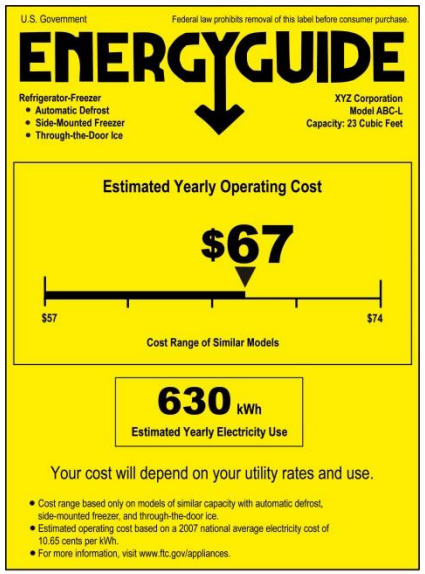
Real-time Data

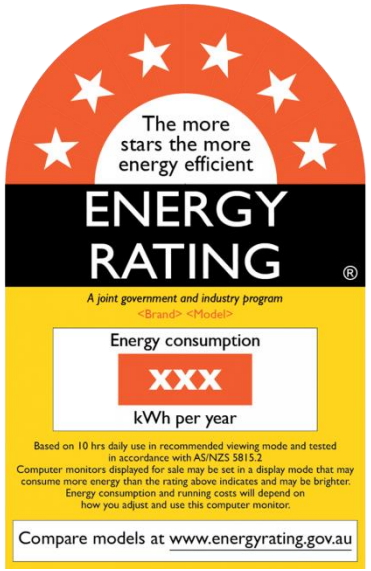
- Voltage/Current
- Energy/Power
- Cost of Energy
- Power-quality
- Plug-load status
- Carbon footprint, …











IEC Type G plug is common in Singapore.

They correspond to BS 1363 and has 13A rating.

Image Courtesy: Google Images, National Environment Agency (NEA), Enterprise Singapore (ESG)

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Existing “Smart” Plug Solutions

No existing “smart” plug or socket can access the useful metadata. Not smart enough!

SAMSUNG D-Link Building Networks for People belkin wemo

tp-link amazon plugwise

Sonoff Xiaomi ORVIBO

S → number of conventional sockets
P → number of smart plugs
A → number of appliances/plug-loads

Most commonly, *S ≥P and S ≥A*

The total states possible, *T=S.(P+1).(A+1)*
Only one of the states is correct.
Large space for configuration error: ***(T-1)***

Image Courtesy: Samsung SmartThings, Dlink, Belkin WEMO, TP-Link, Amazon, Pluwise, Sonoff, Xiaomi, Orvibo, and Powertech

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Our Solution – Smart Electrical Outlet/Socket (SEOS)

Local System (i.e. a building or a floor)

SEOS Features
- ✓Instant Plug-Load Identification
- ✓Electrical Measurements
- ✓Real-time Processing (edge-analytics)
- ✓Relay Control (on/off)
- ✓Wireless Communication

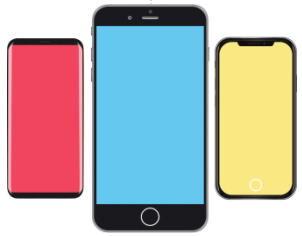
Plug-Load

ID
(Cost < 30 cents)

