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Thermal Comfort Tool | Occupancy Estimation and Prediction | Representative Daylight Illuminance Distributions| Fault Detection and Diagnosis| Benchmark Model and Technology Assessment

Singapore Building Operations During COVID-19 Pandemic

SinBerBEST Recommendations for Singapore Buildings during COVID-19 Pandemic

In April 2020, The Super Low Energy Building (SLEB) Smart Hub, a portal for accessing and examining the latest green technologies with building proprietors, professionals, researchers, and policymakers, incorporated SinBerBEST's Air Conditioning and Mechanical Ventilation (ACMV) consummate recommendations aimed at minimizing the further spread of COVID-19 in Singapore during the Circuit Breaker (CB) period. This document is targeted at the commercial, institutional and residential buildings. In mid May 2020, the guidelines have been refined to provide recommendations beyond the CB period. The latest version of these guidelines are provided below and will be further developed in the coming months.

Background

On 13 March 2020 World Health Organization (WHO) declared COVID-19 as a pandemic [1-2]. Individual hygiene, disinfection practice, isolation, and physical distancing measures have been advocated by the WHO and Singapore Ministry of Health as the main means to control the spread of COVID-19 [1-9].
With the intent to reduce the risk of COVID-19 virus spread further, SinBerBEST provides this Air Conditioning and Mechanical Ventilation (ACMV) expert recommendations document for Singapore commercial, institutional and residential buildings. This document is to provide guidance for:

- Building Owners and Facility Managers that operate buildings;
- Managers and Administrators for schools and childcare centers; and
- Homeowners of public and private residences.

This document follows the use of the precautionary principle to reduce potential risks associated with plausible routes of COVID-19 spread [10-11]. This document takes into account the context in Singapore [12-13]. These are made based on our professional judgment using imperfect data specific to COVID-19 [14-17], yet are grounded in many years of research in the field of indoor air quality, mechanical engineering and exposure science and evidence collected from studies of other infectious agents [18-33]. These recommendations should be used after the recommended primary measures, for example, individual hygiene, disinfection practice, isolation, and social distancing measures (SDM) [1-9].

How COVID-19 spreads

The WHO reports [1] that "COVID-19 is transmitted via droplets and fomites during close unprotected contact between an infector and infectee. The airborne spread has not been reported for COVID-19 and it is not believed to be a major driver of transmission based on available evidence; however, it can be envisaged if certain aerosol-generating procedures are conducted in health care facilities. Fecal shedding has been demonstrated by some patients, and the viable virus has been identified in a limited number of case reports. However, the fecal-oral route does not appear to be a driver of COVID-19 transmission; its role and significance for COVID-19 remain to be determined."

We acknowledge that the airborne transmission route may not be the main pathway. Measures to reduce the potential airborne route may be secondary to others but should be applied if only small negative effects are caused by them or under some circumstances, particularly when ventilation is inadequate. Our recommendations are based on increasing ventilation rate [18-25] and enhancing air cleaning [26-28] as much as technically, environmentally, and economically feasible.

General Recommendations for Buildings

● **Set the outdoor air intake to the maximum setting in air-conditioned buildings**. In buildings with ACMV systems, outdoor air supply shall be set to the maximum setting to enhance dilution indoors. Outdoor air dampers should be opened to as high a percentage as possible with fans running in the high speed mode as indoor conditions permit. Operation times shall be extended to commence the system at least 2 hours before the first occupant arrives and switch off 2 hours after all occupants have left. For example, for office workers on staggered working hours with staff arriving as early as 7.30 am, leaving late at 7.30 pm, the recommended operation times will be from 5.30 am to 9.30 pm. Demand control ventilation and features that only turn on the supply air when the occupants are in the room shall be disengaged. If a carbon dioxide sensor is present, the closer the indoor carbon dioxide concentration to the outdoor value (410 ppm), the better.

