SinBerBEST

Air Pollution

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IoT Sensing for Building Resilience Characterization


Jovan Pantelic and Megan Dawe

In November of 2018, North California was highly affected for weeks by wildfire in Chico. Air pollution spread thorough the San Francisco Bay Area. As a result, many businesses and schools including University of California Berkeley campus were closed. Air pollution caused disruption to many but not all businesses and schools. Variety of responses across Bay Area showed lack of policies on how to respond to the extreme air pollution event and revealed high level of confusion and chaos.

Wildfire smoke is a toxic mixture of particulate matter (PM), carbon dioxide, carbon monoxide, complex hydrocarbons, nitrogen oxides, and many other compounds. Exposure to wildfire smoke is associated with respiratory problems including asthma, chronic obstructive pulmonary disease, bronchitis and pneumonia. Studies have also shown that exposure to wildfire during pregnancy may impact birth weight among term infants, and increases in mental health symptoms among adolescents.

While the health risks are clear, standards such ASHRAE 62.1 and 62.2 only address normal outdoor air conditions. A few guidelines exist for protecting building occupants from pollution caused by wildfire: ‘Wildfire Smoke Response Planning,’ by the British Columbia Center for Disease Control; and ‘Wildfire Smoke Guidelines,’ from the California Department of Public Health. However, these provide very general recommendations such as “reduce infiltration” or installing “effective filters.” Such qualitative suggestions are not sufficient to quantify building properties and determine how indoor conditions affect occupants.

In March 2018, the research team installed low-cost IoT $PM_{2.5}$ sensors on the roofs of two UC Berkeley buildings and 14 indoor sensors in each building. During the 2018 fires, these sensors enabled us to understand and evaluate building resilience to urban scale air pollution, and quantifying particle penetration. The buildings included one mixed-mode ventilated and one mechanically ventilated, both located in Berkeley, CA. Although the study was performed in the San Francisco Bay Area in California, wildfire smoke in California represents the same environmental problem Singapore faces during human-induced forest fires in Indonesia. Tools and approaches depicted in this study can be directly implemented in Singapore to characterize building resilience during the haze period.

We also used this opportunity to evaluate an Internet of Things (IoT) environmental sensing network, with sensors inside and outside of buildings, combined with occupant surveys.

From November 8th through November 21st, the two buildings described below were impacted by wildfire smoke:

Mechanically Ventilated Building (4thSt): This is a mechanically ventilated building with a centralized HVAC system. The HVAC system utilizes three stages of air filtration: (1) a Minimum Efficiency Reporting Value (MERV) 8 pleated filter; (2) gas phase filter; and (3) a high-efficiency MERV 13 filter. Measurements of CO_2 decay showed that building is airtight, indicating that infiltration plays a minor role in bringing outdoor pollution indoors.

Mixed-mode Ventilated Building (wurster): This is a mixed-mode operated building, with the east wing naturally ventilated with a high level of infiltration. During normal operation, the building measurements showed that CO_2 levels most of the time are below 600 ppm.

Sensors used

Clarity and Senseware $PM_{2.5}$ nodes use the principle of light scattering to count the particle number. The accuracy of the all the sensors was the same—within ±10 μg/m^3 in the range of 0 to 100 μg/m^3 and ±10% in the range of 100 to 1000 μg/m^3. Data was collected on 15-minute intervals for Clarity nodes on 1-minute intervals for Senseware nodes.

Indoor air quality during an air pollution episode

Using an IoT sensing network, position outdoors and indoors, enabled us to understand the building operation in the context of indoor and outdoor $PM_{2.5}$ levels. Results in Figure 1 show that the median hourly indoor $PM_{2.5}$ concentration over the entire wildfire event was 21 μg/m^3 for the building on 4thSt building, and 36 μg/m^3 for Wurster Hall. Measured CO_2 decay rates, indicating infiltration of 0.15 air changes per hour (ACH), suggest that 4thSt is airtight, showing that the ingress of $PM_{2.5}$ through mechanical ventilation was the most dominant

FIGURE 1 Outdoor (L) and Indoor (R) $PM_{2.5}$ monitors

mechanism of $PM_{2.5}$ penetration into the building. Combination of $PM_{2.5}$ and CO_2 sensing shows the key buildings aspect where intervention can have the highest impact.

Wurster Hall has operable windows designed to allow the natural flow of air through the building, and although monitored windows were closed (based on contact sensor readings) during the pollution event Wurster Hall had infiltration of 0.40 ACH.

Our measurements enabled us to calculate an indoor to outdoor (I/O) particle ratio as one of the key performance measures of the building. The I/O ratio will tell us how much outdoor pollution penetrated into the building. For the entire period, the I/O ratio for the 4thSt building was 0.27, while for Wurster Hall I/O was 0.67.

Results from Figure 2 and calculated I/O represent overall operation of the building during the entire pollution episode. Combination of $PM_{2.5}$ and CO_2 sensing shows the key buildings aspect where intervention can have the highest impact. Results in Figure 2 do not tell us much about the day-to-day operation, nor will it tell us how these levels of pollution impacted building occupants. Results as shown in Figure 2 tell us that the 4thSt building is more resilient to extreme pollution events than Wurster Hall.

Occupant exposure to pollutants

$PM_{2.5}$ concentration and length of the exposure period affect health, productivity and comfort of building occupants. In the context of building resilience, we simultaneously evaluated ambient concentration and exposure time. We compared the hourly median $PM_{2.5}$ concentration to World Health Organization (WHO) 24-hour exposure guidelines and calculated the exceedance index (E-index). Results in Figure 2 also show ranking of E-index in the context of extreme pollution event timeline.

Results in Figure 3 show that 4thSt E-index was below the WHO suggested threshold 66% of the time, compared to only 23% of the time for Wurster Hall. We can calculate overall E-index by summing up hourly values for the entire pollution episode. The overall E-index for 4thSt is 0.82, suggesting that the building was resilient to air pollution and that filtration with the MERV 8 and MERV 13 filters was able to reduce the $PM_{2.5}$ penetration to maintain normal operation inside the building. For Wurster Hall, the average E-index was 1.69, suggesting that air quality conditions could potentially have severe consequences on those with respirtory health issues.