Local SEOS Server

Router

Wi-Fi, 2.4 GHz

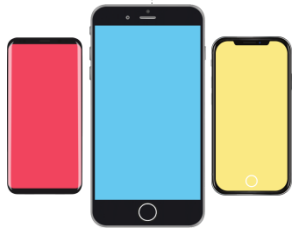


Mobile devices or computers

Internet

Cloud/
Remote Server

Internet



Mobile devices
or computers

Unique ID → Plug-load's Live Digital Profile → Metadata, Real-time Data

Analogy

facebook profile
+
fitbit profile

Image Courtesy: Google Images

+ Patent Pending
Application No. PCT/SG2019/050066

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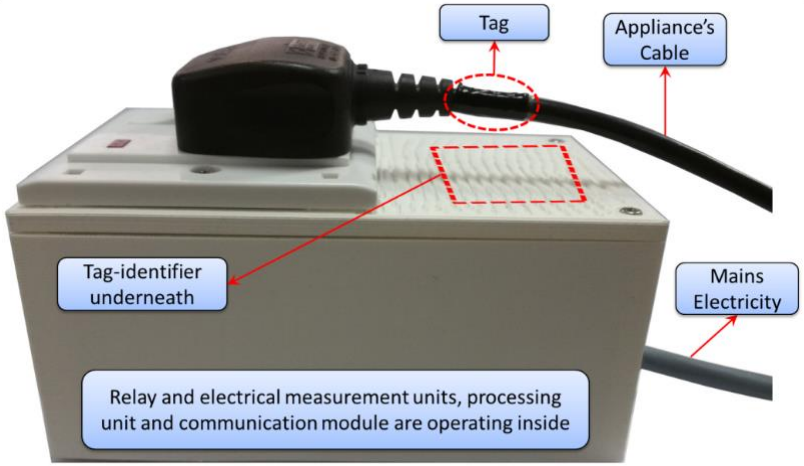
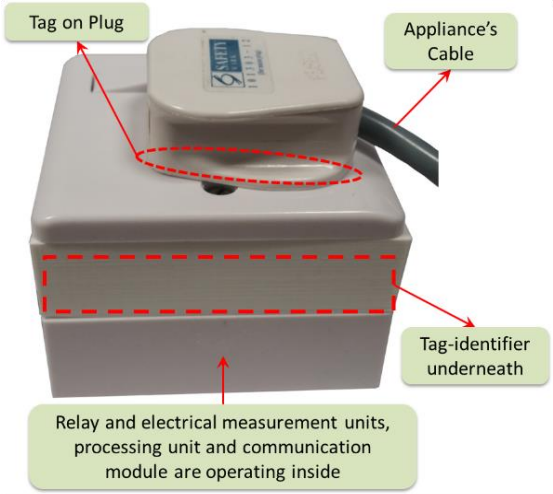
SEOS – Prototypes (IEC Type G plug, BS 1363)

