

# Energy Efficiency in Smart Buildings through IoT Sensor Integration



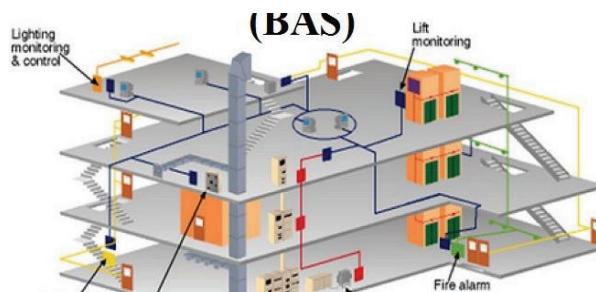
**Keynote Speech**  
**Prof. Saifur Rahman**  
Director, Virginia Tech Advanced Research Inst., USA  
2022 IEEE President-elect

Malaviya National Inst of Tech  
27 May 2022, Jaipur, India





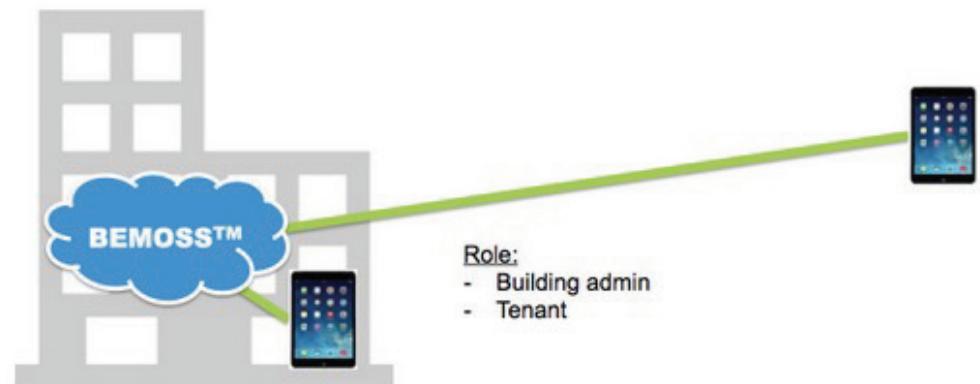
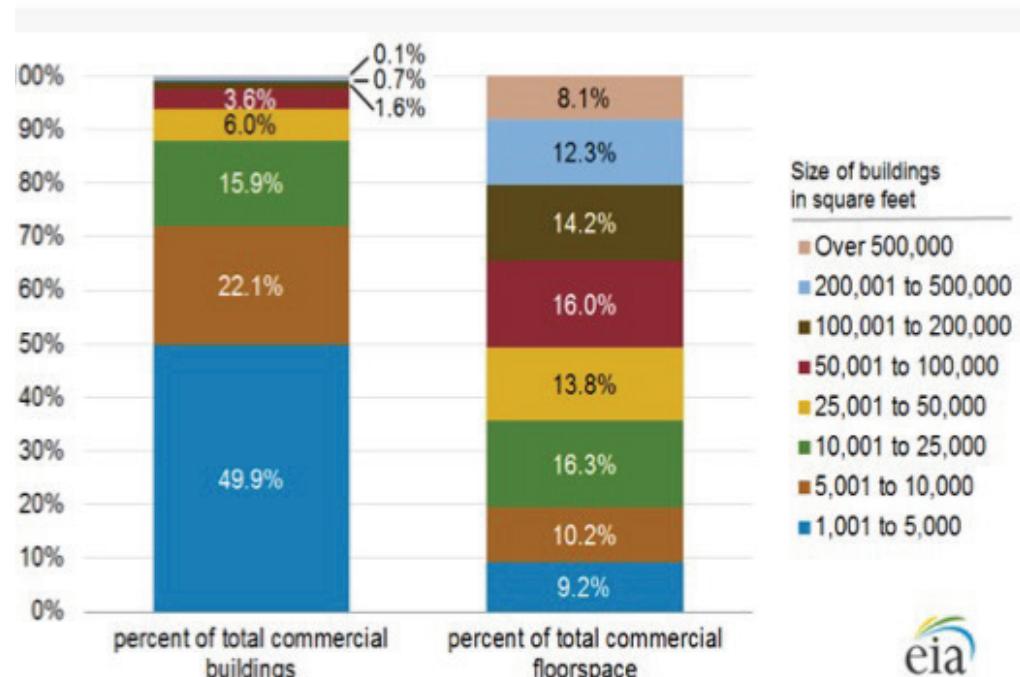
# Purpose & Objectives



- Buildings consume over 40% of the total energy consumption in the U.S. Over 90% of the buildings in the U.S. are either small-sized (<500 square met.) or medium-sized (between 500 sqm and 5,000 sqm).
- These buildings typically do not use Building Automation Systems (BAS) to monitor and control their building systems from a central location.
- **Need to** facilitate energy efficiency applications in commercial buildings using a very simple and scalable building automation system (BAS).