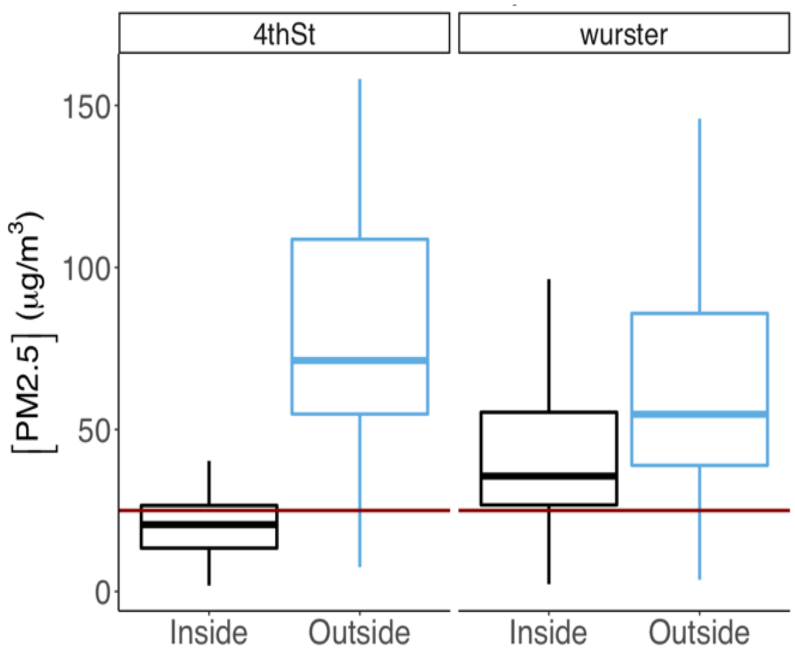

FIGURE 2 Comparison of hourly $PM_{2.5}$ concentrations between the two sites for the entire period of air pollution episode. The box plot represents the 25th percentile, median, and 75th percentile, and the whiskers represent the 5th and 95th percentiles.

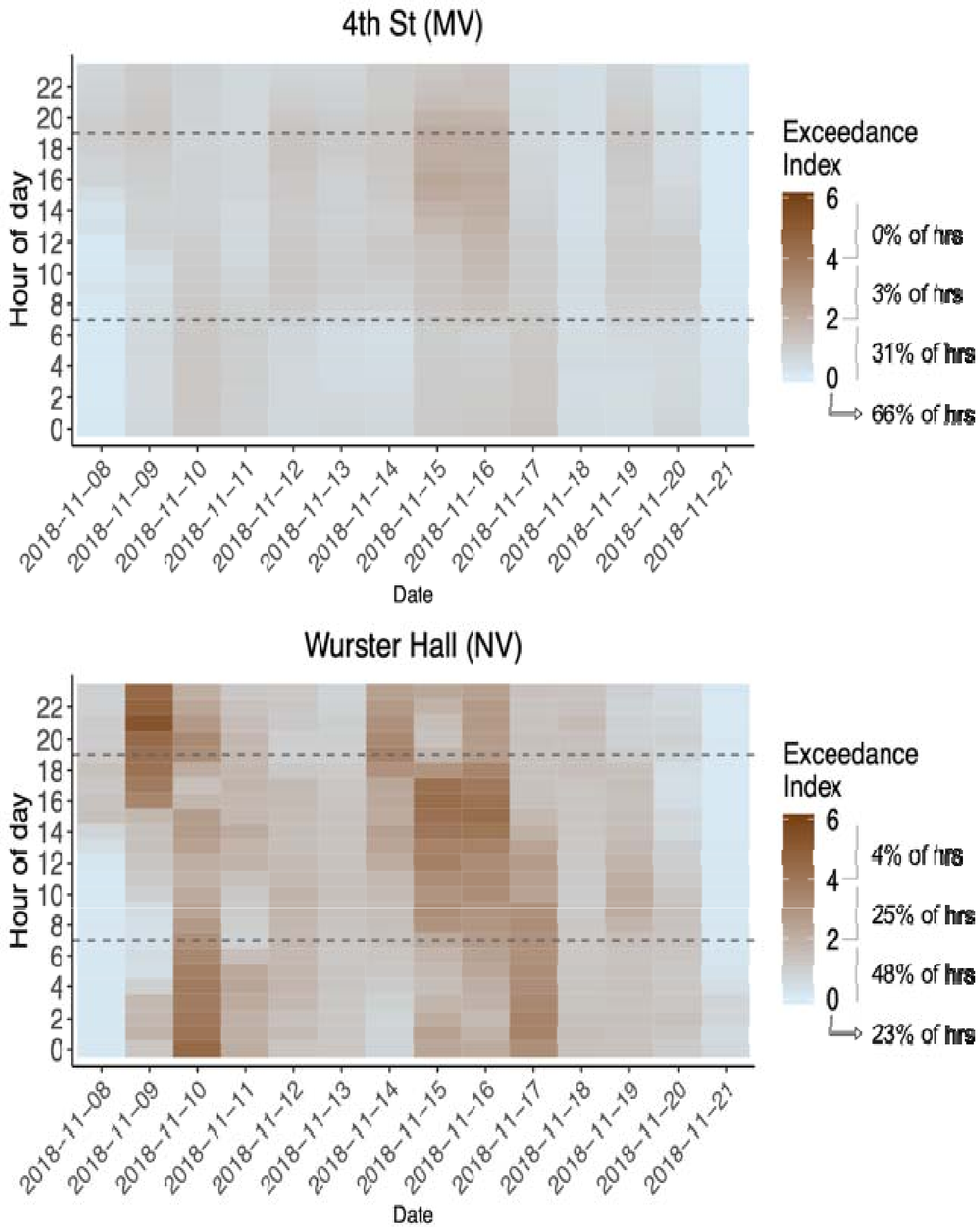

FIGURE 3 Exceedance index $PM_{2.5}$ heat map calculated for WHO 24 hour exposure guidelines at 4th Street (top) and Wurster Hall (bottom)

Conclusion and future

The tool we developed can be used to quantify in real time building resiliency to extreme air pollution episodes (wildfire generated smoke). Such analytical tool might also offer the ability to provide information for planning and in real-time to identify buildings that can serve as clean-air shelters during future fire events or point out most effective interventions. Future studies should be scaled up to a larger cohort of buildings. Unfortunately, such fire events are expected to be more likely due to climate change and continued development in forested areas.

References

Pantelic J, Dawe M, Licina D (2019) Use of IoT sensing and occupant surveys for determining the resilience of buildings to forest fire generated $PM_{2.5}$. PLoS ONE 14(10): e0223136.
https://doi.org/10.1371/journal.pone.0223136

Bayesian Analysis Method to Improve Research on Glare

Michael Kent, Toby Cheung, Sergio Altomonte, Aleksandra Lipczyńska and Stefano Schiavon

Being able to replicate findings is a fundamental part of conducting reliable research. When attempting to replicate glare studies, results have led to inconsistent findings. Even when using the same glare prediction model, studies have seldom used statistical tests designed to compare results with each other, and data used in these studies have not commonly been publicly shared. We think these practices must change to make building science research more reliable, efficient in the use of resources and effective. A similar improvement is happening in the field of thermal comfort, for example, with the development of a database merging the results of thermal comfort studies done in real buildings all over the globe (database, paper).