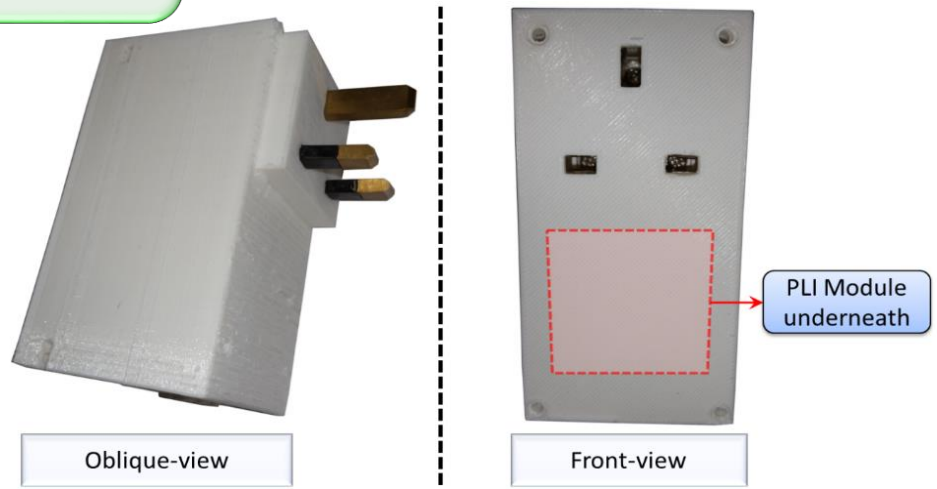
Wall Socket – Version1



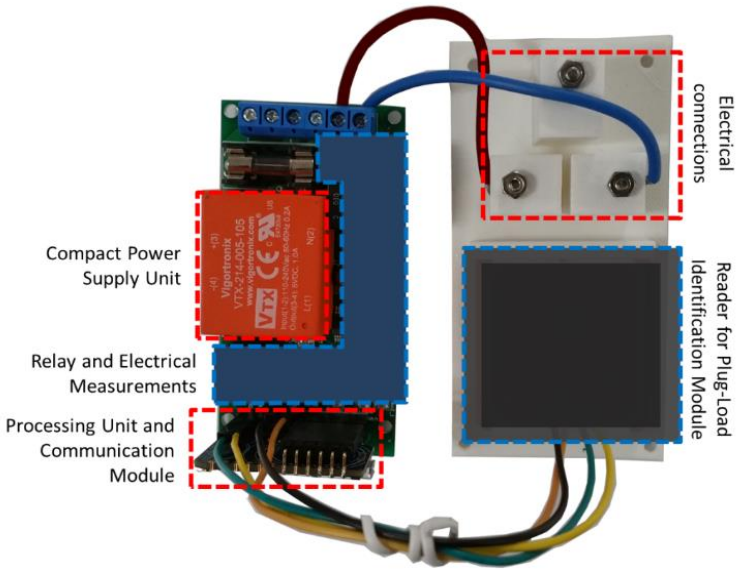
Wall Socket – Version2



Portable Socket – Version1



Portable Socket – Version1 (inside)



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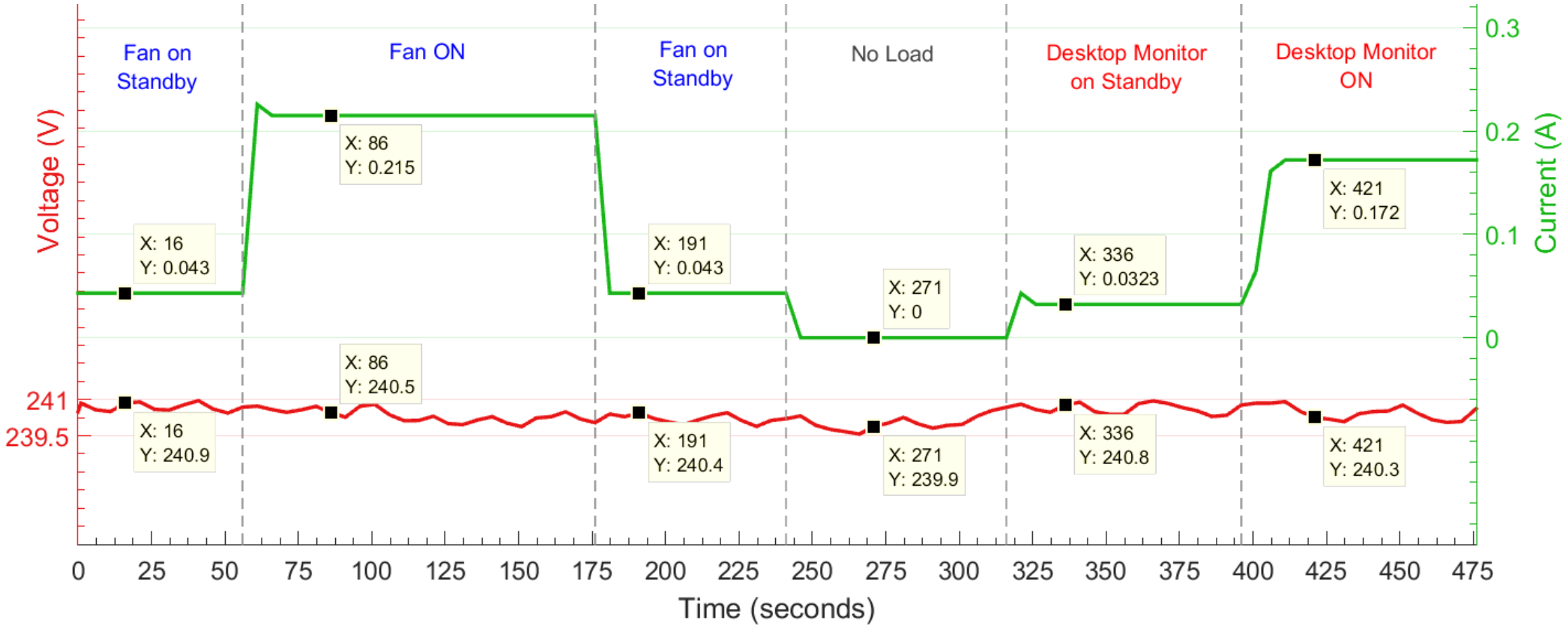
SEOS Features



