CBE Vertical Temperature Gradient Model |
Localization with Transfer Kernel Learning |
Breathing Façades |
Segmentation Analysis in Energy Game-Theoretic Frameworks |
Pulau Ubin Microgrid |

BUILDING in a *Briefcase*

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SinBerBEST

Building in a Briefcase (BiB): A Rapidly-Deployable Environmental Sensor Suite for the Smart Building

Costas Spanos, Weekly K.

Indoor environment monitoring and control plays an important role in the operation of a smart building. One of the main goal of a smart building is to ensure the safety and comfort of the occupants. Tailoring services such as Heating, Ventilation, and Air Conditioning (HVAC), lighting, and electrical power is key to save significant amount of energy consumed. Indeed, HVAC and lighting respectively comprise about 50% and 20% of the total energy use of buildings. In addition to environmental awareness, occupant-aware control schemes have been shown to save between 10–42%, depending on other factors (outdoor climate and control strategy). Having a more detailed view of building environment and its occupants opens the door to more energy savings as well as building services that are tailored to specific purposes and target groups.

SinBerBEST has developed a versatile demonstration tool that exploits the power of sensors, data management and inference to allow for a quick, easy, and inexpensive way to get quality information out of buildings. Called Building in a Briefcase (BiB), each self-contained kit includes up to ten motes that measure temperature, humidity, luminance, 3 axis acceleration and passive infrared in addition to a wireless router equipped with a 3G card that communicates directly with SBB's database. Further kitting options are also possible via hardware expansion ports on the sensor device to support sensory devices for CO_2 and PM2.5 measurements amongst others. The sensors' batteries are good for two years of uninterrupted operation. No IT experience is necessary to put a building on line; simply distribute the sensors and plug the router in. The motes communicate with the router, which sends data directly to the database. Users can log in from anywhere to examine a time series of their building's data.

Evaluation of the power efficiency of the BiB sensor, which is an essential aspect for building monitoring has been performed. Several potential applications, including occupancy estimation and activity recognition, which rely on the BiB for experiments, are described, as a demonstration of the portability and accessibility of the BiB platform.

Power Efficiency

The power efficiency (battery lifetime) is one of the critical aspects when we design the BiB sensor to make it to achieve a multi-year battery lifetime to reduce the maintenance cost of the network. In order to bring down the average current consumption to a target of less than 200 µA, several strategies have been employed. For instance, we select the components with low current requirements only. This helps us reduce the amount of energy consumed, as well as reduce the peak load demanded to be supplied by the linear regulator and battery. Linear regulators with higher peak current capability also typically have a higher leakage current. The high peak current draws can damage or reduce the effective capacity of the battery. Since the most vital component of the BiB sensor is the radio transceiver, we did the selection of it cautiously.

To address issue of increased power consumption with CO_2 extension module, we either lower the sampling rate of the CO_2 sensor, or use high energy efficiency CO_2 sensors. We create power consumption worksheet to determine the feasibility of having a multi-year battery life. We list the power requirements for each device during their sleep and active modes, and the typical amount of time required to be active to perform their functions. After that, we simulate and plot (Fig. 1) the battery lifetime of the BiB sensor powered by battery, over varying values of sample intervals and report intervals.

The current consumption from the light sensor, humidity and temperature sensor, accelerometer, PIR sensor, microcontroller, and radio is simulated. In addition, we also simulate the reduction of battery capacity at a low average current draw. Based on our analysis and evaluation, the BiB sensor can achieve a battery lifetime of over five years by using a 10 s sample interval and 60 s reporting interval. In this configuration, the average current consumption is 168 µA, and the effective battery capacity at this current is 8.03 Ah. The amount of current being used for communication is 56 µA, 57 µA for sensing, and 47 µA for processing. Another 8 µA is used for inactive devices while they are in their respective sleep modes. Furthermore, we note that with the extension of additional modules such as a CO_2 sensor, the power consumption is expected to increase.

Occupancy Estimation

Various methods have been employed for occupancy estimation (passive infrared (PIR) sensors, ultrasound sensors, and magnetic switches). These types of sensors provide accurate detections of occupants; however, the information they provide is limited. For instance, these light-based and ultrasound-based sensors usually have a small detection volume and cannot distinguish the number of occupants or the amount of activity that is occurring. To explore techniques which do not have these limitations, the indoor occupancy levels is directly estimated by measuring the CO_2 concentration with BiB sensors. The dynamics of the CO_2 concentration in the room is modeled using a convection PDE with a source term which is the output of a first order ODE system driven by an unknown input which models the human's emission rate of CO_2. The source term represents the effect of the humans on the CO_2 concentration in the room. In the experiments, a delay is observed in the response of the CO_2 concentration in the room to changes in the human's input. For this reason, the source term is a filtered version of the unknown input rather than the actual input. It is assumed that the unmeasured input from the humans has the form of a piecewise constant signal. This formulation is based on our experimental observation that humans contribute to the rate of change of the CO_2 concentration of the room with a filtered version of step-like changes in the rate of CO_2. Fig. 2 shows a typical trace of CO_2 concentration when the occupancy changes.

As can be seen, the extension capability of BiB sensors to measure CO_2 concentration is directly applied in this study. At the conclusion, a model is developed that describes the dynamics of the CO_2 concentration in a conference room. An observer is designed and validated for the estimation of the unknown CO_2 input that is generated by occupants, which acts as an intuitive proxy for the number of occupants breathing in the local air space.

Activity Recognition

Building intelligence encompasses its ability to sense and understand the activities of occupants to interact with them and achieve goals like comfort and energy efficiency. Individuals perform various activities inside the building. This information, when made available to the building automation and control system, can be very useful. For example, the PMV model proposed by Fanger and adopted by ASHRAE as the primary standard for thermal comfort takes occupant metabolic rate as the most important factor, but it has been widely regarded as the most difficult parameter to measure.

The BiB sensor was adapted into a watch to conduct wearable sensor studies. The goal of using BiB was not to be smaller than the current offerings, rather to be small enough to enable these studies. It was shown via experimentation that indoor occupancy activity can be recognized and classified by leveraging the environmental measurements, including temperature, humidity, and lighting level. Features including temperature gradients and standard deviation, humidity standard deviation, lighting levels are proposed for activity and location recognition. The features are statistically shown to have good separability and are also information-rich. Fusing environmental sensing together with acceleration is shown to achieve classification accuracy as high as 99.13%. For building applications, this study motivates a sensor fusion paradigm for learning individualized activity, location, and environmental preferences for energy management and user comfort. The capability of BiB to measure temperature, humidity, light level, and acceleration is demonstrated in this study.

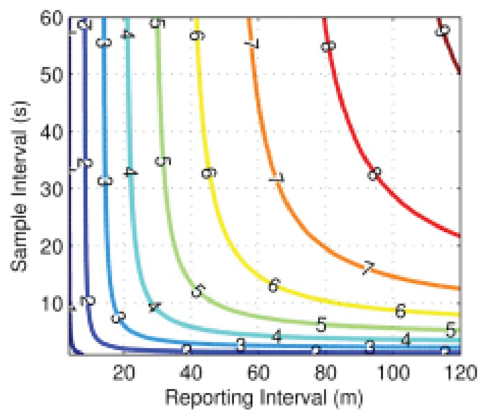


Fig. 1 Battery Life (surface contours, in years) given by varying the amount of time between and time between transmitting the data to the server.