To address this replicability issue, we proposed a Bayesian approach that allows us to build on the work of others. To test it, we applied it to a specific problem in glare research — the effect of order bias that we detected in our previous work (order bias occurs when subjective criteria are evaluated in a strict sequence, for example, first the lowest criterion and then others in increasing order of magnitude). We performed a laboratory test with 55 participants and asked them to evaluate glare using a newly developed glare scale created by the Berkeley Education Alliance for Research in Singapore ('BEARS'), shown in Figure 2.

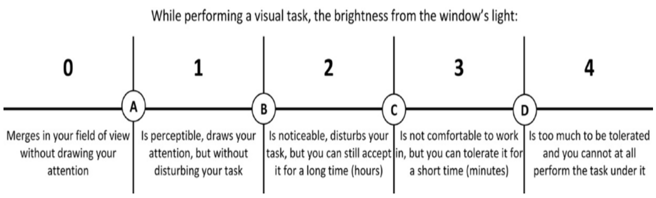

FIGURE 2 The BEARS scale of subjective glare evaluation used to measure the magnitude of visual discomfort.

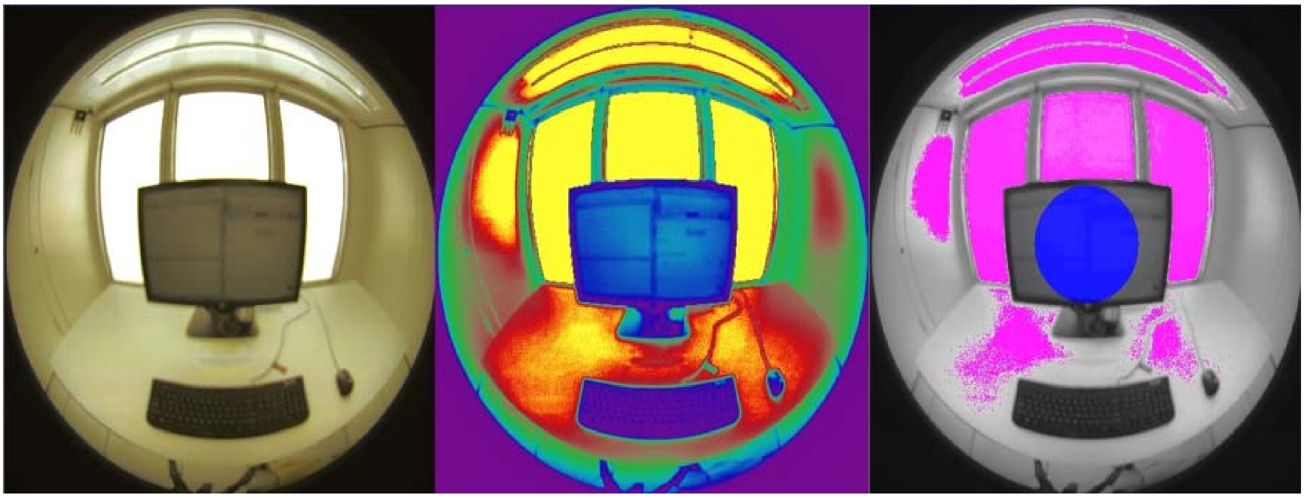

FIGURE 1 Example of a high dynamic image constructed from the seven low dynamic images captured using a camera with fish-eye-lens (left); False-colour Photosphere luminance map with Radiance image formatting (centre); Evalglare image with a blue circle at the centre of the screen representing the point of visual fixation. Pixels highlighted in pink surrounding the screen represent the identified glare sources (right).

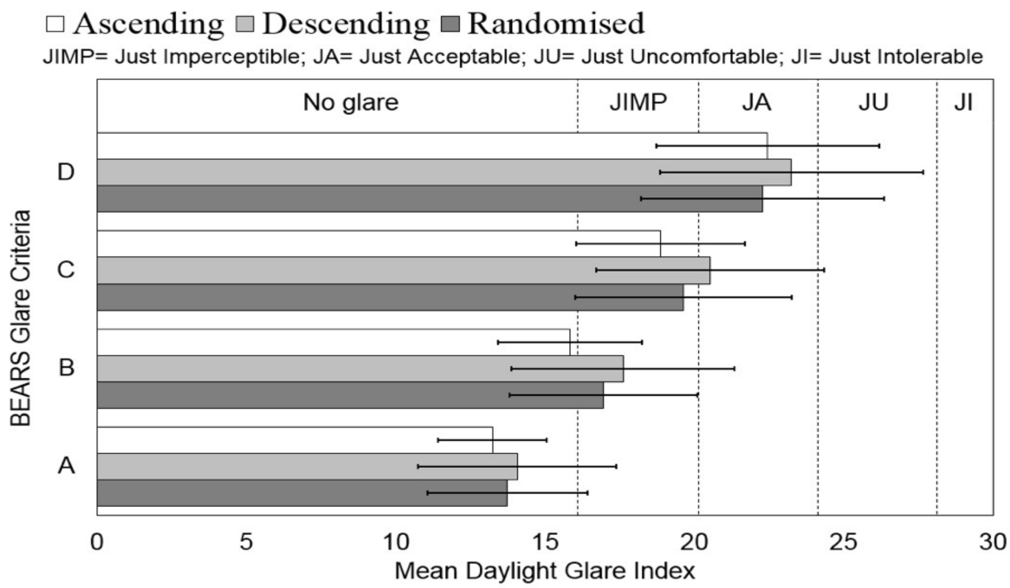

FIGURE 3 Mean Daylight Glare Index values for the three sequences and the four glare criteria found on the BEARS scale. The error bars show the standard deviations.

We performed the tests in three order sequences: ascending, descending, and randomized. We found that the study participants have different thresholds depending on the order of their exposure, as shown in the figure 3. We used Bayesian inferential tests to compare the effect of order bias detected in the previous study to results of the new experiment. The results showed a close replication, highlighting that the order bias effect found in the original study was also present in the new data.

We believe that the wider application of Bayesian methods and the making of the collected data open-source can lead to improved and new glare models. This in turn, will help provide better design solutions.