# Targeted Buildings & Loads

- With respect to load types, there are **three major loads** in commercial buildings: **HVAC, lighting and plug loads**.
  - According to the data from EIA published in 2008, electricity use by **HVAC** equipment, i.e., space heating, cooling and ventilation accounts for **30% of the total electricity consumption** in buildings.
  - Lighting loads** constitute the majority share of electricity use at **38%**.
  - Electricity use by **plug loads**, i.e., office equipment, computers, etc. accounts for **6% of total electricity use** in buildings.
  - Other loads include water heating, refrigeration, elevators, etc.
- The figure below illustrates electricity use in buildings by load type.



# An Open Architecture Platform for Building Energy Efficiency

**BEMOSS** ➤ It is a Building Energy Management Open Source Software solution that is engineered to improve sensing and control of all IoT-enabled equipment in commercial buildings

## Monitoring & Control

### Three major loads in buildings

- Heating, Ventilation, AC
- Lighting loads
- Plug loads

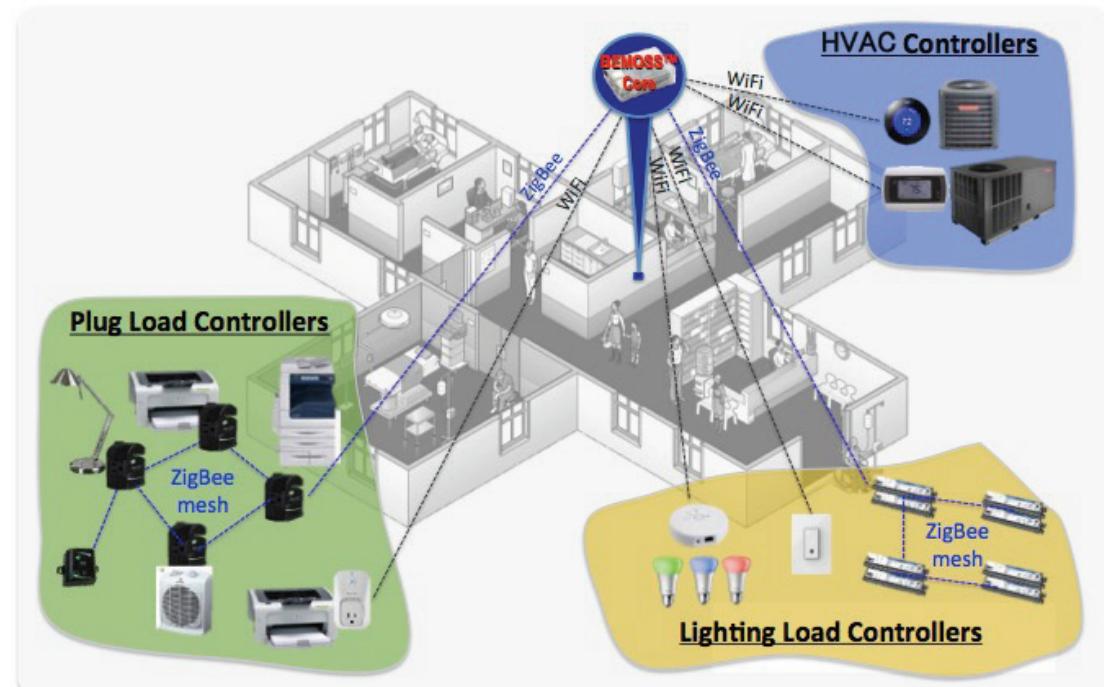
### Value

➤ Improves energy efficiency and facilitates peak load savings in commercial buildings.