● **Minimise recirculation in air-conditioned buildings**. For air-conditioned buildings that have the capacity to operate with 100% outdoor air (no recirculation), they should be operated under such conditions. The return air dampers shall be closed and the outdoor air intake damper fully opened. The operator shall verify that acceptable conditions are maintained indoors. If full closing of the recirculation air is not possible to achieve adequate comfort (for example, air temperature above 27), the recirculation air shall be kept at a minimum level and treated with high-efficiency media-based filters in place in the AHU and/or the indoor space

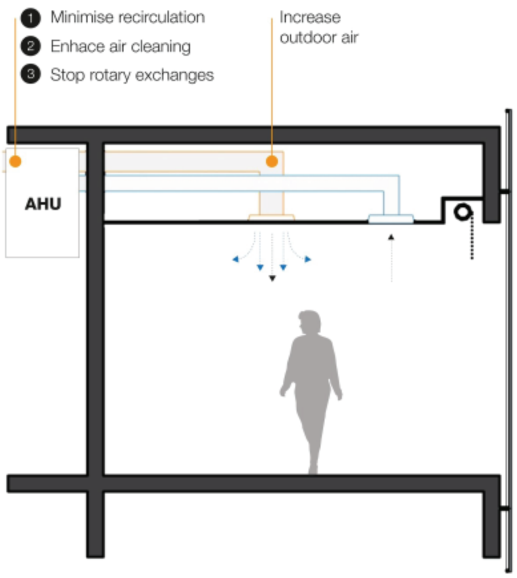

Fig. 1 Diagram showing some of the recommendations given for air-conditioned buildings.

deployed with localized air cleaning using HEPA-based PACs in the office (see below).

● **Air purging in air-conditioned buildings.** For air conditioned buildings, an air purging system should be operated twice a day (before and after working hours), introducing outdoor air into the space and discharging indoor air outside of the building at a minimum rate of 2 air changes per hour [12].

● **Stop rotary exchangers in air-conditioned buildings.** Rotary heat exchangers or heat wheels shall be switched off, leaks identified and sealed to prevent exhaust/recirculated air from getting entrained (bypass) into the supply air.

● **Maximise ventilation in toilets and common areas.** To avoid the possibility of fecal-oral transmission [32], the exhaust ventilation in the toilet shall always be kept on. Water seals in the plumbing system and use of toilet lid should be ensured to minimise the risks associated with under-pressure (lower pressure than outdoor). In common areas with a risk of crowd gathering, such as the entrance lobby, sufficient ventilation openings and air extraction/exhaust should be in place.

● **Consider the airflow pathway (air distribution) and occupancy layout.** Singapore Ministry of Manpower is enforcing safe distancing measures (SDM) in workplaces. As there have been reports on the association of airflows and spread of the COVID-19 virus [14], it is recommended the occupancy layout for social distancing take into consideration the airflow patterns and pathways (e.g. staggered layout instead of linear placement of live workstations). It is also recommended that workstations be rearranged so that employees do not face each other, or establish partitions if facing each other cannot be avoided. If fans are used, ensure that air does not get blown from one person directly to another.

● **Open windows and turn off or use less often air-conditioning in naturally ventilated buildings.** For naturally ventilated buildings with operable windows, windows shall be fully opened to allow air to flow indoors without obstacles, ideally in the opposite side of a building. Ensure safety requirements and acceptability of outdoor noise and/or air pollution are met. Increased air motion, such as from a ceiling, desk or standing fans, can be used. In buildings designed to be naturally ventilated (such as residential buildings), if air-conditioning is used, it is recommended that sufficient outdoor air be provided by keeping the windows a bit open in every room. For rooms lacking windows, the internal doors may be kept open. Air-conditioning can be used to provide comfort but higher energy use may be expected.

● **Enhance air cleaning.** High-efficiency media-based filters, preferably MERV 14 (ASHRAE 52.2) [34] or F7 (EN 779 / EN 1822) [35,36] shall be installed and operated in the Air Handling Unit that serves the return and outdoor air. The filters shall be properly installed and well-sealed to prevent filter bypass. The filters shall be regularly inspected to ensure no leakage and that it is not fully loaded. Adequate precaution shall be taken when changing the filters (done while the system is off, wearing personal protection equipment and gloves) and disposing of them.