Plug-Load state identification using SEOS

A stand fan and an LCD desktop monitor were connected to a hardware unit of SEOS one after another. Corresponding voltages and currents are shown.

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SEOS Features

Socket On/Off Information

SEOS Info | Log | About

☐ Enable TTS

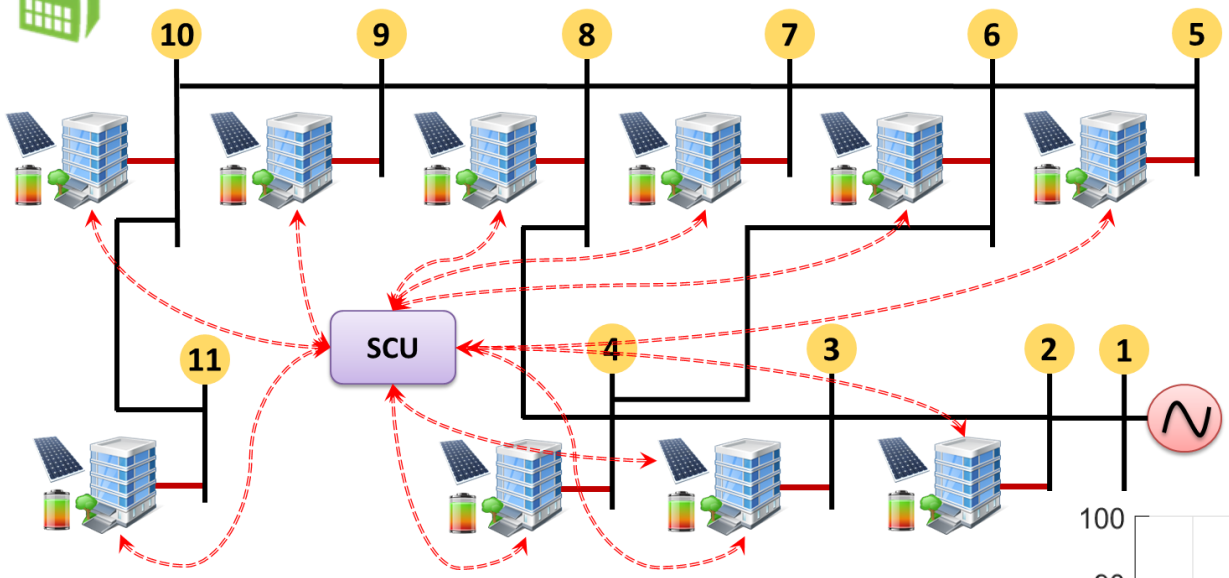
SEOS Hardware	STATUS	Appliance	Details	Voltage	Current	Active Power	Energy	Cost	TIME	DATE
SS-1	ON	**Dell Laptop**	RATING: 230 V, 130 W Asset No.: 8263013706-0-D1 Price: S$ 1,899.00 Owner: Dr. Chinh E-mail: hoangducchinh@nus.edu.sg Handphone: HIDDEN [Request Contact]	239.98 V	0.21 A	50.4 W	864.6 Wh	0.07 SGD	02:15:07 AM	1/16/2018
SS-2	ON	**Fujitsu Laptop**	RATING: 230 V, 41 W Owner: Unknown Remarks: Server Running	239.75 V	0.16 A	38.36 W	321.48 Wh	0.07 SGD	02:15:07 AM	1/16/2018
SS-3	OFF	**MicroLabBox**	RATING: 230 V, 125 W In-Charge: Prof. S.K. Panda Price: S$ 16,000.00 URL: https://www.dspace.com/en/pub/home/products/hw/microlabbox.cfm	240.04 V	0.44 A	105.62 W	968.42 Wh	0.19 SGD	02:13:31 AM	1/16/2018
SS-4	ON	**Custom Load-box**	RATING: 230 V, Variable [0-2400] W Owner: Krish E-mail: krish@nus.edu.sg Full-Pofile: **9e7dfe91-583b-4a70-93e8-135f-2eec30d6.json**	239.93 V	4.64 A	1113.28 W	923.3 Wh	0.2 SGD	02:15:12 AM	1/16/2018