# Architecture (Small Commercial Building )

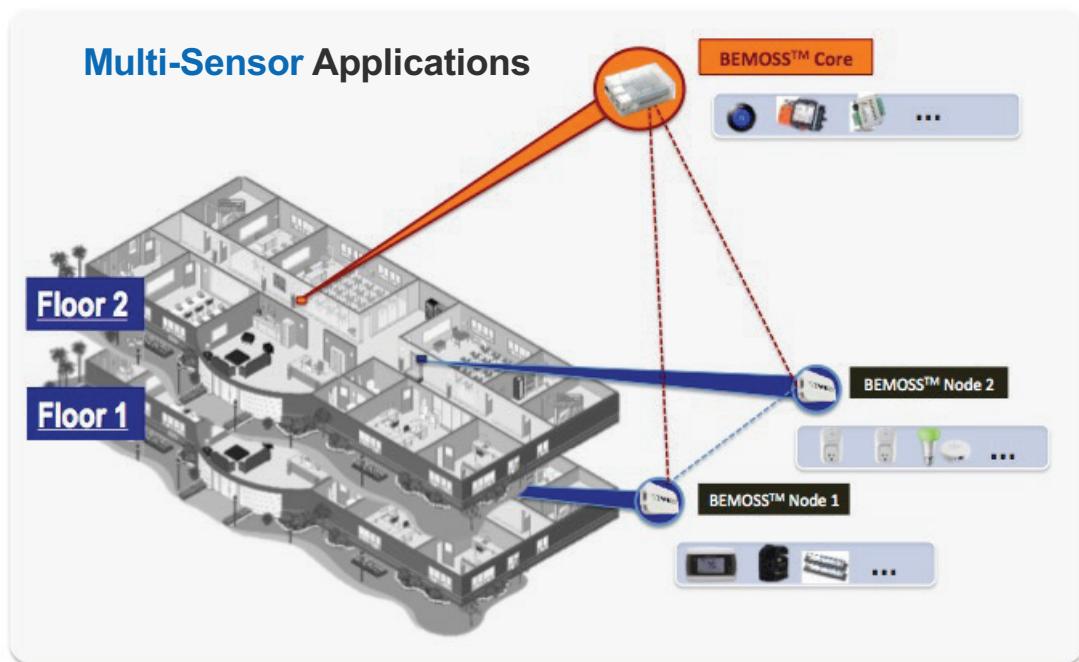
- The BEMOSS™ architecture for a small commercial building with a few load controllers of each type.
- In this architecture, only **one single-board computer** (e.g., Odroid) embedded with the BEMOSS™ software platform is used to enable monitoring and control features of all load controllers in the building.
- This embedded system can **communicate** with different types of load controllers, i.e., thermostats, lighting load controllers, plug load controllers and sensors/power meters via wireless signals (either Wi-Fi or ZigBee).
- Local and remote monitoring and control via a smart phone or a tablet are also enabled.



BEMOSS™ system architecture for **small** buildings  
with a few load controllers

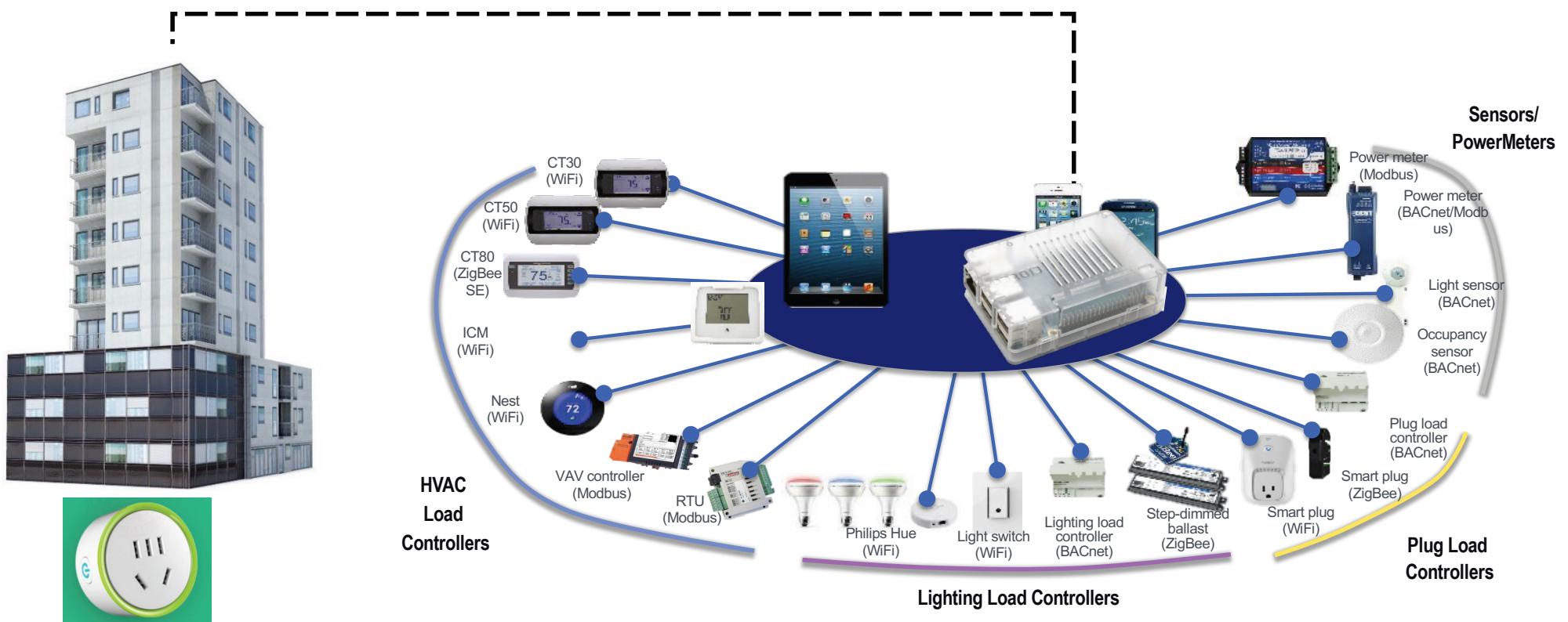
# Architecture (Multi-Floor Building)