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SMART & ENERGY TECHNOLOGIES

Assessment of Cyber Security for Smart Building IoT System

Nishant Kumar, Krishnanand Kaippilly Radhakrishnan, Sanjib Kumar Panda

Today, to increase the user comfort level, all commercial and residential buildings are integrated with smart electronics appliances, which provide user-friendly high-level operation and wide range of control ability. The wide range of control ability is possible due to the involvement of the Internet of Things (IoT), which provides seamless interactions between physical environment and the smart devices. The IoT ecosystem is formed by enabling sensors, actuators, data canters, middleware and communication network, where different technologies are involved, such as networking technology, software technology, control technology etc., for information and optimal decision making.

The significance of the economic impact of IoT enabled smart buildings is well proven on the commercial level as well as at governmental level. It provides an optimal use strategy for appliances, without compromising user comfort and minimum electricity charges, which reduces the peak demand on the grid and provides financial support to the consumer. It also optimises the use of parking space, which is the key issue of every city. Video surveillance and its analysis become very much easier, which is manually impossible. Due to real-time distributed information, water and electricity demand forecasting, planning and quality management become easier, as well as during fault, it helps in location detection. Therefore, today data can be considered as blood and IoT system is the heart of the society.

However, high flexibility always comes with a high-security issue. Similarly, in IoT enabled smart building, cybersecurity is the key challenge. Previously, different manufacturers of the different buildings follow different automation and communication protocols, which provides space to add compatible data addition or manipulation.

In the modern automation and communication system of Smart Building Management (SBM) uses advanced and common protocols such as Operational Technology (OT) protocol follows ModBus or BACnet and Information Technology (IT) protocol follows HTTP or FTP. However, still, the junction node of OT and IT is the key point for hackers. Easy disconnection and coupling on the junction node give a route for traffic analysis. Through this traffic reconnaissance, hacker performs scanning of IP addresses and vulnerabilities of the system. After that the hacker can go for man-in-the-middle attacks, channels jamming, plantation of viruses, or can take permanent access as administrator. Through these they can easily retract the important data, which harms individual or damage on a societal level. Therefore the " De Facto Operational Model" for SBM needs to change.

Setting aside organisational barriers and acknowledging the IT/OT disconnect is the critical first step towards implementing and operating cyber-secure smart building control systems. Therefore, try to follow IEC 62443 global set of cybersecurity standards, which improve safety, availability, integrity and confidentiality of systems used for personal/commercial/industrial automation and control. From a user point of view, the five key steps for secure SBM system are as follows:

1. Assess and protect legacy OT building control systems.
2. Choose IoT devices and vendors that follow a secure development lifecycle approach.
3. Implement secure OT building control system architectures.
4. Bridge the secure OT building control systems through an IT security monitoring zone.
5. Keep all software UpToDate and run full scan periodically.

From a developer or support provider point of view, the five key steps for secure SBM system are as follows:

1. Teams of OT and IT must work together to create a more secure system.
2. Always perform testing on recent practical data.
3. Frequently provide updates for every new bug.
4. Divide the limit of overall control access in three parts, which are user access limit, customer support provider access limit and developer core committee access limit.
5. Provide freeze option and factory reset option for critical conditions.

Apart from these, the role of IMDA (Info-communications Media Development Authority) and their IoT/cybersecurity initiatives are also very important, which needs to make policies and standard for types of equipment. These policies secure data security and, standards secure equipment quality, which are necessary for the open market for consumer security. In the end, the most important role in cybersecurity is of user intelligence because majority of the time hackers "phishing attack" create loopholes in the system. In a phishing attack, step by step hacker gives allurement and takes a few confidential information, which are essential for administrative control. Therefore, awareness and alertness of end-user are extremely important.

FIGURE 1 The IoT Ecosystem for Smart Building

Multi-criteria Decision-making for Sustainable and Resilient Building Design under Uncertainties in Singapore



Yidan Gao, Umberto Alibrandi and Khalid Mosalam

Uncertainty in building performance

Building performance simulation is a widely accepted method to predict energy performance during the design stage. A simulation model helps to predict the energy performance of a building and select the most energy efficient design strategies and alternatives. This is helpful to design new buildings and/or retrofit old ones. However, large discrepancies have been observed between predicted and actual energy performance. This is attributed to several sources of uncertainty, e.g., occupants' activities, weather conditions, and material properties. Figure 1(a) compares the Energy Use Intensity (EUI, kWh/m^2) between simulated (predicted) energy consumption modelled during the design phase and the measured energy consumption for 62 LEED certified buildings in the United States. Figure 1(b) shows that in some cases, the actual mean value of material density would be far from quoted value provided by manufacturers. Some researchers found that thermal conductivity is correlated with material density and moisture conditions.

The geographical location and maritime exposure make Singapore's climate very humid (relative humidity in the range 70-80%). Thus, the moisture effect on the uncertainty of thermal conductivity of materials cannot be neglected.

In this research, a case study for a typical room in Singapore is considered. The floor, ceiling and three walls are made of 150 mm concrete with two 20 mm cement sand plaster. In the remaining wall (east facing), two alternatives façades are considered: (i) similar to the other walls, traditional 150 mm concrete façade, with two 20 mm cement sand plaster layers outside concrete layer, and (ii) phase change material (PCM) façade, composed of one 10 mm phase change material in the core, two 70 mm outside concrete layers and two 20 mm cement sand plasters in the most outside layers. The described PCM façade is expected to reduce the temperature inside the room in the daytime and to release the heat in the night. An integrated approach based on multi-criteria decision making under uncertainty is presented to select the optimal design alternative.

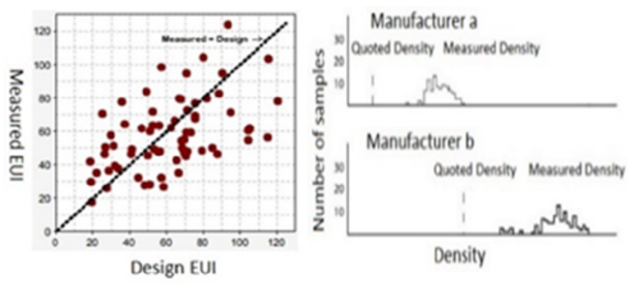

FIGURE 1 (a) Measured versus design EUIs. (b) Spread in measured densities and their relation to quoted density for lightweight concrete blocks supplied by two different manufacturers

Multi-criteria decision-making platform

Two criteria have been considered: energy consumption and economical cost (initial cost + equivalent annual cost). Energyplus V9.0 and R package are used here to evaluate the value of energy consumption. Detailed insights into energy usage are considered. At first, sensitivity analysis has been performed for all material parameters related to the façade. The most important variables have been screened according two different criteria: (i) their degree of uncertainty, and (ii) how they may affect the energy performance of the buildings (Mosalam and Alibrandi, 2018).