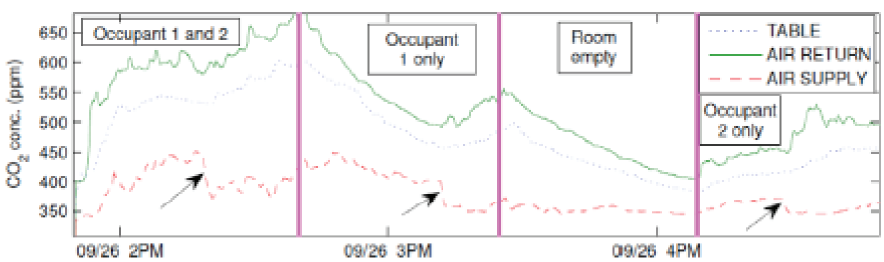


Fig. 2 CO_2 concentration when the occupancy changes in a room and in different sampling locations.

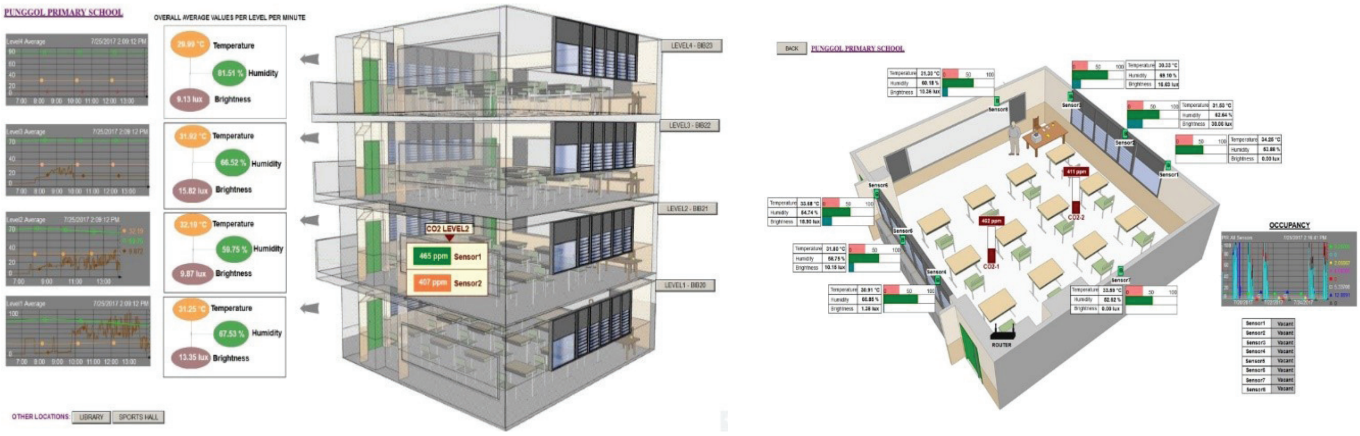


Fig. 3 BiB kit deployment at a Punggol Primary School. LHS: Visualization generated on OSI Soft PI Processbook system for end user viewing as well as a general performance dashboard. RHS: 1 BiB Kits featured with 2D render for spatial depth of view of physical sensor deployment.

The Kit, Current and Future Plans

The kit, which comes neatly packed into a briefcase, demonstrates how easy it can be to put a building on line. But they do more than just make a point; they can also guide some basic building retrofits and make a building much more efficient. Applied use of mined data varied form general thermal comfort supporting studies, occupancy detection studies to simple environment monitoring and measurement. It also provides information visibility, but also can be connected to actuators responsive to the data. In other words, the kit can help run a building. The latest version of the BiB Kit features as permanent sensor solution installation for an already kicked off SBB and BCA project where the mined data is used to enhance the lighting and air-conditioning in the first floor of the BCA net zero energy plus building (Fig. 4).

Fig. 4 BiB installed on a table top

In total, briefcases are being distributed free up to 25 sites in Singapore as a demonstration project. Current deployments which continue till today includes office buildings, personal spaces of collaborators and 2 Singapore public schools (voluntarily or via collaborating research partners). For the deployments in Singapore public schools, mined data was used as the basis to study thermal comfort impact on student productivity and general wellbeing as well as study the impact of breathing facades in classroom environment. Mined data was used to compare CO_2 impact on student productivity in the second school. These deployments continue till today to provide insightful information through analysis and observations of the mined data. We are continuously upgrading the BiB to further improve the kit as part of our on-going activities. We are extending the capability of BiB sensors to measure other indoor air quality (IAQ) pollutants concentrations that is on the standards. The quick, easy and temporal deployment of the BiB kit with IAQ measurement capabilities is suited for enabling rapid building diagnostics and solutions arising from building occupants complaints.

Fig. 5 BiB variation model measuring PM2.5 concentration.

The CBE vertical temperature gradient model can predict the percentage of thermally dissatisfied people

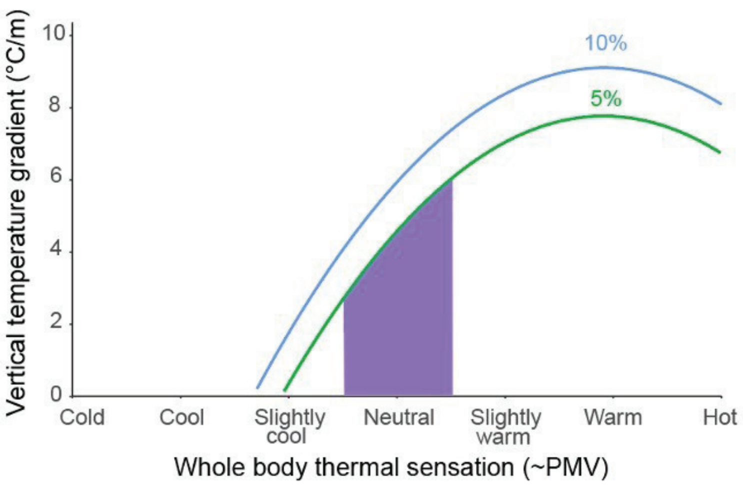
Stefano Schiavon.

Displacement ventilation and underfloor air distribution systems take advantage of thermal stratification, with cooler air at floor level and warmer air above. Such vertically stratified environments offer both opportunities and risks. On one hand, may offer improved ventilation effectiveness and energy efficiency, however, vertical temperature gradients can also cause local (individual body part) thermal discomfort. While the current thermal comfort standards — ASHRAE 55 and ISO 7730 — prescribe a 3°C/m limit between head and feet for a seated person (5.4°F for a seated occupant and 7.2°F for a standing one), an increasing amount of evidence suggests that this is too restrictive.
To understand how a vertical temperature gradient influences local thermal discomfort, we conducted experiments with four vertical temperature gradients (0.4, 2.9, 5.9, and 8.4°C/m). Ninety-eight subjects participated in a blind within-subject experiment and reported their thermal experience.

We found cold-feet discomfort was more frequently reported than warm-head discomfort with increasing temperature gradients. Results showed that thermal dissatisfaction increases only slightly (< 10%) with a vertical temperature gradient, even up to 8.4°C/m. We also found that the amount of acceptable vertical temperature gradient depends whether one's overall perception is warm, neutral or cool.

We developed a model, shown in the figure below, to predict the percentage dissatisfied for local discomfort as a function of thermal sensation and vertical temperature gradient. The predicted percentage dissatisfied is 5% when the vertical temperature gradient is roughly 5°C/m. A warmer whole-body thermal condition (e.g., by increasing room air temperature, or locally warming the feet) can reduce dissatisfaction. We implemented the model in the CBE Thermal Comfort tool under the section "local discomfort."