● **Use Ultra-Violet Germicidal Irradiation (UVGI).** Other physical means of cleaning the air, such as UVGI (portable, upper room, AHU, and in the airstream) may be used [27]. Note that effective UVGI use will not be achieved for naturally ventilated spaces.

● **Use Portable Air Cleaners (PACs).** For mechanically ventilated buildings and air-conditioned schools and childcare centers, HEPA-based portable air cleaner may be deployed in a small room [28,37]. The selection of PACs depends on its performance (clean air delivery rates (CADR)). For larger indoor space, the numbers of PACs to be deployed shall be calculated on the performance of the PAC (CADR) and the space volume [37,38]. The use of PACs will have minimal impact in naturally ventilated spaces.

Recovering from Circuit Breaker [39] - associated building shutdown or operations

● Address potential Legioannaire's bacteria colonization. Waterborne pathogens, particularly Legionella bacteria, may colonize in stagnant water after an extended period of time in water mains, building plumbing lines, water heaters and cooling towers [40]. Building owners and operators shall assess and manage the risk of colonization, implement preventative measures and conduct remedial treatment if needed [40]. Prior to building re-entry, operate water systems, toilets, faucets, etc. on a regular basis (3-5 days) to

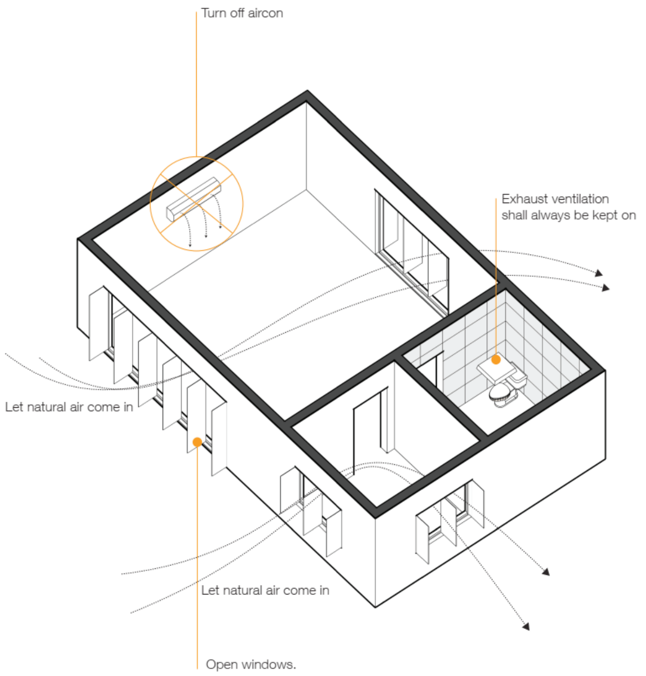

Fig. 2 Diagram showing some of the recommendations given for naturally ventilated buildings

avoid the accumulation of biofilm and other bacteria.

● Control indoor humidity to prevent dampness and mold growth. Occupancy patterns that have changed as a result of social distancing associated situations may reduce a building's heat load and affect the ACMV's ability to control indoor relative humidity levels. This may create conditions favourable for moisture and mold damage on building surfaces. It is recommended that ACMV systems operate effectively to minimise and control indoor relative humidity to avoid dampness and mold growth in occupied spaces and ACMV systems.

Specific recommendations for residences with Person of Interest (POI)

● A person of interest in this document is defined as an individual issued with Stay-Home-Notice (SHN) [3], Leave of Absence (LOA) [4,5], or displaying COVID-19 like symptoms and not a confirmed case.

● All the room windows of the POI shall be opened without opening the door that links to the rest of the house. If the toilet attached to the POI room has an exhaust fan, it shall be turned on all the time. The door gaps of the POI room shall be sealed to ensure the air does not leak into the rest of the house.

● If doable, high-efficiency HEPA-based PAC is to be deployed in the room of the POI. Adequate precaution shall be taken when changing the filters (wearing personal protection equipment and gloves) and disposing of them. Additionally, portable UVGI (portable or upper room) may be installed in the room of the POI.