As a result, the following random variables have been selected with reference to the annual energy consumption: thickness, conductivity, density and specific heat of concrete layer in the concrete façade, thickness of the PCM layer, thickness, conductivity, density and specific heat of the outside concrete layer and the inside concrete layer in the PCM façade.

For economical cost, the market unit price of concrete, PCM, and cement sand plaster are selected as random variables for the initial cost, which include installation fee. In order to consider both the time value of money and energy saving cost using PCM façade compared with traditional façade, Equivalent Annual Cost (EAC) is adopted.

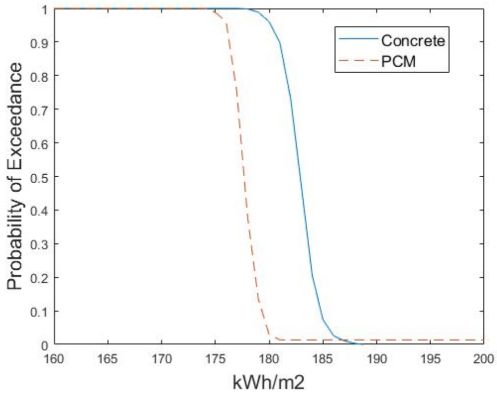

FIGURE 2 Criteria 1: yearly energy consumption per total building area.

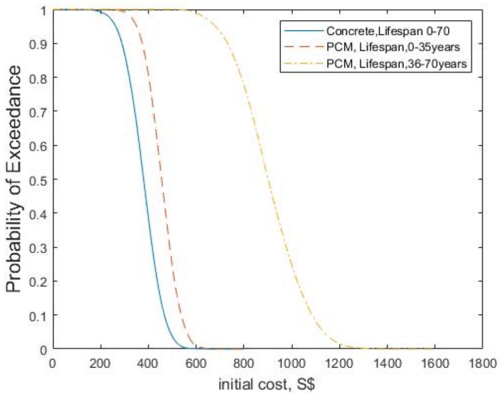

FIGURE 3 Criteria 2: Initial cost of façade systems

The case study results show that the criteria are conflicting. In terms of energy consumption, PCM is performing better than concrete façade, as expected (Figure 2). However, the initial cost is higher especially considering a lifespan longer than 35 years (Figure 3). Since after 35 years, there is another initial cost for pcm façade, there is a discontinuity in EAC of PCM in Figure 4. From the other side, after around three years, the EAC for PCM is lower than that for concrete, which means lower lifecycle costs. For a lifespan of 50 years, the two alternatives have comparable cost (Figure 4), and thus PCM can be considered the best option.

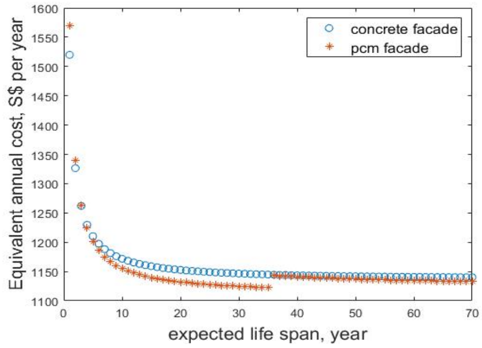

FIGURE 4 Mean value of EAC for two façade alternatives versus year

References

Mosalam K.M., Alibrandi U., Lee H. & Armengou J. (2018). Performance-based engineering and multi criteria decision analysis for sustainable and resilient building design, Structural Safety, 74, 1-13

AI AND MACHINE LEARNING

Using Wearable Sensors to Predict Thermal Comfort

Shichao Liu, Stefano Schiavon, Hari Prasanna Das, Ming Jin, and Costas J. Spanos

Predicting thermal comfort is difficult. We recently showed that the most used thermal comfort model, the PMV, predicted the thermal sensation correctly only one-third of the time. One way to have better predictions could be to directly measure physiological parameters using wearable sensors. To test this hypothesis, 14 participants wore lab-grade wearable sensors (e.g., heart rate, skin temperature, accelerometry) for two weeks (Figure 1) and self-reported their thermal preference (cooler, no change, warmer) as many times as possible every day. Each day they wore the sensors for at least 20 hours in order to capture their daily activity dynamics, which may not be covered in a controlled lab environment.

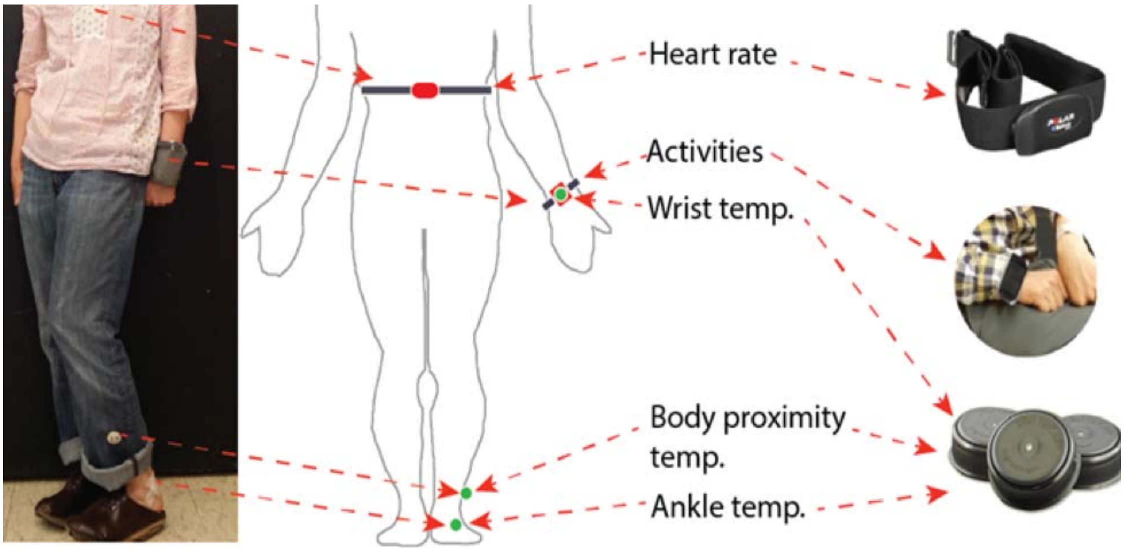

FIGURE 1 Physiological sensors and wearing locations

We related the thermal preference to the measured parameters (Figure 2). We then built personal comfort models using machine learning. We found that the predictive powers of the personal comfort models were approximately 24%/78%/79% (Cohen's kappa/accuracy/AUC), much higher than the conventional PMV and adaptive models as expected. However, the predictive power is highly dependent on thermal sensation. For example, the Cohen's kappa is only 3% (0% means random guess) when the thermal sensation is from -0.5 to 0.5 as the general design practice aims (Figure 3).