This study found that the percentage dissatisfied with the vertical temperature gradient to be less than described in both thermal comfort standards ASHRAE 55 and ISO 7730. A vertical temperature gradient between head and feet up to 5°C/m (9°F for a seated occupant) would likely be acceptable in thermally stratified environments for a person that feels thermally neutral. We are working with ASHRAE to implement this new model in hopes that this may lead to more design flexibility in the ASHRAE 55 standard.



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A Transfer Kernel Learning based Strategy for Adaptive Localization in Dynamic Indoor Environment

Han Zou, Xie Lihua, Costas Spanos.

WiFi has been recognized as the most promising technique for indoor positioning services, due to the widely installed network infrastructures and pervasive WiFi-enabled COTS mobile devices (MDs). Existing WiFi-based IPSs for practical large-scale implementation usually adopt fingerprinting-based localization algorithm. It localizes an MD by comparing the real-time RSS readings with a pre-established RSS fingerprint database, (a.k.a. radio map). The major bottleneck of WiFi fingerprinting-based IPS is the vulnerability to environmental dynamics. The real-time RSS readings may deviate significantly from the fingerprints stored in the static radio map due to severe multi-path and shadow fading effects caused by various interferences, which leads to huge degradation on localization accuracy. To accommodate environmental dynamics, radio map recalibration is extremely time-consuming and labor-intensive and deploying fixed reference anchors to obtain fresh RSS readings introducing extra hardware cost.

To overcome this problem, we propose TKL-WinSMS as a systematic strategy, which is able to construct a robust model for adaptive localization in dynamic indoor environments. We developed WinSMS that enables COTS WiFi routers as online reference points by extracting real-time RSS readings among them. With these online data and the onine calibrated radio map as labeled source data, we further combine the RSS readings from target MDs as unlabeled target data, to develop a robust localization model using an emerging transfer learning algorithm TKL. It is able to learn a domain-invariant kernel by directly matching the source and target distributions in the reproducing kernel Hilbert space. By leveraging the resultant kernel as the input for SVR training, the trained localization model can inherit the information from online phase to adaptively enhance the offine calibrated radio map. Extensive experiments have been conducted and demonstrated that TKL-WinSMS can provide high localization accuracy under various environmental dynamics consistently.

WinSMS

We develop WinSMS, which enables COTS WiFi routers as online reference points by overhearing the data packets transmitted between each MD and other routers, and precisely retrieve the RSS values and corresponding MAC addresses as identiers without introducing any extra hardware infrastructure. This is an intelligent wireless system that is able to overhear the RSS data packets in the existing WiFi traffic in real-time without any intrusiveness on the user side. The main AP provides the basic WLAN Internet services, receives UDP packets sent by remote APs, and forwards the data to a server. The server is responsible to store and parse the data. We upgrade the firmware of remote APs with OpenWrt, and use Libpcap to capture and analyze RSS packets in the existing WiFi traffic, extract relevant data and forward them to the main AP. Since these remote APs can overhear packets of other remote APs as well, all of them become natural online reference points with their physical coordinates and real-time RSS readings. In this manner, WinSMS is able to collect the data among the APs as the online labeled data DSAP and the RSS data associated with MDs as the unlabelled data DT without introducing extra infrastructure or any intrusiveness on user side.

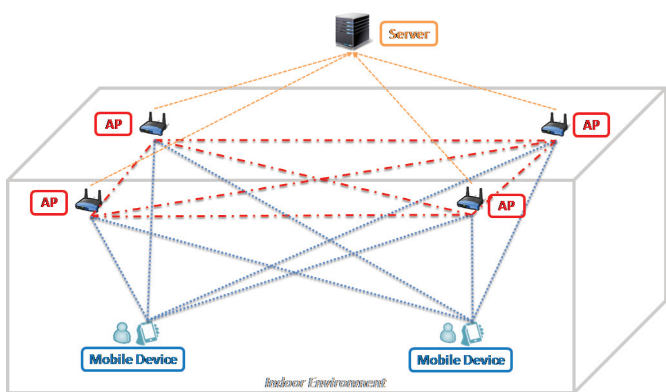


Fig. 1 System Architecture of WinSMS.

Transfer Kernel Learning (TKL)

Transfer Learning uncovers the latent features between □_□ and □_□. It minimizes the distribution discrepancy across domains, and identify the shared characteristics. Transfer Kernel Learning (TKL) learns a domain-invariant kernel by directly matching the source and target distributions in the reproducing kernel Hilbert space. The learned domain-invariant kernel can respect both the target eigensystem and source approximation quality. It uses the domain-invariant kernel as input data for SVR training, and then construct an adaptive localization model to precisely estimate the locations of MDs in dynamic indoor environments.

Experimental Results

Extensive experiments were conducted in a 600m2 real multi-functional lab across 6 months to validate the performance of TKL-WinSMS (Figure 2). We found that TKL-WinSMS outperforms SVR and SVR-WinSMS on nearly every testing point. The localization model learned in the de-noised latent space is more robust and reliable than those constructed in the raw signal space. By fully exploring the eigenspaces of both □_□ and □_□, TKL-WinSMS is able to correctly revealing the related knowledge, and kernelizing the original RSS data across different domains for adaptive indoor localization.

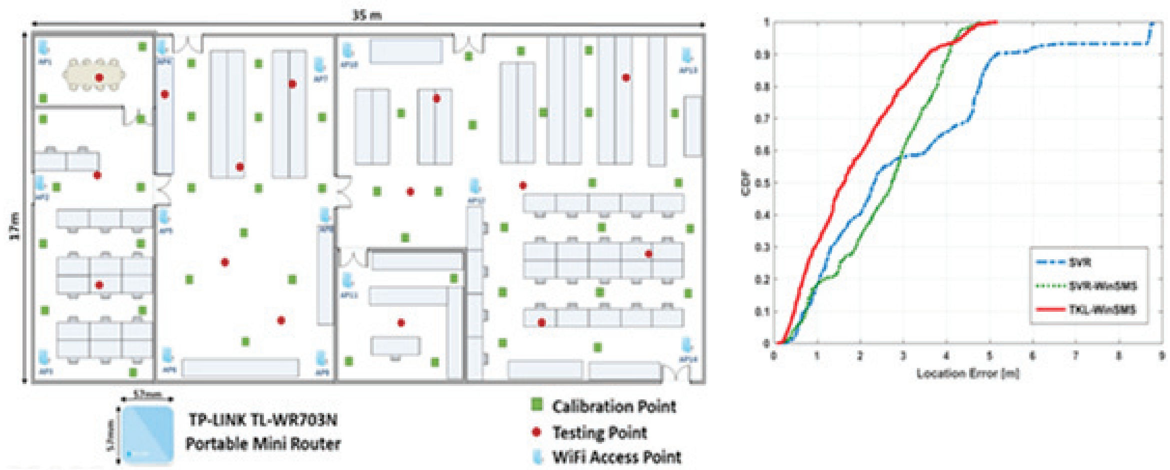
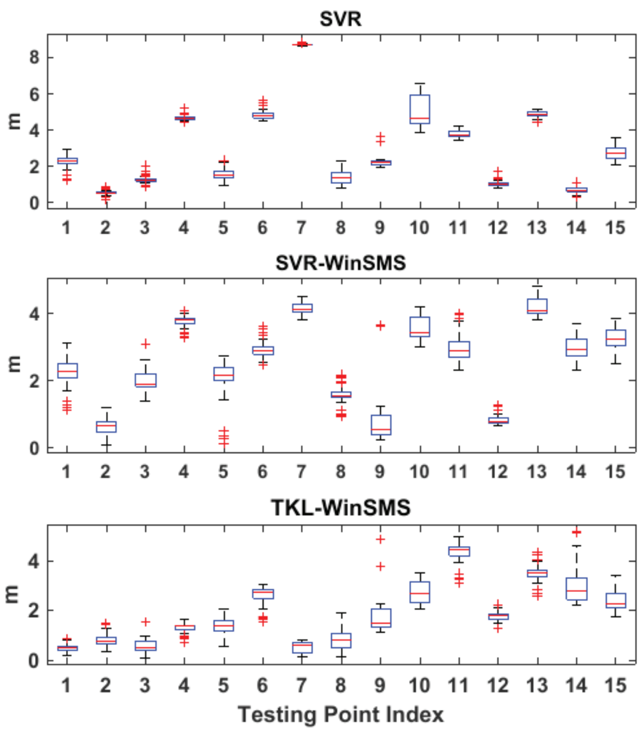


Fig. 2 Layout of the testbed and CDF of location error.