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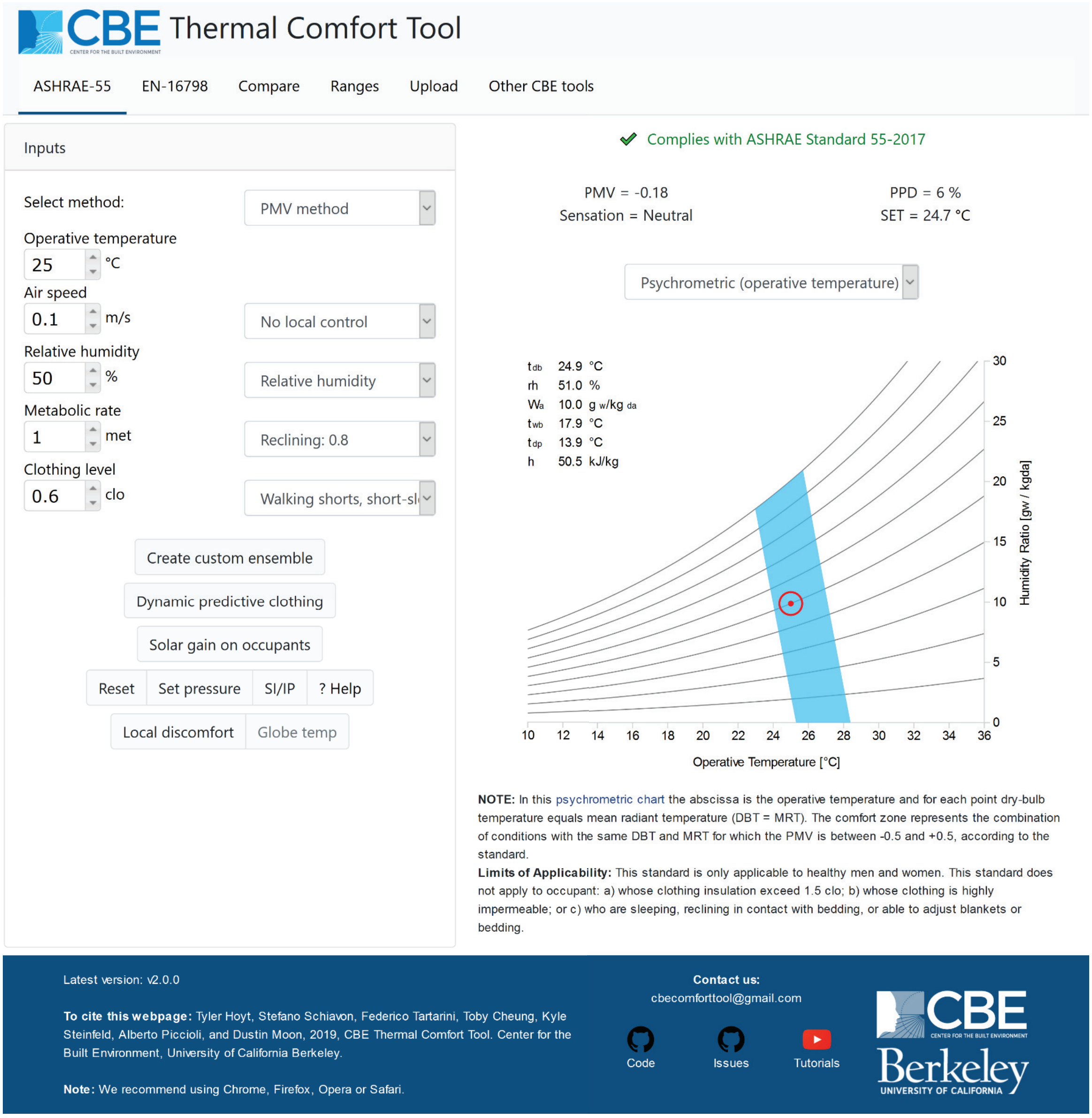
For a full list of references, please refer to the document in the website: https://www.sleb.sg/Context/ContentDetails/46/17

CBE Thermal Comfort v2. Web-based Tool for Thermal Comfort

Federico Tartarini, Stefano Schiavon.