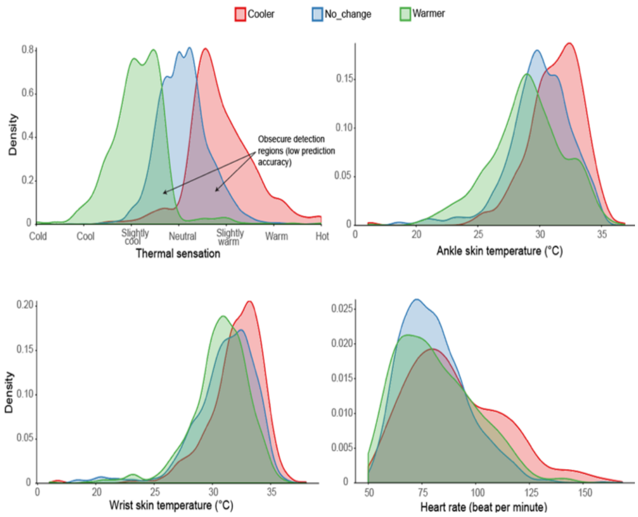

FIGURE 2 The distributions of thermal preference votes

In the study, we also calculated the predictive powers of different features combinations because we wanted to explore the trade-offs between predictive accuracy and costs related to those inputs collected. We found that the skin temperature measured at the ankle provides a better prediction of thermal sensation than the measurement taken at the wrist.

For more details on the paper: Shichao Liu, Stefano Schiavon, Hari Prasanna Das, Ming Jin, and Costas J. Spanos. "Personal thermal comfort models with wearable sensors." Building and Environment (2019): 106281. 10.1016/j.buildenv.2019.106281

Open-source version:
https://escholarship.org/uc/item/3fb0p5gk

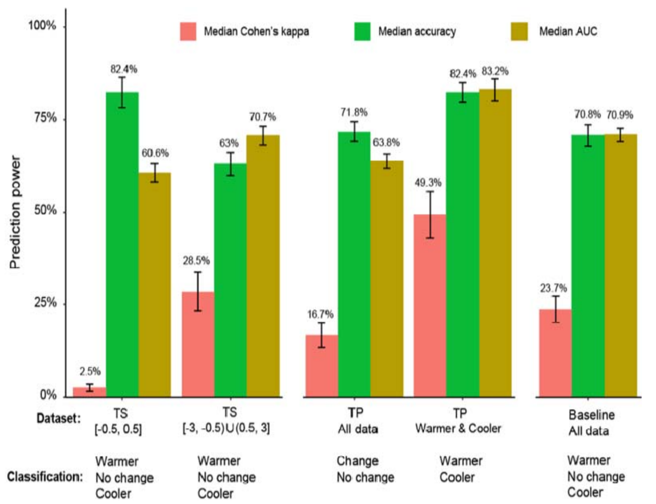

FIGURE 3 Predictive power with different thermal sensations and classification methods

The SinBerBEST Daylight Emulator

I Komang Narendra

Daylighting is one of many crucial aspects to consider in the design of a building. When utilised in conjunction with controls and sensors, daylight can help reduce the energy consumed from artificial lights and promote levels of visual comfort and satisfaction. Based on research, the building façade envelope can have a strong influence on both the artificial and natural light inside the occupied space. To study these unique influences, SinBerBEST have setup a specialised test-bed chamber equipped with a fully glazed façade and a controllable indoor lighting system. To emulate the behaviour of daylight inside the test-bed, an array wall of light emitting diodes (LEDs) which can be varied in both brightness and colour temperature is used. This system is known as the Daylight Emulator.

The Daylight Emulator array consists of eight wall panels covering a total area of 27 m2 (9 metres in length and 3 metres in height). Each wall panel consists of a mixture of 'cool' and 'warm' LEDs (Figure 1), which are mounted in an alternating arrangement. Between the array wall of LEDs and glazed façade, a membrane with diffusive properties is used to uniformly distribute the light across the area of the window. The Daylight Emulator is capable of producing a maximum illuminance of approximately 100,000 lux and colour temperatures ranging from 2400 to 10,000 K, respectively. At its maximum output, the Daylight Emulator has a total power rating of 32 kW.

The Daylight Emulator can be programmed to simulate a range of different time conditions (i.e. sunrise or sunset) and sky conditions (i.e. a clear sky with no clouds). All lighting controls that are linked to the Daylight Emulator can be accessed via a web-browser user interface. At SinBerBEST, the Daylight Emulator has been setup for two different test-beds. This allows a wide range of daylighting-based experiments to be conducted by SinBerBEST researchers. Due to the wide range of flexibility over the test-beds, studies with different research objectives have been conducted to investigate, respectively, indoor lighting controls, translucent concrete panels, glare, and the influence of window view.

There were a few studies conducted where the Day Light Emulator was used extensively:

Indoor Lighting Control Development.
In practice, light is delivered into buildings so that it achieves a minimum level of light and that it is uniformly distributed on a desk level surface. Since this light can originate from either artificial or natural sources of illumination, the active use of daylight can help reduce the reliance placed on electrical power lights and thus save energy. Both test-beds are equipped with light (lux) meters that are placed on a regular grid, which are used to accurately measure the amount and distribution of light falling on surfaces of interest. These lux meters have been used in the development of controls that can be used to reduce energy from indoor artificial lighting. When light from the Daylight Emulator is received on a lux meter, a feedback signal will be sent to reduce the output of a nearby ceiling light in that area of the room – reducing its output so that the target light level is achieved. In other words, if the target level is 500 lux and the Daylight Emulator provides 450 lux, then a nearby ceiling light will be dimmed so that it provides the remaining 50 lux that is required. Conversely, should the incoming daylight excessively exceed the target light level, a feedback signal will be sent to the roller blind(s) to reduce the harsh light received on the surface. These controls are also programmed so that when the light is below the target level, the roller blinds will be retracted. Because of the high degree of control over many important parameters, the SinBerBEST team has been able to develop and test the lighting controls under a wide range of conditions in a relatively short period of time.