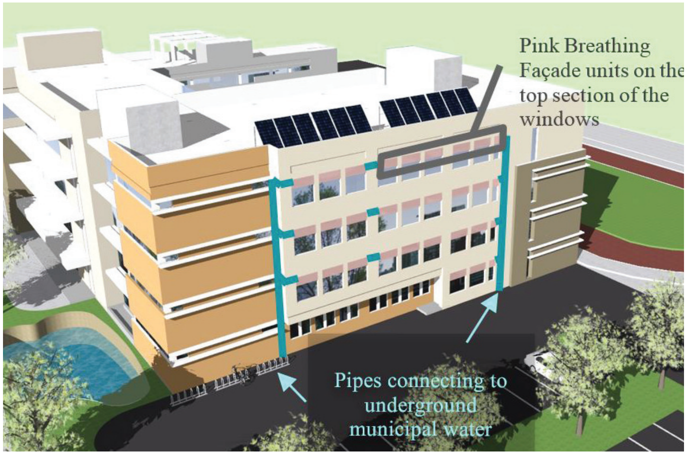
We envision the TKL-WinSMS as a fundamental and indispensable part for WiFi-based IPS to cope with various environmental dynamics and achieve a robust localization service consistently.

Fig. 3 Localization accuracy at each testing point.

Breathing Facades:

A Sustainable and Affordable Cooling and Dehumidification Solution for Public Schools in the Tropics

Satomi Angelika Murayama, Hazelynn Khoo, Meijun Liu, Hayden Taylor.



A 2012 study by the Association for Learning Environments found that academic performance is directly correlated with classroom comfort. Today, public schools in tropical countries such as Singapore do not have typical cooling and dehumidification systems, like air-conditioning (AC), installed in classrooms. The Berkeley Breathing Facade team is tackling this issue with a new way to cool down the space with minimal energy cost.

The Breathing Façade is a low-cost, energy-efficient, environmentally-friendly heat exchanger system used for cooling, dehumidification, and ventilation in an indoor environment. The Breathing Facade utilises materials that are recycled plastics, water, photovoltaics. The figure on the left illustrates the deployment of the breathing façade system in a public school in Singapore.

Building on existing Matlab code for comfort, the researchers were able to model the amount of power required to run the entire Breathing Façade system of a single school. Then a code was developed to calculate the initial/recurring costs to install and run the Breathing Façade system over its lifetime. Next, a numerical model to determine a value which has never been defined before: levelized cost of comfort (LCOC) was created. Finally, an interactive tool is used to help our stakeholders decide whether to implement the Breathing Façades technology via a Graphical User Interface (GUI).

In May 2020, Medium, an online publishing platform with over 60 million monthly active users, highlighted the UC Berkeley MEng Class of 2020 Capstone Award Winners for their annual accomplishments and research inventions. The 2020 awards include the Fung Institute Mission Award, the Alumni Award, and the Leadership Capstone Award. Satomi Angelika Murayama (Fritsch,) Hazelynn Khoo, and Meijun Liu, supervised by Professor Hayden Taylor at UC Berkeley, a SinBerBEST Principal Investigator, collaborated on the Breathing Facade as their capstone project and received an honorable mention for the Fung Institute Mission Award. Furthering SinBerBEST's ongoing research efforts, the team explored novel solutions to lowering the temperature of public school classrooms in tropical countries such as Singapore without using the typical cooling and dehumidification systems, like AC.

The Berkeley Breathing Facade team successfully devised a new way to cool down a school's space with minimal energy cost by calculating the levelized cost of comfort using a Matlab model for making implementation decisions, and the team's expertise in thermodynamics, fluid mechanics and materials science to calculate the levelized cost of comfort.

Levelized Cost of Comfort (LCOC)

1,140	Students in School
6.5	hrs/day Students Spend in Class
15	Chiller Coefficient of Performance
2,062	m^2 Roof Area for Photovoltaics
2%	Loan Interest Rate

Levelized Cost of Comfort (LCOC)

$18.10

Cost to make one primary school student comfortable for one year

A Novel Graphical Lasso based approach towards Segmentation Analysis in Energy Game-Theoretic Frameworks

Hari Das, Costas Spanos.

Energy consumption of buildings, both residential and commercial, account for approximately 40% of all energy usage in the United States. In efforts to improve energy efficiency in buildings, researchers and industry leaders have attempted to implement control and automation approaches alongside techniques like incentive design and price adjustment to more effectively regulate the energy usage. The heterogeneity of user preferences in regard to building utilities is considerable in variety and necessitates a system that can adequately account for differences from one occupant to another. With this in mind, focus has shifted towards modeling occupant behavior to incorporate their preferences in building control and automation. But, the occupants of a building typically lack the independent motivation necessary to contribute to and play a key role in the control of smart building infrastructure. One of the successful methods proposed to encourage occupant participation in building control is an energy game-theoretic framework, which creates a friendly competition between occupants/users, motivating them to individually consider their own energy usage and hopefully, seek to improve it to have a better score/achieve a lucrative incentive in the game. The incentive design process in prior works is dependent on utility functions of players in the game, which is hard to compute as buildings involve participation of a large number of energy users, and hence is often approximated.

Our research proposes that the utilities of players in such a framework can be grouped together to a relatively small number of clusters, and the clusters can then be targeted with tailored incentives. The key to above segmentation analysis is to learn the features leading to human decision making towards energy usage in competitive environments. We propose a novel graphical lasso based approach to perform such segmentation, by studying the feature correlations in a real-world energy social game dataset. To improve the explainability of the model, we perform causality study using granger's causality. Proposed segmentation analysis results in characteristic clusters demonstrating different energy usage behaviors. The dataset used for our work is from an energy social game experiment conducted at Nanyang Technological University to encourage energy efficient resource consumption in buildings. The overview of proposed segmentation method is illustrated in Fig. 1. We propose a hybrid segmentation method that uses the novelty of both unsupervised and supervised segmentation.