Our research team recently released an improved version of the CBE thermal comfort tool. This free online tool allows building designers and others to perform thermal comfort calculations that comply with ASHRAE Standard 55-2017. This resource was adopted as the official ASHRAE comfort tool in 2017, and has been upgraded extensively since then. It is used by over 48000 unique users (94000 sessions in one year) from around the world each year, with many users from the United States (25% of the total users) followed by Brazil, Australia and the United Kingdom.

The tool is powerful due in part to its integration of numerous comfort models, including: (1) the Predicted Mean Vote (PMV) model for determining thermal sensation in still air; (2) the Standard Effective Temperature (SET) model for determining the effect of air movement; (3) the adaptive model for buildings without mechanical conditioning; (4) the SolarCal model for solar gain on people; (5) the dynamic predictive clothing model; and (6) several local discomfort models (radiant temperature asymmetry, draft, ankle draft, vertical air temperature difference, and floor surface temperature).

The CBE thermal comfort tool can serve many use cases. For example, one can compare various design scenarios, assess the effect of the variation of one variable (for example air speed) on the thermal comfort range, to calculate the major thermal comfort indices (PMV, Predicted Percentage of Dissatisfied (PPD), Cooling Effect (CE) and SET) for a large set of measured or simulated data; and to accurately model the mean radiant temperature in a room. Below we provide a brief summary of the improvements with this release:

● We added an Upload Tool that allows users to upload time-series, or large set of input parameters and it automatically calculate: PMV, PPD, SET, and CE. This may allow users to perform exceedance predictions (e.g. annual or seasonal) for simulated or real buildings.

● We also added a display option for 'heat losses vs. air temperature' to the pull-down menu on the ASHRAE-55 tab. This chart i The user can also selectively choose which lines to plot by clicking the relevant labels in the legend.

● Responsive and improved design: We created an improved layout and made it responsive to screen size so it can be used with mobile devices. We also made clearer which input parameters are allowed to vary and which are constant.

● Compare Tab: For each set of inputs a user can now select whether or not or not to use air speed control.

● We added link to the MRT Tool. Users can model the spatial resolution of mean radiant temperature (MRT). The MRT Tool can be accessed using the MRT Tab in the top right corner of the CBE thermal comfort tool.

● We added brief descriptions under each chart to explain the limits of applicability of the standards.

●We added practical limits on user inputs. For example, users can only select a value of clothing insulation up to 1.5 clo.

● Psychrometric variables are now interactive on the chart for 'relative humidity vs air temperature.'

● Users can now log issues or request new features by clicking the relevant button at the bottom of the page.