Daylight Fenestration via Translucent Concrete Panel
The study of Translucent Concrete Panels (TCP) is one of the key areas of our research. This special concrete panel is embedded with multiple fibre optic tubes, which can be used to replace conventional glazed materials. This allows the building façade envelope to maintain a suitable window-to-wall ratio, whereby the fibre optic tubes act as the window to allow daylight to enter into

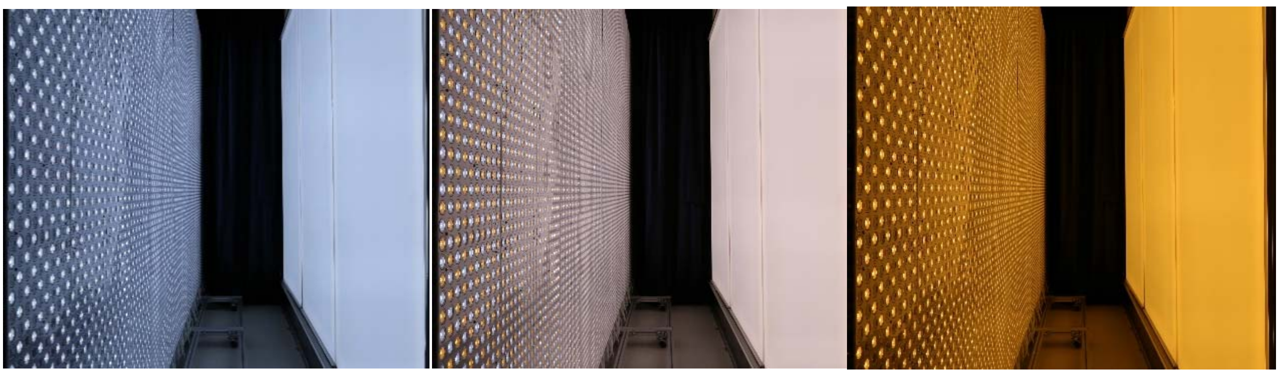

FIGURE 1 Left to right: Cool Light for clear blue sky, Mixture of cool and warm light for cloudy sky, Warm light for sun set and sun rise

the building. TCP have been installed in the façade of wall of a test bed and lux meters have been used to evaluate the daylight performance. By varying the light intensity of the Daylight Emulator, tests are used to determine how well light is transmitted through the TCP and into the room.

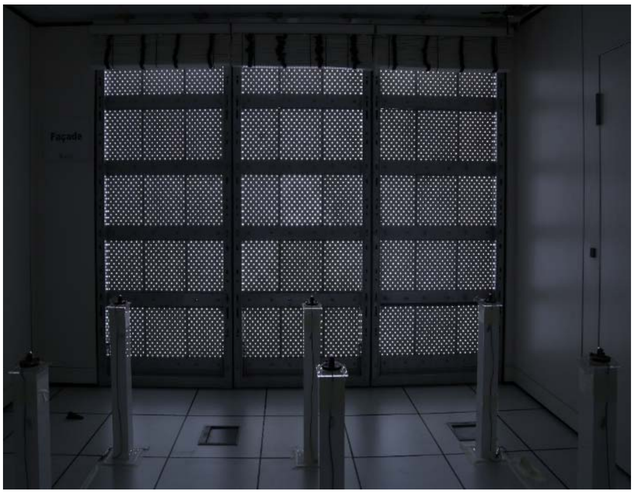

FIGURE 2 TCP facade wall, lux meters measuring light from the Daylight Emulator

Glare and Visual Comfort Study

The Daylight Emulator can also be used to produce excessive levels of light that causes a sensation of visual discomfort commonly known as glare. This is a phenomenon that often leads building occupants to use blinds to protect themselves against high levels of brightness from the window, and resultantly reduces the overall levels of daylight inside the building. An experiment was designed using human participants, whereby they were asked to make self-evaluations of glare that they had experienced from the Daylight Emulator. The objective of the experiment was to test the reliability of the predictive glare index formula used to minimise glare from windows.

FIGURE 3 Glare study showing participant providing their self-evaluations

Besides allowing daylight to enter into the space, windows in buildings also contain dynamic visual information from the outside environment. This is delivered to the occupants in the form of a view and is an essential part of any window design. The Daylight Emulator setup was modified by mounting photographic images behind the glazed façade and using the LED array to backlight them. This gave the impression of a daylit window view, which allowed different types of experimental studies to be performed. Using 30 different images captured around the National University of Singapore (NUS) campus, another study involving human participants was performed. The overall aim of this study was to evaluate the importance of having a window view in the building.

FIGURE 4 Window view study showing the experimental setup (left) and participant viewing the window view image (right).

SinBerBEST Scientific Advisory Committee Meeting

The Scientific Advisory Committee (SAC) meeting was held on August 6th, 2019 in CREATE Tower in Singapore. This meeting is held in accordance with SinBerBEST's research contract with the National Research Foundation (NRF). Attendees in the meeting include the SAC members, Drs. Lim Khiang Wee and Adeline Lim and Md Rafi Othman from NRF and Dr Gao Chun Ping from the Building Construction Authority (BCA). At this review meeting, the theme leaders from the SinBerBEST program presented on their theme's progress achievements and future plans. The SAC provided valuable inputs to the program and recommended avenues to be taken. The program thanks the SAC for their review and look forward to further success in future outcomes.

SAC meeting at the CREATE Tower.

Visiting Faculties

Pawel Wargocki

Prof. Pawel Wargocki, currently an Associate Professor in the Department of Civil Engineering, Technical University of Denmark, is an indoor climate scientist with over 20 years of research experience. His works have fundamentally influenced our understanding of ventilation and indoor environmental quality's impact on occupant performance. His recent works have focused on human emissions and performance of sustainable buildings.

As part of his ongoing collaboration with SinBerBEST, Prof. Wargocki was with us during the second week of September. Theme A members have been working with him on the design of a comprehensive study of the impact of elevated levels of carbon dioxide (CO_2) on occupant performance and physiological and psychological markers of cognitive effort. The rising atmospheric levels of CO_2 make this study very relevant and timely. During this visit, the efforts were focused on finalising the experimental design and on going over some preliminary results obtained on physiological effects of working in different CO_2 concentrations. He also shared with the team his recent work on indoor environment benchmarking for buildings that have undergone deep energy renovations, ALDREN TAIL. Collective discussions between Theme A members and Prof. Wargocki deliberated future, holistic examination of occupant comfort in sustainable buildings.

Elliott Gall

Prof. Elliott Gall is currently an Assistant professor at Portland State University and the director of the University's Green Building Research Lab. His research interests focus on physics and chemistry of indoor and urban air quality, human exposure to air pollution, and heat and mass transfer in the built environment.