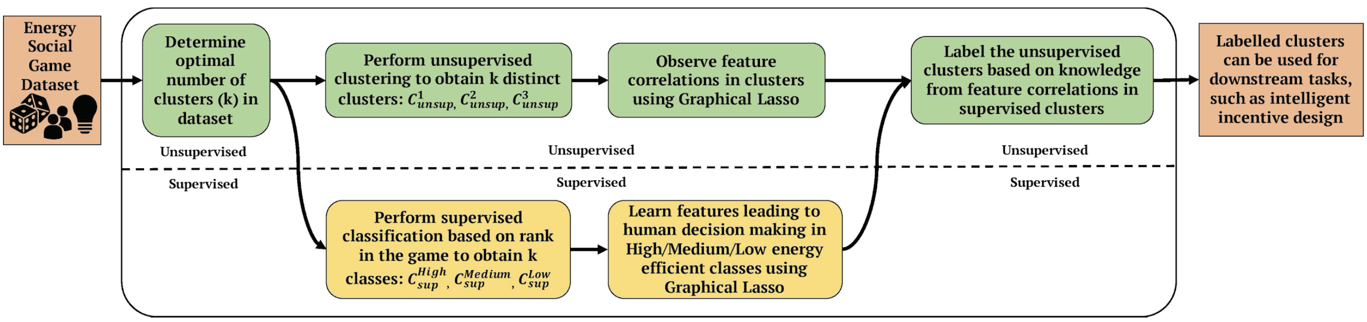
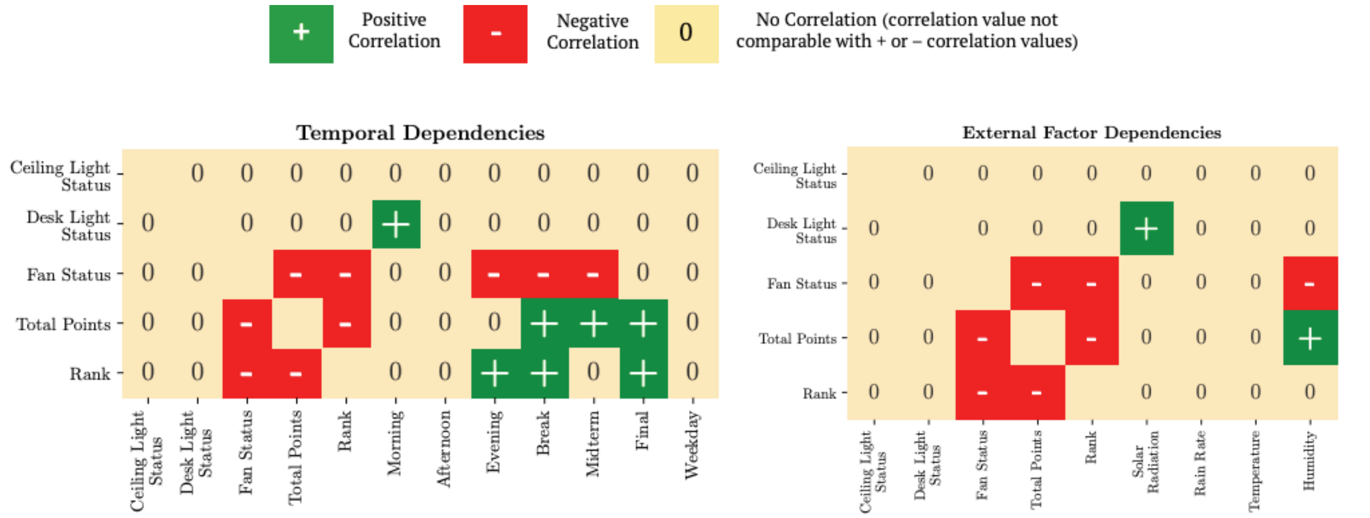


Fig. 1 Overview of the proposed segmentation method.



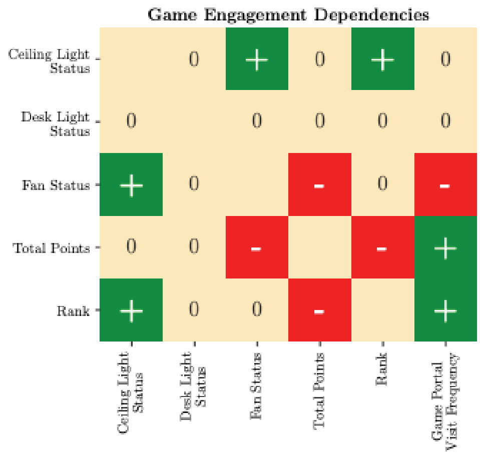
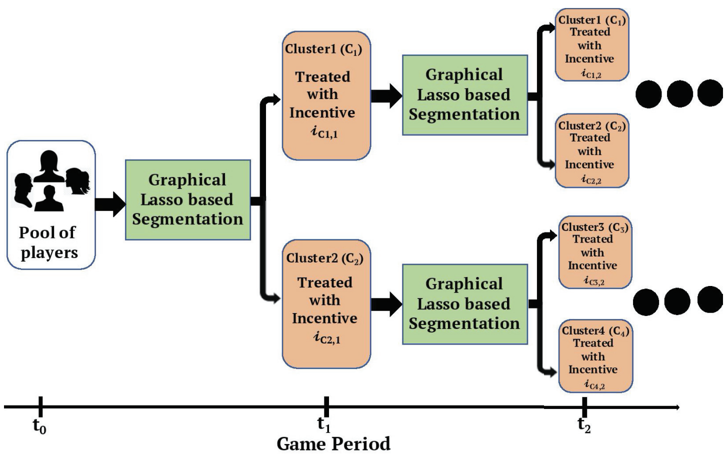


Fig. 2 Feature correlations for a player in low energy efficient class.

First, the optimal number of clusters in the dataset is derived using elbow method and silhouette scores, which comes to be 3 for used dataset. Following this, we use Minibatch K-means algorithm with k= 3 (optimal number of clusters in the data) to obtain the clusters. Since the dataset corresponds to energy usage behavior of the players, the three clusters obtained correspond to high, medium and low energy efficient behaviors, but we don't have the labelling of the clusters. We then use supervised classification and graphical lasso to label the unsupervised clusters. We divide the players into three classes in a supervised way taking the ranks of the users as the label. Then we study the feature correlations in all the supervised classes and unsupervised clusters using graphical lasso. For illustration, the feature correlations for a player belonging to low energy efficient class is given in Fig. 2. The player tries to use each resource independently with no correlation between the corresponding resource usage identifiers. There is a positive correlation between morning and desk light usage indicating heedless behavior towards energy savings. The absolute energy savings increase during the breaks and finals, but it is not significant as compared to other players during the same period, thus increasing the rank. External parameters play a significant role in energy usage behavior of this class. We do similar analysis for medium and high energy efficient classes and all 3 unsupervised clusters. Knowledge of feature correlation similarity among members of the supervised classes and unsupervised clusters is used to label the unsupervised clusters as high/medium/low energy efficient.

By leveraging proposed segmentation analysis, an adaptive model can be formulated that learns how user preferences change over time, and thus generate the appropriate incentives. Furthermore, the learned preferences can be adjusted through incentive mechanisms to enact improved energy efficiency. Above two operations can be carried out in a tree structure, with segmentation carried out in regular intervals in each of the tree branches, as depicted in Figure 3. Summing up, this would result in a novel mechanism design, effectively enabling variation in occupant's behaviors, in order to meet, for instance, the requirements of demand response.

Fig. 3 Tree based incentive design mechanism employing proposed graphical lasso based segmentation method.



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Condition Monitoring and Health Prognosis System (CMHPS) of Micro-Grid in Pulau Ubin

Nguyen Hoan Thong.

Background and Project Objective

Phase 1 of the micro-grid at jetty area of Pulau Ubin was piloted by the Energy Market Authority of Singapore (EMA) in 2013. Since then it has been an isolated AC system at 400 V, 50Hz supplying power for about 30 participants consisting of restaurants, bicycle shops, telecommunication stations and government agencies. This grid was also operated as a micro-grid testbed for research and demonstration on renewable-energy-related technologies in design, storage and management. In 2017, grid capacity was around 500 kVA produced by distributed energy resources (DERs) including solar photovoltaic (PV), energy storages, and diesel generators. They are distributed in 4 generator plants (GR): Assembly and Visitor Centre, Natural Gallery, Singtel site and Jelutong. (Fig.1). Capacities of these GRs are shown in table 1.