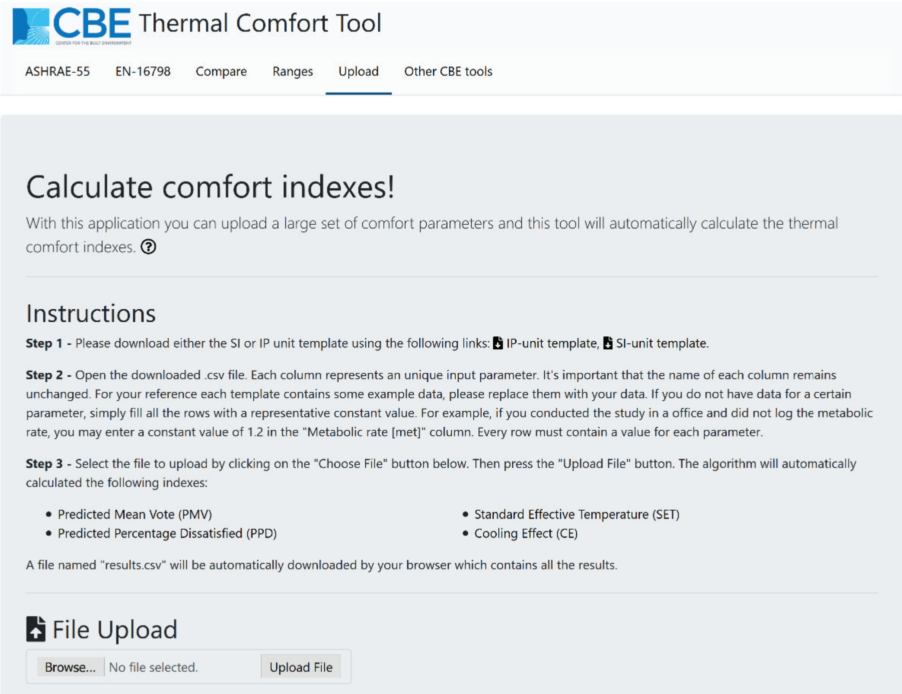


Fig. 2 The upload tool allows users to upload a set of thermal comfort input parameters and calculate PMV, PPD, SET and CE.

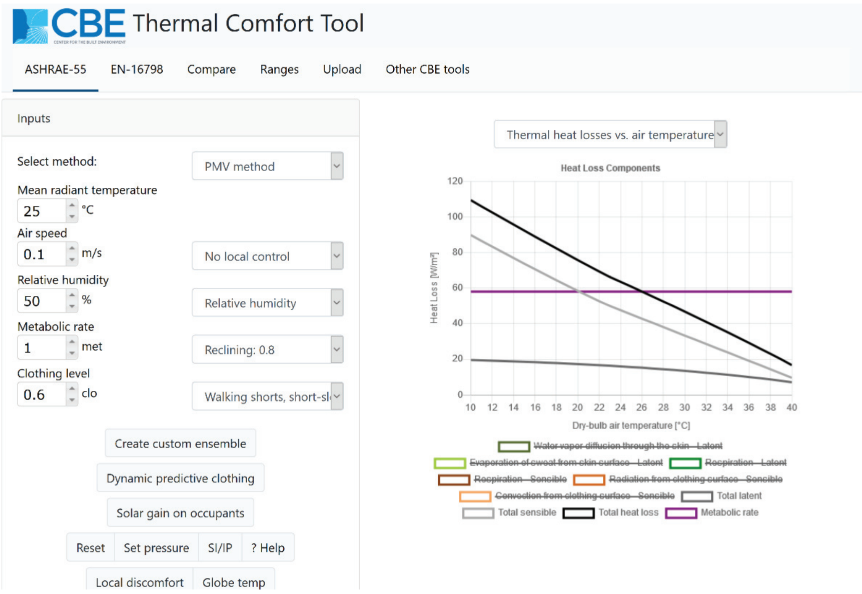


Fig. 3 Users can now view body heat losses (estimated with the PMV method) as a function of the indoor air temperature. Users are allowed to change the input parameters and see how they affect the overall heat losses. In addition, users can click on the field in the legend to show/hide the respective curves.

● The LEED tool has been deprecated and removed and we fixed many things (a small error in the calculation of the "Solar gain on occupants", error in the Adaptive Chart of EN-15251, and "Local control of air speed" is automatically selected when the clothing level is higher than 0.7 clo or the metabolic rate is higher than 1.3 met, as defined in the ASHRAE Standard 55-2017.

You can contact us via email at cbecomforttool@gmail.com or please submit issues or requests for new features here.

Multimodal Indoor Occupancy Estimation and Prediction Model

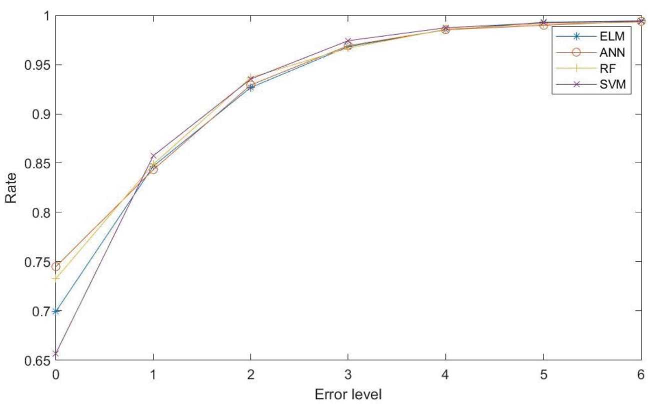
Yushen Long,
Lihua Xie.