Theme A has recently established a collaborative venture with Prof. Gall and as part of this, he was with us from the 28th of August to the 17th of September. During his stay, the primary focus was on carrying out a pilot study looking into how the burden of cognitive tasks changes human emissions. The study was carried out in the SinBerBEST climate chamber, over one week, with 16 human participants. Prof. Gall collected air samples for later, detailed spectrometric analysis of volatile organic compounds emitted by the occupants while they were relaxed and while they were working on cognitive tasks. During his stay, he also planned with the Theme members studies of personal exposure to indoor and outdoor air pollutants, to be carried out in the near future.

Events and Outreach

Dr. Li Jiayu will be attending the Healthy Buildings 2019 Asia and Pacific Rim (HB2019 Asia) conference in October 22-25, 2019 at Changsha, China.

Professors Chandra Sekhar, Adrian Chong and Clayton Miller attended and presented papers the 2019 ASHRAE Annual Conference in Kansas City, Missouri, USA.

Professor Alberto Sangiovanni-Vincentelli and Dr. Baihong Jin attended and presented papers in 2019 IEEE International Conference on Prognostics and Health Management in San Francisco and 2019 IEEE International Conference on Machine Learning and Applications in Boca Raton. Papers presented were in the topics of fault diagnosis and prognosis and machine learning.

Professors Tham Kwok Wai, Stefano Schiavon and Dr. Zuraimi Sultan provided invited speeches at the 14th International Congress of Physiological Anthropology in 24-27 September at Singapore.

New Staffs

Arulmani Natarajan, *Senior Instrumentation & Control Engineer*

Ivanna Hendri*, Design Engineer*

Kavitha D/O Krishnasamy, *Administration & Human Resource Executive*

Koh Tsyr Harn, *Senior Research Engineer*

Sivasithamparam Karvannan, *System Administrator*

Interview with Prof. Elliott Gall

For this issue, we talked with Dr Elliott Gall who is an assistant professor at Portland State University (PSU) in the department of Mechanical and Materials Engineering. Professor Gall obtained his Ph.D. at the University of Texas, Austin. He was recently acknowledged with the 2018 Yaglou Award from the International Society for Indoor Air Quality and Climate for his work on indoor ozone chemistry. His research and teaching seeks to improve the sustainability of the built environment through an understanding of the intersection of indoor air quality, urban air pollution, and human exposure to air pollutants. We are fortunate to be working with Dr Gall in Singapore again as a collaborator. In this interview, we took the opportunity to learn from Dr. Gall's experiences with SinBerBEST.

Tell us about your area of research and why it is so important?

I study indoor and urban air quality. My group does experiments and modelling to understand sources, sinks, and transformations of indoor and urban air pollution. We spend around 90% of our time indoors, and over half the world's population lives in cities. There exist many air pollution sources and transformation processes in both the urban and indoor environment that may adversely impact human health. This makes indoor air in buildings in cities an especially important microenvironment for understanding air pollutant dynamics and air pollution exposure.

What made you joined SinBerBEST back in 2003?

I joined SinBerBEST in 2013 for a few reasons. The first was that it presented an opportunity to work on a new set of problems that were related to the area of my Ph.D.: how to improve indoor air quality without incurring a major energy penalty. SinBerBEST framed this question specifically for the challenging case of the tropics, where building energy use can be higher due to a year-round climate with high heat and humidity. There was also a chance to work within a team of postdocs and faculty, which included a number of well-known experts in the field. Finally, my wife and I had always hoped to have an opportunity to live and work abroad, and to really experience a new culture.

Prof Gall and Drs Li and Mishra preparing IAQ experiments in the test bed chamber

What were your goals in SinBerBEST and did you achieve all of them?

I had a various goals that were in some way related to my time as a postdoc in SinBerBEST: professional goals that were practical and specific, other professional goals that were more abstract, as well as personal goals. My practical goals were to ensure I achieved outcomes that would build my CV and make for compelling applications to faculty positions. That included publishing papers, improve proposal and academic writing, and initiating new research within SBB. I'd recommend that any postdoc consider such practical outcomes, as most postdocs are, by definition, not intended to be long-term employment. More abstractly, I had hoped to grow expertise in a few new analytical skills by leveraging resources and new collaborations in Singapore. Finally, my wife and I had personal goals that included traveling to other SE Asian countries to experience life in the region, but while also settling in to Singapore in a way that it felt like a second home.

After 3 years in SinBerBEST, what can you tell about your impressions working in SinBerBEST and living in Singapore?

I worked for almost 3 years in Singapore as a postdoc, and returned for 3 weeks in the summer of 2019 to conduct experiments with SBB2. As a postdoc, it was a major life change, and took time for me to adapt and adjust to a new place and what was, at the time, a new research institute. In hindsight, I feel that Singapore can be an excellent place to conduct research, but can also be a difficult place to initiate research. The latter is, to an extent, true of anywhere. In Singapore, I get the sense that there are major funding initiatives that can provide intellectual freedom and opportunities that are unique. For example, it is exceedingly rare in the US to see funding opportunities like those provided to the CREATE research centers and to centers at NTU and NUS. I expect that these investments will pay off for Singapore for many years to come, as facilities like SBB's testbed become published in the literature and well-known to researchers around the world.

What do you hope to do next?

I hope to continue to grow my own research group at Portland State, where my lab, the Green Building Research Lab (ww.pdx.edu/green-building) conducts research on indoor and urban air quality. My hope is to focus on a few key research areas, including conducting work focusing on better linking air pollution measurements, mitigation measures, and health outcomes. My group has spent the past few years doing field work, and I so am also ready to slow down on field work and spend a bit more time on controlled lab experiments with a more fundamental focus.

What are you doing now with the current SinBerBEST researchers?

This past summer I joined Theme A researchers (Prof Schiavon, and Drs. Mishra and Li) to conduct controlled experiments in the test bed concerning human emissions of VOCs under varying emotional states. The experiments were a success, and it was very exciting to see the test bed and have a chance to take full advantage of the suite of capabilities that I remember being worked on when I was a postdoc. Thus far, our data looks very interesting – we hope to complete analysis and see the full story by the end of this calendar year. A big thanks to all the lab staff and researchers who helped make it possible.

We wish Professor Gall all the best.

SinBerBEST aims to deliver energy efficient building technologies for the tropical built environment, while optimising human comfort, safety, security, and productivity within the building. This interdisciplinary research project is organised into five themes: A - Human-Building Nexus; B - Smart Technologies and Resilient Buildings; C -Agile Design for Energy Efficiency and Human Comfort; D - Data Analytics; and E - Test Beds and Deployments

If you are interested to learn more about our program, participate in our research or use our test-bed facilities, please contact Dr. Zuraimi Sultan at zuraimi.sultan@bears-berkeley.sg or visit us at www.sinberbest.berkeley.edu

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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