Reliability and energy efficiency are the important parameters of operating a power system. It is more challenging in the case of two-way power-flow electrical grid in which there are intermittent sources such as solar photovoltaic. “Real-time Monitoring of Micro-grid Performance”, one of two projects under Phase 2, was awarded to SinBerBEST (SBB) by the Energy Market Authority (EMA) in 2017. This project aims to develop a sensor system to collect real-time data of grid assets as well as the power flows. Based on the database of this real-time condition monitoring, a health prognostic system will be developed to improve the reliability, energy efficiency and reduce the maintenance cost.

Fig. 1 Map of Jetty area of Pulau Ubin and locations of distributed energy sources.

Generator Plant	PV (P_{max}300W /panel)	Generator	Energy Storage
Assembly and Visitor Centre (GR1)	57kW (190 panels)		960kWh +144kWh
Natural Gallery (GR2)		100kW	98kWh+85.2kWh
Singtel site (GR3)	15.9kW (53 panels)	200kW (2 × 100kW)	108kW+170.4kWh
Jelutong (GR4)		60kW (2 × 30kW)	

Table 1

Real-time data System Overview and Implementation

The data flow is shown in the structure of the real-time condition monitoring and health prognosis system (CMHPS) that was deployed for Pulau Ubin micro-grid (Fig.2). The solar photovoltaic, diesel generator, battery and power flow are the four monitoring sections of this system.

The real-time operating parameters of major grid assets are measured by sensors and meters. These data are collected by the data acquisition platform of each section, and, sent to the onsite server which is known as the monitoring data management (MDM) and is located at Visitor Centre via gateways. Such data are then transferred to another server located at SBB's office, Create Tower, through 4G network. The OSI Soft PI database system is adopted for real-time data management. The use of OSI Soft PI system offers a complete historian solution with a comprehensive data management, visualization, and ad-hoc reporting solution.

A retrofit of sensor, metering network and communication system was installed in the existing micro-grid. Values of temperature, voltage, current of each of the 60 PV panels at Visitor Centre, and each of the 53 PV panels at Singtel Site were monitored, together with the values of irradiation and ambient temperature at two these sites. The highlighted specifications of sensors used can be found in Table 2. The National Instruments (NI) industrial computing platform is applied for PV and generator sections.

For power flow monitoring, PQube3 power analyser was installed in each of 10 over-ground (OG) boxes of power distribution. In addition, the PowerShield System were applied to capture the data of 240 lead-acid cells of 960 kWh battery bank located at Visitor Centre. Both PQube3 and PowerShield were adopted as monitoring platforms for power flow and battery sections respectively (Table 3).

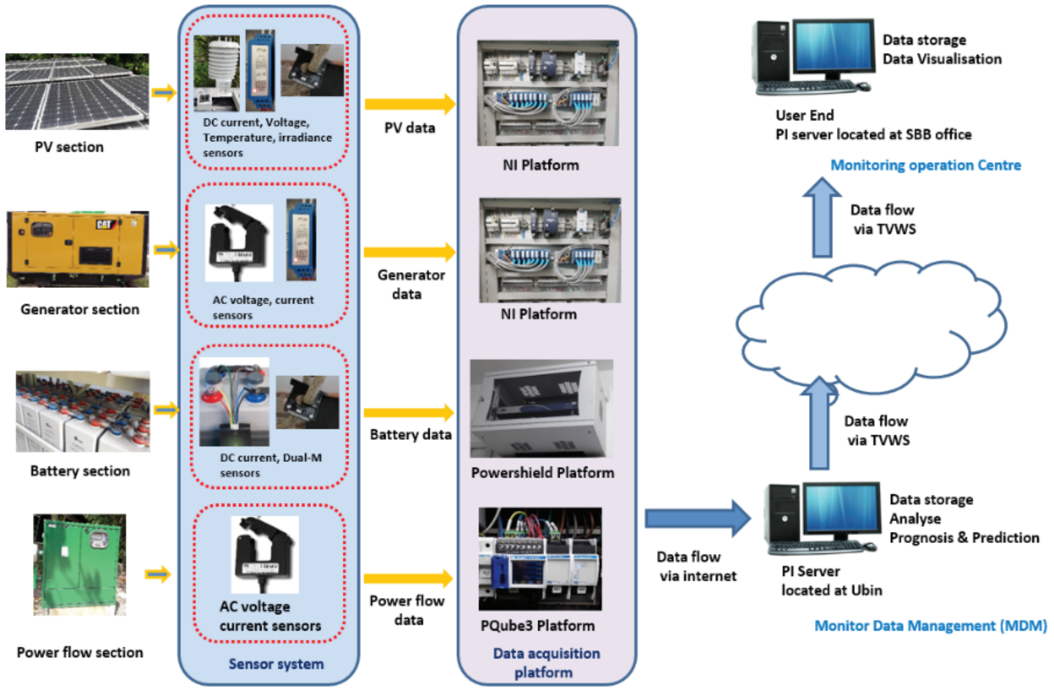

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Fig. 2 The structure of CMHPS.

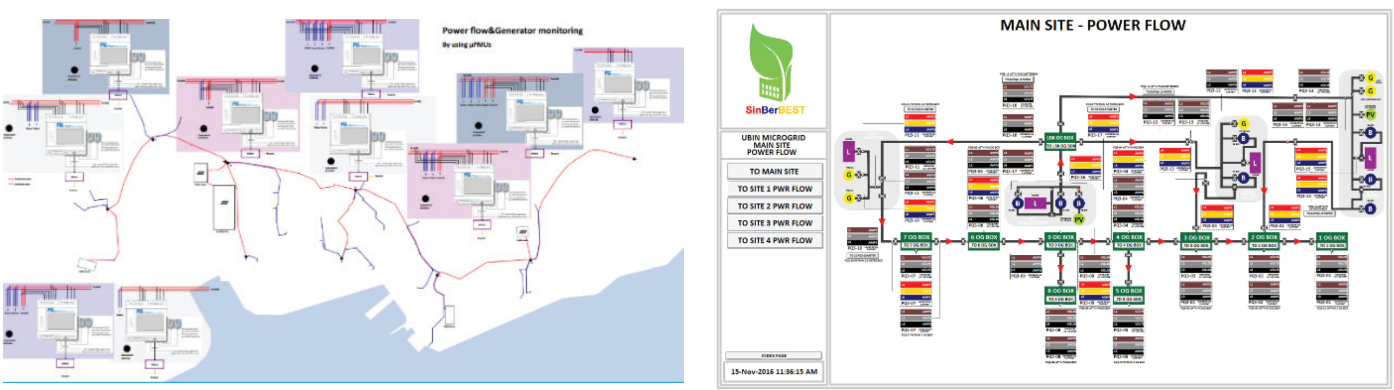


Fig. 3 Pulau Ubin distribution system.