- For multi-floor buildings with larger number of devices, BEMOSS™ can be set up to deploy its multi-layer architecture feature.
- In this architecture, a BEMOSS™ node is responsible for monitoring and control devices on one floor.
- Each BEMOSS™ node communicates with each other and also communicates with the BEMOSS™ Core.
- The BEMOSS™ Core is responsible for supervising the overall system operation, managing multiple BEMOSS™ nodes, and allowing local and remote access for monitoring and control of all devices in buildings.



BEMOSS™ system architecture for **larger** buildings

# Supports multiple IoT devices through industry standard protocols and communications technologies



# Multiple-protocol Interoperability

## Communication Technologies

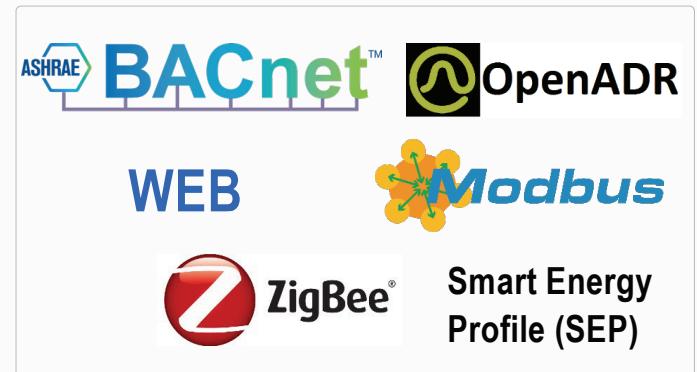
- ✓ Ethernet (IEEE 802.3)
- ✓ Serial Interface (RS-485)
- ✓ ZigBee (IEEE 802.15.4)
- ✓ WiFi (IEEE 802.11)



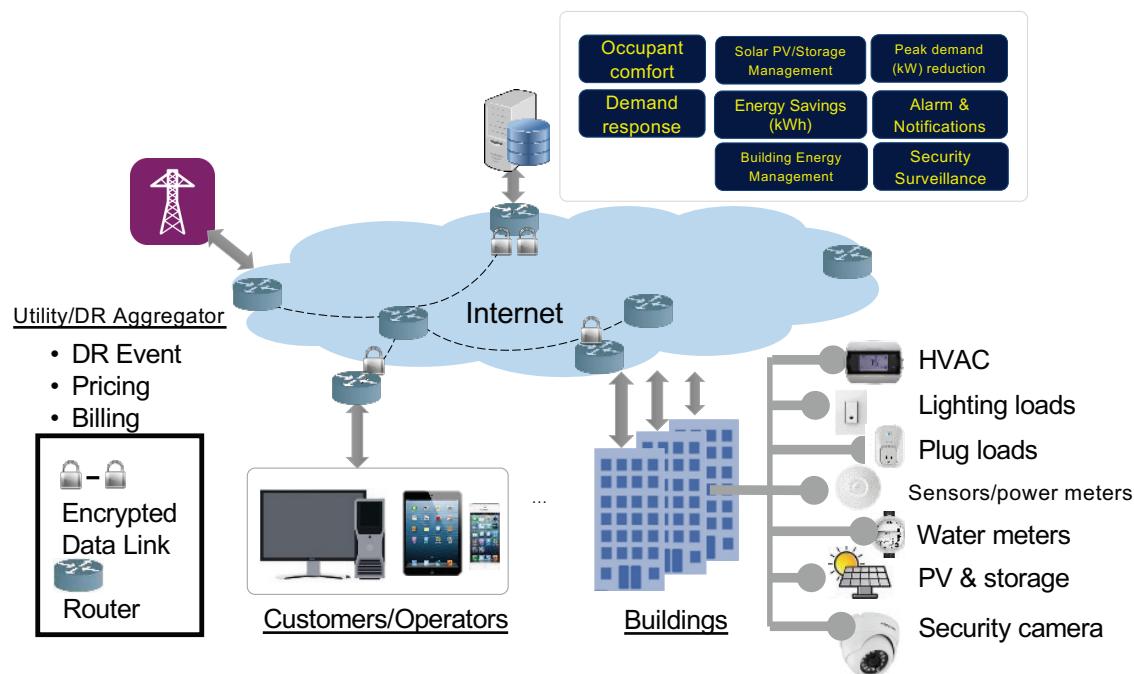
IOT

## Data Exchange Protocols

- ✓ BACnet (IP and MS/TP)
- ✓ Modbus (RTU and TCP)
- ✓ Web (e.g., XML, JSON, RSS/Atom)
- ✓ ZigBee API
- ✓ Smart Energy (SE)
- ✓ OpenADR (Open Automated Demand Response)