Sample Metadata

Sample Real-time Data

Screenshot of a GUI capturing real-time information on plug-loads connected to multiple SEOS hardware.

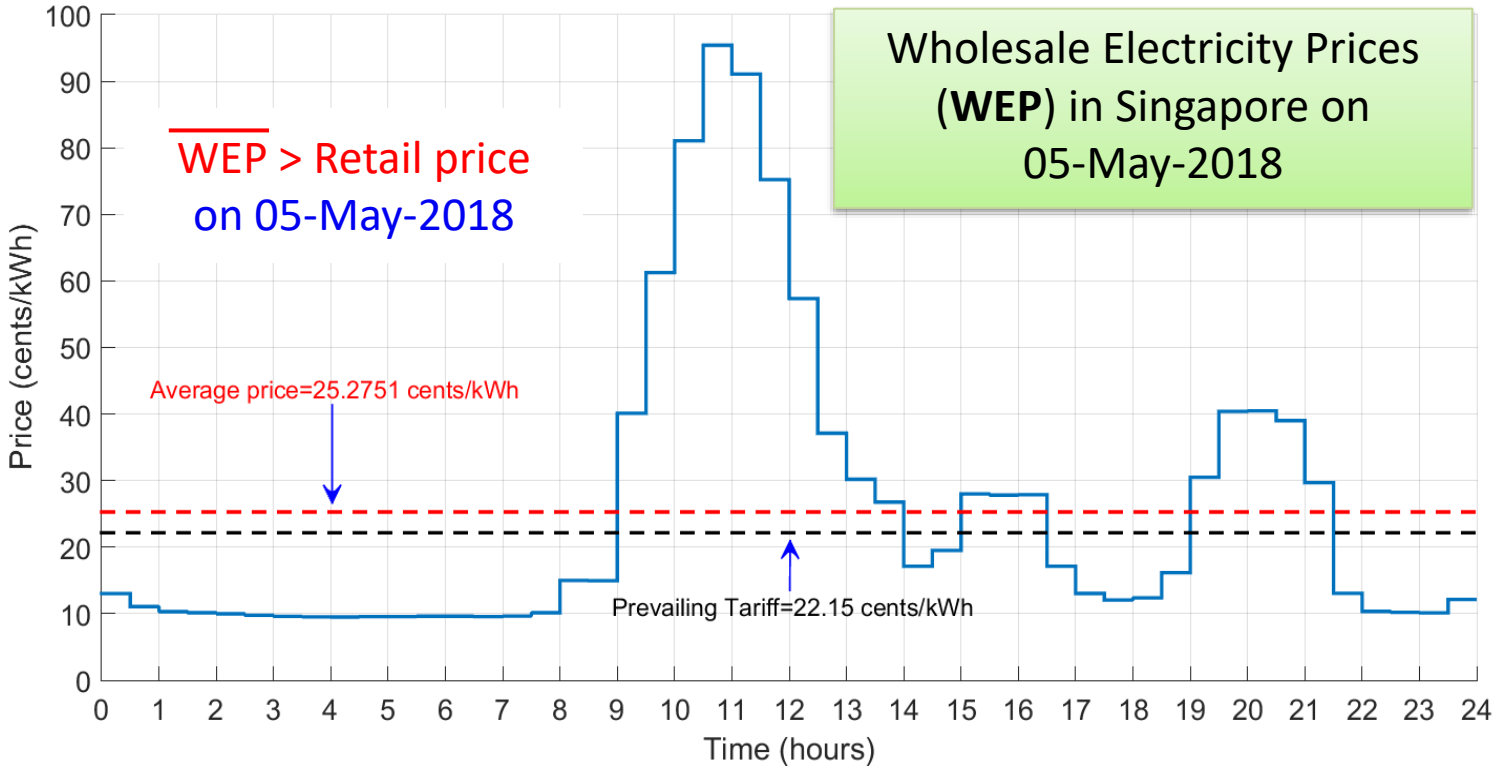
Case Study – Scheduling for n-Building-grids