Table 2

Sensors	Highlighted Specifications
Surface temperature of PV panel	RTD pt1000, Accuracy ± 1%, measuring range up to 150 C, IP66,
Ambient temperature	measuring range up to 50 C, Accuracy ± 0.5%,
Silicon Irradiance sensor	IP 67, linear output in the range 0-1500W/m^2; ±5%
DC current	Hall-effect, output 4-20mA, Accuracy ± 1%, split core type
DC Voltage	Output 4-20mA, Accuracy ± 0.5%,
AC current (Combined CT and PQube3)	Output 0.333V, Magnitude accuracy ±0.1% at 50Hz, Angle accuracy ± 0.1% Bandwidth 40Hz – 3000 Hz

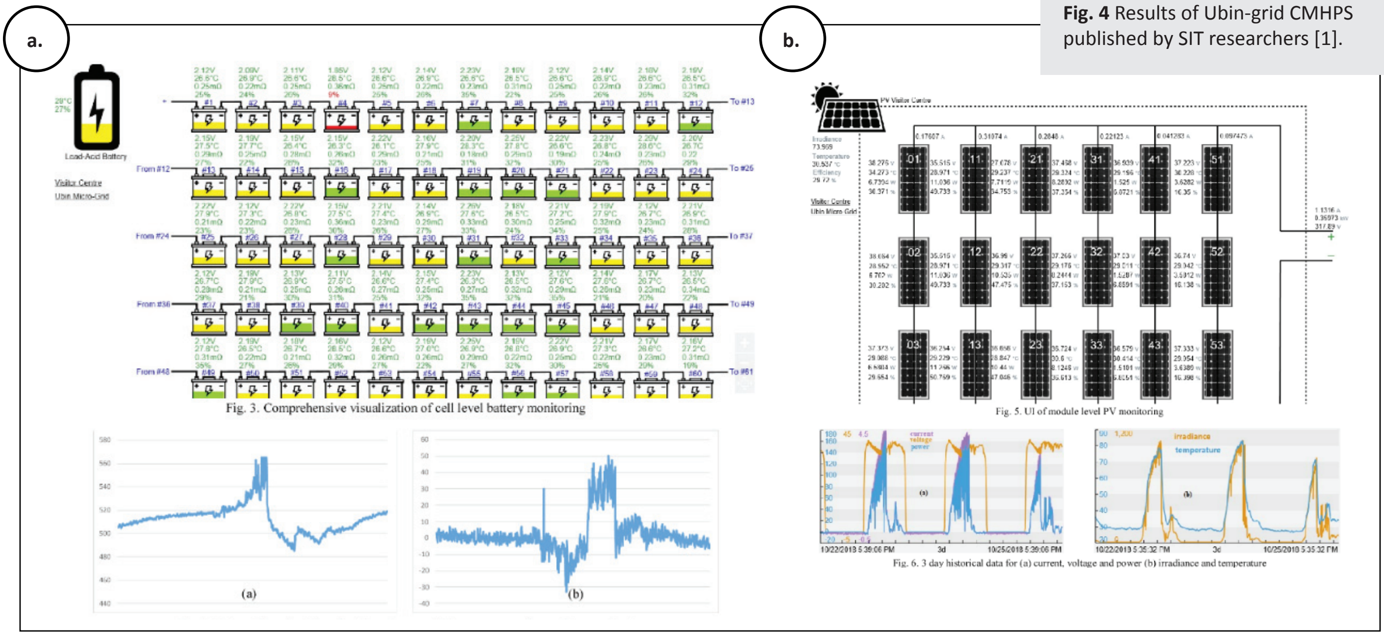
Table 3

Platform	Highlighted Specifications
PQube3_for power monitoring	8 measurement channels, Storage SD card, Ethernet port, Voltage & Current accuracy: magnitude±0.01%, angle ±0.002%; Sampling rate 512/cycle for 50Hz, 4 MHz for high-frequency impulse
PowerShield_for battery monitoring	Solution for lead acid, Ni-Cd and VRLA. Ambient temperature, String current and voltage, Cell voltage, Cell temperature, Cell Impedance

Working conditions faced such as pressure from authorities in not exceeding power downtime limit, working at height, engaging live loads and severe weather condition made cabling and sensor installations challenging (Fig. 5). Under effective supervision and management from SBB's staff, the sensor system was deployed 1 week ahead of schedule with excellent safety record.

As part of the deliverables, the web-browser user interface (UI) was developed for visualisation. It took about one year from the first site visit in the last quarter of 2016 to the end of 2017 before data could be accessed and visualized remotely.

Fig. 4 Results of Ubin-grid CMHPS published by SIT researchers [1].

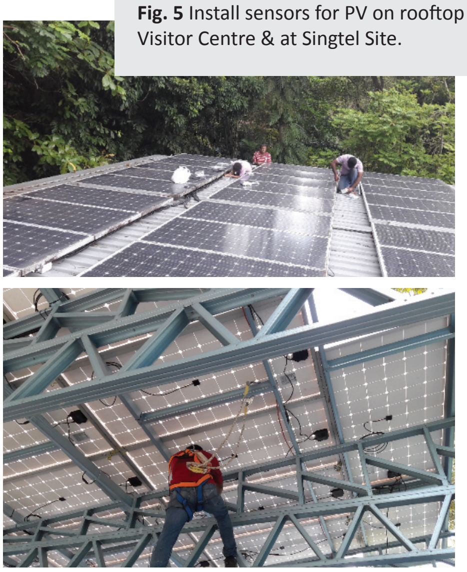


(a.) Cell level monitoring for battery bank (b.) Module level monitoring for PV system.

Experimental Results

The real-time sensor network provides variety of data at node level of power flow, as well as at module level and cell level of PV system and battery bank, respectively. Based on the real-time power and expected power at specific conditions of irradiance and temperature, the efficiency of individual PV panel can be obtained. This efficiency is an indication of health condition of PV module. Similarly, the voltage, current, temperature, impedance of each cell and the ambient temperature are used to obtain the state of charge (SoC), as well as to estimate the state of health (SoH) of individual battery cell. High accuracy and sampling rate power data offered by PQube3 analyser at each power node are useful for energy efficiency improvement in two-way power flow electrical system. As a result, they can help to reduce the cost associated with grid maintenance, and also to enhance the reliability during operations. In 2018 this system was handed over to Singapore Institute of Technology (SIT) for further research.

Fig. 5 Install sensors for PV on rooftop of Visitor Centre & at Singtel Site.



Interview with Rohit Chandra

Rohit Chandra is currently pursuing the Ph.D. degree in electrical engineering with the National University of Singapore, Singapore. He served as an Engineer with the Engineering Department at Power Grid Corporation of India, Gurgaon, India, from 2014 to 2017. He represented POWER@NUS team at the Global Final of IEEE Empower A Billion Lives competition held in Baltimore, USA in Oct., 2019. His main research interests and experience include transactive energy, building energy, AC/DC microgrids, energy management systems, rural electrification, and power electronics.

1) What is the mode of interaction between you and your supervisor? How often do you interact with your PI? Do they provide adequate guidance and mentorship?
I usually interact with my supervisor and PI Assoc. Prof. Sanjib K. Panda once a week in person or over a call (during COVID 19 lockdown). He has been actively guiding me in my research projects and has also encouraged me to interact with other PIs and researchers in the program.

2) How do you use the facilities/laboratories provided by the program?
My research is focused on the interaction between buildings and electricity grids. We have been actively involved in the planning, procurement and commissioning of the nanogrid part of the testbed. We utilize the nanogrid testbed to model electrical resources within buildings as an "energy node" and implement, test and demonstrate our algorithms for demand response.

3) How do you interact with other researchers within your theme and outside your theme?
We interact within the theme during regular monthly Theme-B meetings where we share recent research outcomes and discuss opportunities. I have interacted with researchers from other themes while working in the testbed facilities including ACMV and nanogrid areas. Interaction with PIs of other themes was facilitated through presentations in the Monthly PI's meeting.