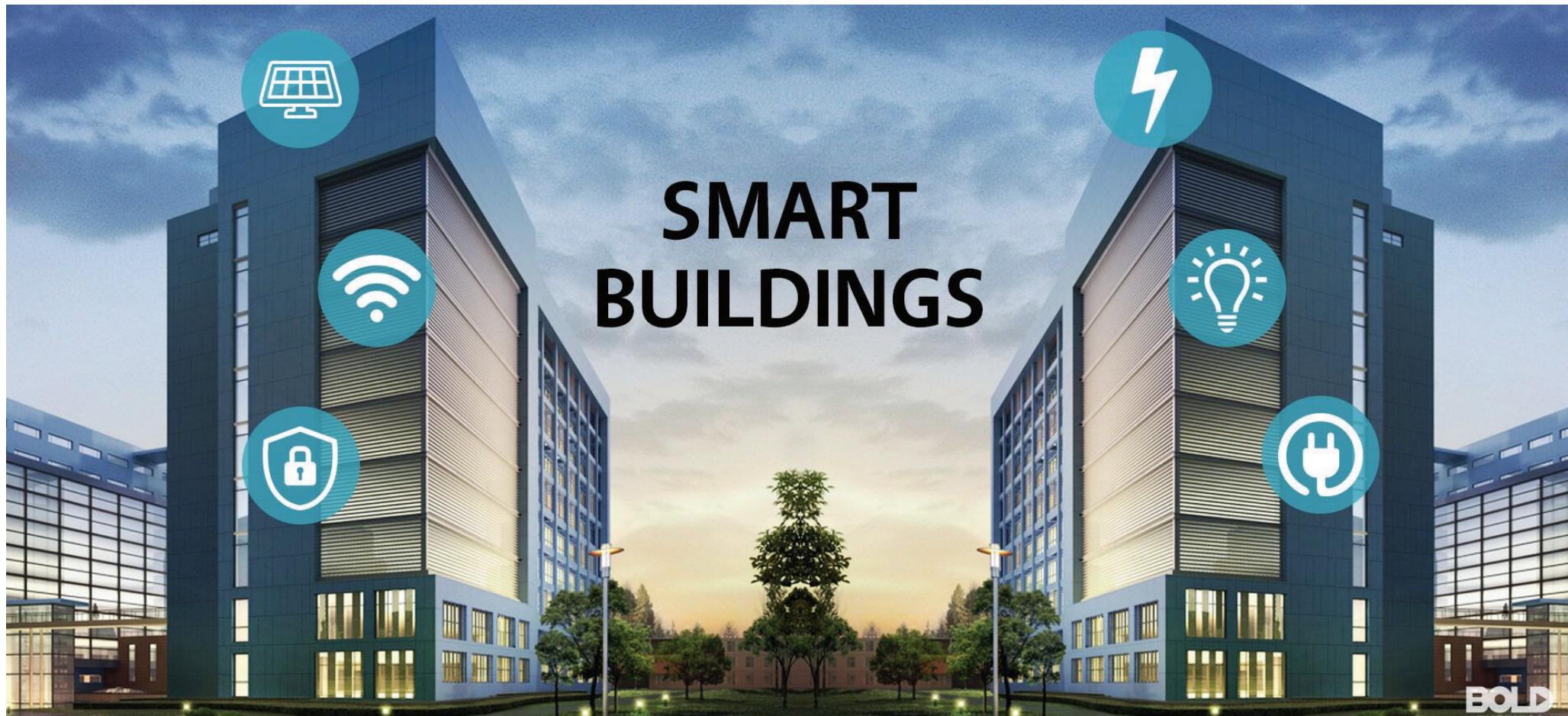


# Campus-wide Application



[www.bemconrtols.com](http://www.bemconrtols.com)

# How to make an old building smart



# Customers Controlling Buildings Optimized for Savings



Measured energy savings across deployments



**Improved operations and maintenance:** The building automation system (BAS) analytical platform enables operators to detect faults when devices operate outside standard thresholds enabling building operators to investigate prior to device failure.

**Occupant satisfaction:** spaces controlled by BAS have been more comfortable due to more consistent temperature profiles and healthier air quality through consistent monitoring of environmental factors (CO<sub>2</sub> levels, PM 2.5).