11-Node Test-system of 10 Prosumer Buildings

Differential Evolution (**DE**) algorithm has been used to schedule 10-20 plug-loads to minimize cost of operation, under power constraints.

Load scheduler must also check for voltage violations of building cluster to ensure power-quality of supply.



Wholesale Electricity Prices (**WEP**) in Singapore on 05-May-2018

A cost reduction of 30%-35% has been achieved in the cases within the study, despite the increase in WEP.

Node voltages have been checked to be within ±5% limits using Holomorphic Embedded Power-Flow (**HEPF**) algorithm.

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Discussions

- ✓ An innovative plug-load management solution (SEOS) has been presented for future buildings, to realize Responsive Building-grids.
- ✓ SEOS configuration enables access of metadata and real-time data of plug-loads, leading to many digitalized services.
- ✓ SEOS facilitates high-fidelity Demand Side Management (DSM), and ideally must operate based on power-flow information so as to maintain power-quality.
- ✓ Other than DSM, SEOS solution holds potential for:

Asset Management (real-time inventory)

Customized Electrical Safety (limit currents)

Access Management (allow/disallow plug-loads)

Grid Services (demand response)

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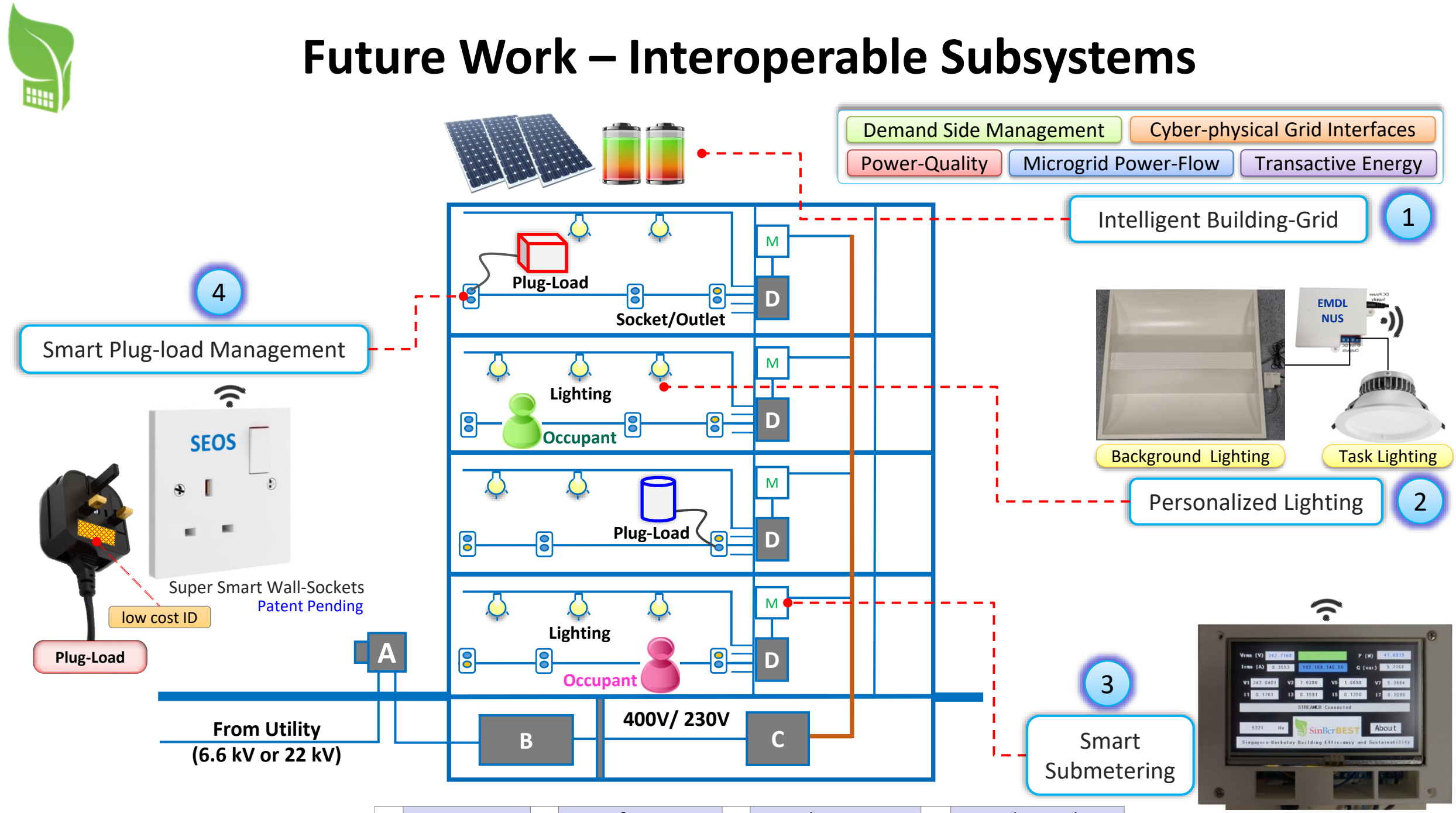
Future Work – Interoperable Subsystems