4) Did you get the opportunity to work with industry and Singapore government agencies in your work?
No, not at this point of time as we are still developing the research work at laboratory level. Once, we can demonstrate results to the industry partner, we will try to get them involved for a possible implementation of proposed solution at a small scale microgrid. We have also been participating in different grant calls advertised by EMA related to microgrids and energy management systems.

5) Can you describe how you have grown as a researcher through the program?
Before joining NUS and SBB, I had separate experiences in academic research and industry. In SBB, I have seen the close collaboration between research and industry. Further, I have been mentored by various PIs and have learned from their extensive experiences in translation of research outcomes to products/services. Thus, as part of SBB, I have grown to understand the novelty in technologies as well as practical considerations which enable the technologies to be adopted readily by the industry. The demonstration of proposed technologies through test-bedding is an important factor in developing confidence.

6) What is your view of the SBB mission? How does your research contribute to the mission?
SBB mission involves improving energy efficiency and reducing carbon footprints from building which consume significant portion (40-50%) of total energy in developed and tropical countries. This is a well identified research subject as buildings are energy-dense and provide opportunities for interventions which can be economically justified. Further, the SBB approach of Measuring, Modeling, and Mitigation provides unique approach to solving this problem. My research area is Building-Grid Interaction. We have proposed simplified models for buildings as "energy nodes" and proposed electricity market-based approach to energy management. We propose coordination among "cluster of buildings" and aggregation of individual building capacity to realize higher energy benefits and provide demand response and other grid services. These grid services also enable reliable integration of renewable energy sources into the electricity grid and corresponding reduction in carbon footprint.

7) What are your career plans and how is it shaped by the SBB program?
My plans involve pursuing a research career in either academic or industrial environment. In my association with the SBB program, I have been part of interaction between academia and industry, learned alignment of research goals to industry needs, and methods of incorporating translational aspects into research methodology.
This knowledge would help me in my future career as a researcher to do impactful research and be part of translation of research outcomes to products/services.

8) What could be improved within the SBB program?
The SBB program is well organized and run. Regular inter-theme research interactions may be a possibility of improvement for the program.

2020 American Automatic Control Council O. Hugo Schuck Best Paper Award

Interview with Baihong Jin

Baihong Jin is currently a Ph.D. candidate in the Department of Electrical Engineering and Computer Sciences at University of California, Berkeley, and is currently a research affiliate at the Lawrence Berkeley National Lab. Baihong is advised by Prof. Alberto Sangiovanni Vincentelli and Prof. Kameshwar Poolla, and is part of the first and the second phases of the Singapore-Berkeley Building Efficiency and Sustainability in the Tropics (SinBerBEST) program. Baihong was recognized for his notable contributions to soft computing and its applications with the Lofti A. Zadeh Prize. Baihong's research interests include machine learning, fault management, and anomaly detection techniques, with a focus on their applications in energy cyber-physical systems and healthcare AI. He also served as a reviewer for several top-tier journals and conferences including Applied Energy and IEEE Conference on Decision and Control (CDC). After his graduation, Baihong will continue with the SinBerBEST 2 program as a postdoctoral scholar.

1) What is the mode of interaction between you and your supervisor? How often do you interact with your PI? Do they provide adequate guidance and mentorship?

I have bi-weekly regular meetings (online or in-person) and frequent email interactions with both of my advisors, Prof. Alberto Sangiovanni Vincentelli and Prof. Kameshwar Poolla. Both PIs provide great intellectual guidance and support to my research.

2) How do you use the facilities/laboratories provided by the program?

My research is mostly centered around fault detection and diagnosis in commercial buildings. As a result, my collaborators and I have been using the data collected from JTC buildings instead of the data from the SBB laboratories.

3) How do you interact with other researchers within your theme and outside your theme?

During my six years in the SBB program (both phase 1 and phase 2), I have collaborated with multiple colleagues in Singapore and in Berkeley in our joint projects. My collaborators include Dr. Dan Li, Dr. Seshadhri Srinivasan, Dr. Yuxun Zhou, PI Stefano Schiavon, and PI Costas Spanos. The collaboration with people across different themes enables me to look at research problems from a more holistic perspective.

4) Did you get the opportunity to work with industry and Singapore government agencies in your work?

Yes. I have been working with the JTC Corporation in my fault detection research. The data and the operational insights from JTC constitute valuable parts in my research and help me gain a better understanding of real-world challenges in the building domain.

5) Can you describe how you have grown as a researcher through the program?

The six years at SBB have been a rewarding experience to my life and career. I have learned how to be a good researcher and collaborator, and have gained a deeper understanding of real-world problems and challenges. I would like to express my sincere appreciation towards the SBB program as my fellow researchers. The exchange of knowledge and thoughts, as well as the friendship and bonds that were formed during the collaboration, will be invaluable throughout my life.

6) What is your view of the SBB mission? How does your research contribute to the mission?

I view the SBB mission as a pursuit to transform how smart buildings are designed, built and operated. My research on incipient fault detection and diagnosis is important in reducing the operation costs of buildings. If faults and degradations can be identified in an early manner, we can take proper measures to address them, thus helping avoid further costs and losses.

7) What are your career plans and how is it shaped by the SBB program?

I plan to continue as a postdoctoral scholar with the SBB program after I obtain my PhD degree in late 2020. Later on I plan to pursue a career in academia or in industry research labs. My experiences at SBB have provided me adequate training in conducting fault detection and energy related research, which is of great benefit to my future career in related fields.

8) What could be improved within the SBB program?

I would like to see more Singapore colleagues have the chance to visit UC Berkeley and participate in the studies conducted in the US.

Research collaboration between SinBerBEST 2 and UC Berkeley's Electrical Engineering and Computer Science (EECS) team resulted in a O. Hugo Schuck Best Paper Award from the American Automatic Control Council (AACC) in 2020. AACC consists of of nine member societies' control systems divisions, representing the American systems' perspective to the global systems community. Additionally, it supports its member societies in "enhancing the role and contributions of automation to the benefit of humankind." The AACC hosts an annual, interdisciplinary American Control Conference (ACC,) offering annual awards to acknowledge individuals who have contributed significantly to control theory and application, and supports control education. This Best Paper Award is a significant achievement as there were over 1,200 paper submissions. The winning paper, "Distributed Storage Investment in Power Networks," was written by Junjie Qin, Sen Li, Kameshwar Poolla, and Pravin Varaiya. These writers built and examined a network storage investment game to determine if a market-driven distributed storage investment will lead to a socially-desirable outcome.

SinBerBEST

The SinBerBEST program, funded by the National Research Foundation (NRF) of Singapore, is a research program within the Berkeley Education Alliance for Research in Singapore (BEARS). It comprises of researchers from University of California, Berkeley (UCB), Nanyang Technological University (NTU) and National University of Singapore (NUS). SinBerBEST's mission is to advance technologies for designing, modeling and operating buildings for maximum efficiency and sustainability in tropical climates. This newsletter, published quarterly, is to showcase the excellence of SinBerBEST faculty, post doctoral fellows and students.

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1 Create Way, #11-02, CREATE Tower, Singapore 138602

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EDITORS
Costas Spanos
Zuraimi Sultan

DESIGN
Ivanna Hendri
Samuel Foo

CIRCULATION
Kavitha D/O Krishnasamy

Please contact at kavitha@bears-berkeley.sg
for any inquiry or further information.

CONTRIBUTORS
Costas Spanos
Kevin Weekly
Stefano Schiavon
Han Zou
Xie Lihua
Satomi Angelika Murayama
Hazelynn Khoo
Meijun Liu
Hayden Taylor
Hari Das
Nguyen Hoan Thong