# Sample Examples

## Building 1

### VT Classroom Building

- Location: [Alexandria, VA](#)
- Demonstration: HVAC, plug load control



## Building 2

### Equipment Bureau Building

- Location: [Arlington, VA](#)
- Demonstration: Lighting control



## Building 3

### VT Lab Building

- Location: [Blacksburg, VA](#)
- Demonstration: HVAC control



## Building 4

### PG County Community Building

- Location: [Camp Springs, MD](#)
- Demonstration: HVAC control



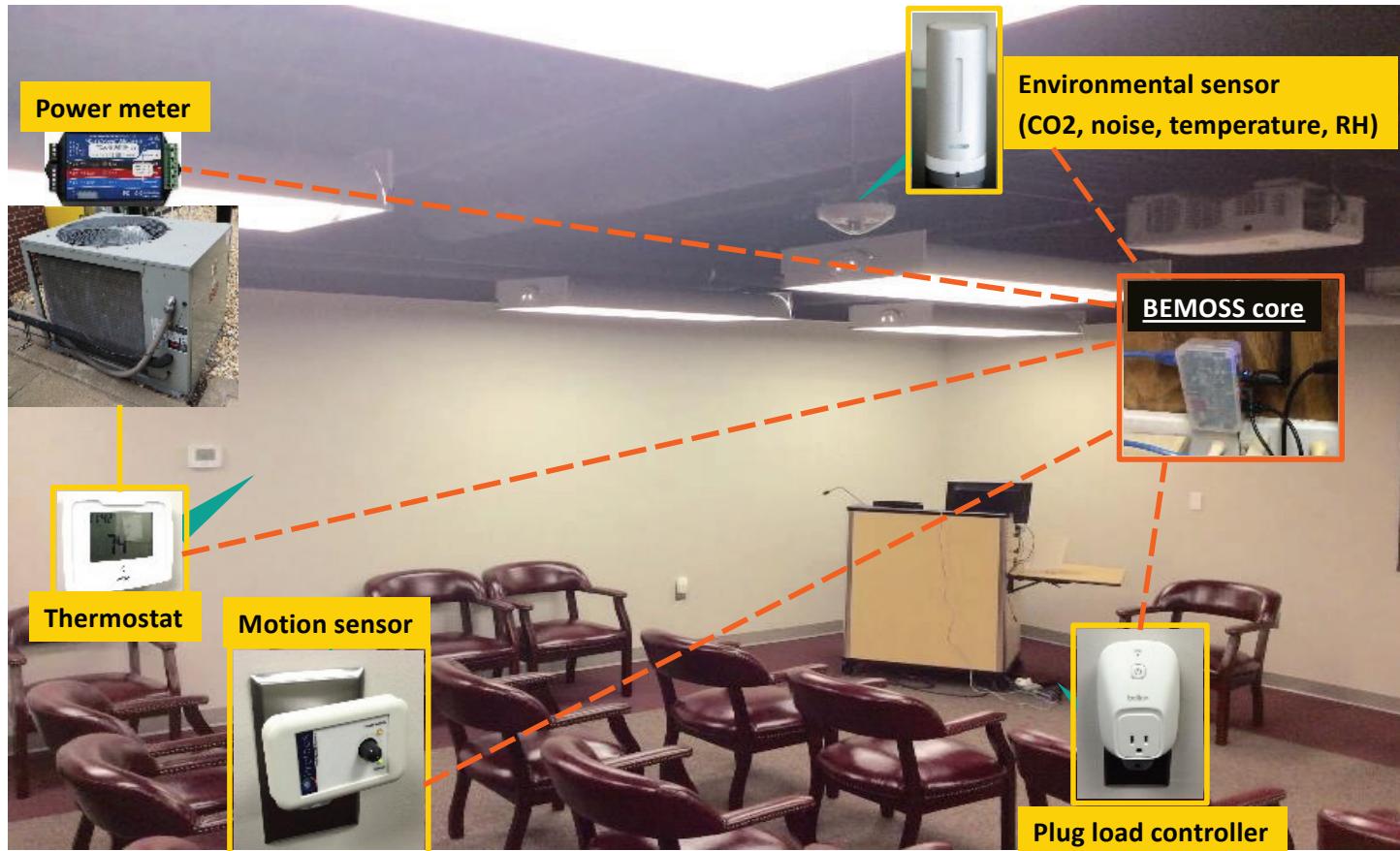
# **Building 1 – VT Building in Alexandria, VA**

Area: 2500 sqm  
Energy: 14-25 MWh/mo.  
Peak load: 61 kW

**Alexandria,  
Virginia, USA**



# Classroom Under Real-time Monitoring



# Indoor Environmental Monitoring

The screenshot displays the Bemoss Core interface for monitoring environmental data. On the left, there's a sidebar with navigation links: HOME, DISCOVER NEW DEVICES, DISCOVER/MANAGE (with 6 items), NETWORK STATUS, ALARMS & NOTIFICATIONS, MANAGE USERS (with 1 item), and MISC SETTINGS. Below the sidebar is a photograph of a multi-story brick building.

The main content area shows the title "Bemoss Core : Weather\_Sensor21". It is divided into two main sections: "Indoor Environment Status" and "Outdoor Environment Status".