A	Meter	**B**	Transformer	**C**	Switch Gear	**D**	Branch Panel

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APPENDIX – Spin-off Company – ENBED Pte. Ltd.

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ENBED
Energy Embedding
Information . Intelligence . Insight

- Plug-load identification
- Remote control of loads
- Load-specific safety
- Access management & Security
- Energy Management & Statistics
- Real-time metrics & Analytics
- Plug-load asset tracking
- Smart Scheduling

Image Courtesy: Google Images

NUS GRIP
GRADUATE RESEARCH INNOVATION PROGRAMME

Funding up to S$100,000 Secured

Feature	Value
Operating Voltage	220V – 240V
Operating Frequency	50Hz
Maximum Current	13A
Maximum Power	3200W
Metering Accuracy	Class 1, IEC 62053-21
length x breadth x depth	86mm x 86mm x 35mm
Standards	IEC-61508, BS-1363, SS-145
Communication Protocol Used	Wi-Fi 2.4GHz
Supported App Platforms	Android >=4.4 iOS >=8, >=Win7
Physical Configurations	• Wall-socket/fixed • Smart-plug/portable

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APPENDIX – SEOS Feature Comparison

	FEATURES FOR COMPARISON	TYPICAL SOCKET	MOST COMMERCIAL SMART PLUGS	SEOS WALL-SOCKET	SEOS PORTABLE-SOCKET
1	Electrical connectivity to the appliance	✓	✓	✓	✓
2	Fuse-based protection or current limiting protection	-	✓	✓	✓
3	Physical security (not easily displaceable)	✓	-	✓	-
4	Remote ON/OFF control of the socket	-	✓	✓	✓
5	Measurement of energy consumption	-	✓	✓	✓
6	Real-time voltage, current, active & reactive powers	-	Optional	✓	✓
7	Recording/display of electrical measurements and analysis	-	Optional	✓	✓
8	Monitoring of power-quality information and anomalies	-	-	✓	✓
9	Plug-load specific customization of protection	-	-	✓	✓
10	Automated identification of appliances	-	-	✓	✓
11	Automated, real-time and online appliance list	-	-	✓	✓
12	Automated locating of appliances	-	-	✓	-
13	Automated appliance authentication (**Building Firewall**)	-	-	✓	Optional
14	Act as realistic infrastructure for **smart-grid** applications (scheduling, optimization, accurate item-wise billing, auditing)	-	-	✓	Optional

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