**Indoor Environment Status:**

- TEMPERATURE: 71.4 °F
- HUMIDITY: 22.0 %
- PRESSURE: 30.65 Pa
- CO2: 484.0 ppm
- NOISE: 47.0 db
- MUM RECORDED TEMPERATURE: 73.8 °F (Date Recorded: Thu, 23 Mar 2017)
- MINIMUM RECORDED TEMPERATURE: 71.4 °F (Date Recorded: Thu, 23 Mar 2017 at 08:36)

**Outdoor Environment Status:**

- TEMPERATURE: 74.3 °F
- HUMIDITY: 49.0 %
- MAXIMUM RECORDED TEMPERATURE: 74.3 °F (Date Recorded: Wed, 15 Jun 2016)
- MINIMUM RECORDED TEMPERATURE: 74.3 °F (Date Recorded: Wed, 15 Jun 2016)

A blue arrow points from the "CO2" value in the Indoor Environment Status section to the "Weather\_Sensor21 : CO2" graph below.

**Graph:** Weather\_Sensor21 : CO2

The graph plots CO2 concentration (ppm) over time (from 03/22/17 to 03/23/17). The CO2 level starts around 500 ppm, rises to a peak of about 1100 ppm around 03/22, 19:35, and then gradually declines to approximately 500 ppm by 03/23, 09:15.

# Energy and Peak Savings from HVAC Control

**Location:** Alexandria, VA  
**Area:** 2,500 square meter  
**Deployed Devices**

- 6 Thermostats
- 6 Power meters
- 1 Li-ion battery
- 1 Environmental sensor

**Using BAS, Building Operator saved 27% on HVAC consumption alone**

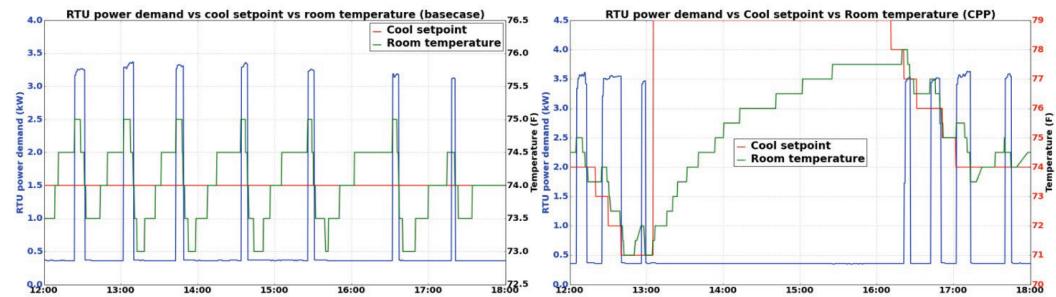
**Summer Months  
(June-July-August)**

Compressor consumption 2014 (Before BAS)	8,340 kWh
<b>Compressor consumption 2016 (After BAS)</b>	6,071 kWh
Average savings	<b>26.8% savings</b>



Temperature profile **BEFORE**  
BAS Demand Reduction

Temperature profile **AFTER**  
BAS Demand Reduction



## Base case (w/o WiseBldg)

- Setpoint: 74 deg F
- Energy usage = 2.72kWh
- Max demand = 3.98kW

## Managed by WiseBldg

- Setpoint: 77 deg F
- Energy usage = 1.42kWh
- Max demand = 0.5kW

# Office Building, Arlington, Virginia



**Office building size: 5,000 sqft**

## Energy Savings from Lighting Control



**Location:** Arlington, VA

**Area:** 5,000 sq ft

**Deployed Devices**



- 3 Lighting controllers
- 1 Power meter

An Average Energy Savings Of 35% Was Achieved Through Dimming Control

Oct 2016	Nov 2016	Dec 2016	Jan 2017	Feb 2017	Mar 2017	Apr 2017	May 2017	Jun 2017	AVERAGE
33.7%	33.9%	34.4%	33.4%	35.9%	36.2%	35.0%	36.0%	36.3%	34.5%

# Energy Savings By Controlling Light Intensity

Month	Total Measured Energy Consumption (kWh)	Total Calculated Energy Consumption without Dimming (kWh)	Energy Savings by Dimming (%)
October 2016	264.37	399.90	33.89%
November 2016	278.13	423.78	34.37%
December 2016	280.76	426.40	34.16%
Total (October-December)	823.26	1250.08	34.14%



Note: Scheduled dimming level from 6:30am to 9:00pm. Open office area A: 50%; Open office area B: 45%; Chief office's desk area: 60%; Chief office's meeting area: 50%; Conference room A: 50%; Conference room B: 45%. Lights are off after 9:00pm.

# Solar PV System Monitoring and Control



# DER Devices

## (Rooftop Solar)



**BEMOSS**

main : Rooftop\_Solar

**Power**

INCIDENT	DC	AC
23178.96 W	3479.78 W	3378.0 W

**Efficiency**

PANEL	INVERTER
15.01 %	97.08 %

**Voltage**

DC	AC
398.6 V	209.1 V

**Current**

DC	AC
8.73 A	16.16 A

**Energy**

TOTAL	TODAY
42.93 MWh	15.45 kWh

**Irradiance**

567.0 W/m <sup>2</sup>
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**Temperature**

AMBIENT	MODULE
68.0 °F	74.0 °F

**Wind Velocity**

0.0 m/s
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**CO2 Saved**

66534.97 lbs
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**Power Factor**

0.98
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**HOME: DER DEVICES**

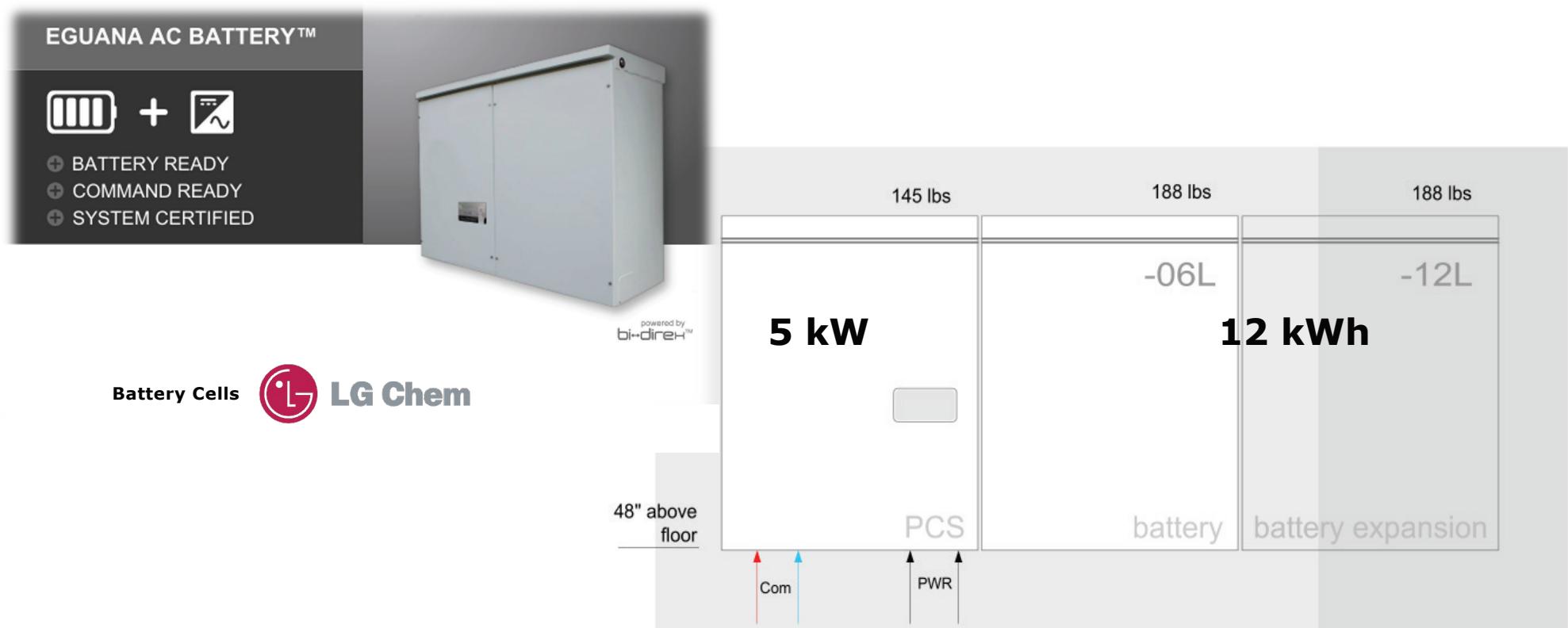
**Der Controllers**

ROOFTOP\_SOLAR

W  
3378.0

Vac : 209.1  
ONLINE

# Managing Battery Storage



# Battery Storage Setup



# Battery Storage Monitoring & Control

The screenshot shows the BEMOSS web interface for monitoring battery storage. The top navigation bar includes the BEMOSS logo, user status (Admin), and a log out option. A red notification badge with the number 4 is visible above the Admin link. The main title "Tumalow Energy Ingenuity : Battery\_Storage3" is displayed. The interface is divided into several sections:

- BATTERY STORAGE**: A large section containing:
  - CURRENT STATUS**: Shows a green battery icon.
  - ACTIVE**: Status indicator.
  - View Past Values**: A button.
- CURRENT READINGS**: Two sub-sections:
  - STATE OF CHARGE**: Shows 98.9 %.
  - OUTPUT POWER**: Shows -0.013 kW.
  - CHARGING**: Status indicator.

[www.srahman.org](http://www.srahman.org)



Thank You