Occupancy distribution is one of the most important information for energy-efficient building management to provide indoor context-aware services and location-based services. WiFi based indoor localization technology has been extensively developed and applied to estimate occupancy distribution in different types of buildings.

WiFi based indoor localization technology is essentially to detect WiFi-enabled mobile devices and uses the assumption that every occupant always carries one and only one such device. While such assumption is true for most cases, occasionally it results in miscounting. For instance, an occupant may carry multiple devices (e.g. with a phone, an iPad and a laptop) at the same time. We also have observed that some occupants have left their devices activated on their work desk area even after going out of the office to the washroom or lunch break. Furthermore, WiFi based indoor localization technology usually only provides current occupancy distribution and will not anticipate future occupancy conditions. However, prediction of occupancy distribution has been proved to be very useful for the control of heating, ventilation and air-conditioning systems, scheduling of the usage of shared space and energy demand management.

To overcome these issues, we propose a two-phase multimodal occupancy estimation and prediction scheme and test it in the SinBerBEST big meeting room. In phase 1, we integrated data from WiFi based localization system and CO_2 sensors to produce more reliable estimation of occupancy level. We chose the CO_2 concentration, first order difference of CO_2 concentration as well as the number of detected WiFi-enabled mobile devices as the features and train different machine learning models, including artificial neural network (ANN), extreme learning machine (ELM), support vector machine (SVM) and Random Forests (RF), for the estimation of occupancy level.

Fig. 1 Comparison of estimation error of different models.



Estimation	MAE	RMSE	FPR	FNR	FDR
WiFi+CO_2	0.5788	1.3575	0.0662	0.1843	0.0995
WiFi Only	0.8187	1.8394	0.0964	0.3542	0.1692
CO_2 Only	0.6722	1.4866	0.0619	0.2361	0.1111

Table 1 Comparison of estimation using different features (ELM).

	5 min ahead	15 min ahead	25 min ahead	45 min ahead
ELM (100 nodes)	0.9336	1.0982	1.2320	1.4630
ANN (3 layers times 10 nodes)	0.9684	1.1121	1.2480	1.4736
SVM	0.8536	1.0050	1.1481	1.4283
RF (depth=10, 200 trees)	0.8743	1.0282	1.1756	1.4357
Pure Markov Chain	1.4681			

Table 2 Prediction error of different models and different horizons.

We introduced the following performance indices to evaluate the performance of the multimodal occupancy estimation and prediction scheme:

1. Root mean square error (RMSE)
2. False positive rate (FPR): the rate that room is empty but estimated as occupied
3. False negative rate (FNR): the rate that room is occupied but estimated as empty
4. False detection rate (FDR): the rate of false detecting whether the room is occupied or not

The comparison of estimation error is depicted in Fig. 1. It can be observed that all models have similar performance though ANN and RF slightly outperform others at the 0-error level. In Table 1, the performance indices are compared for different features under ELM estimator. It can be observed that combing WiFi and CO_2 provides the most accurate results.

In phase 2, based on the estimation result from phase 1, a Markov chain model is applied to give occupancy prediction in a future period. In Table 2, we compared the prediction error over different horizons and different models. It can be observed that all machine learning models have similar performance and all of them outperform the pure Markov chain model, which only uses historical data but no real time occupancy information, in short prediction horizon cases. The reason is that for shorter prediction horizon, current occupancy is more informative, so the prediction based on it is more accurate.

A Dimensionality Reduction Method to Select the Most Representative Daylight Illuminance Distributions

Michael G. Kent, Stefano Schiavon, Alstan Jakubiec.

Climate-based annual daylighting simulations model the dynamic distribution patterns of natural light inside of buildings. These are communicated in research and practice as aggregate performance results. In practice, daylight distribution patterns on the horizontal plane – that represent workstation surfaces – are evaluated at standardised time periods across the solstices and equinoxes under specific sky conditions. The alternative being an arduous process of evaluating hundreds, if not thousands of annual time conditions corresponding to the occupied hours of the given building design. This approach creates an equal amount of daylight illuminance data and visualisations that the designer needs to carefully analyse.

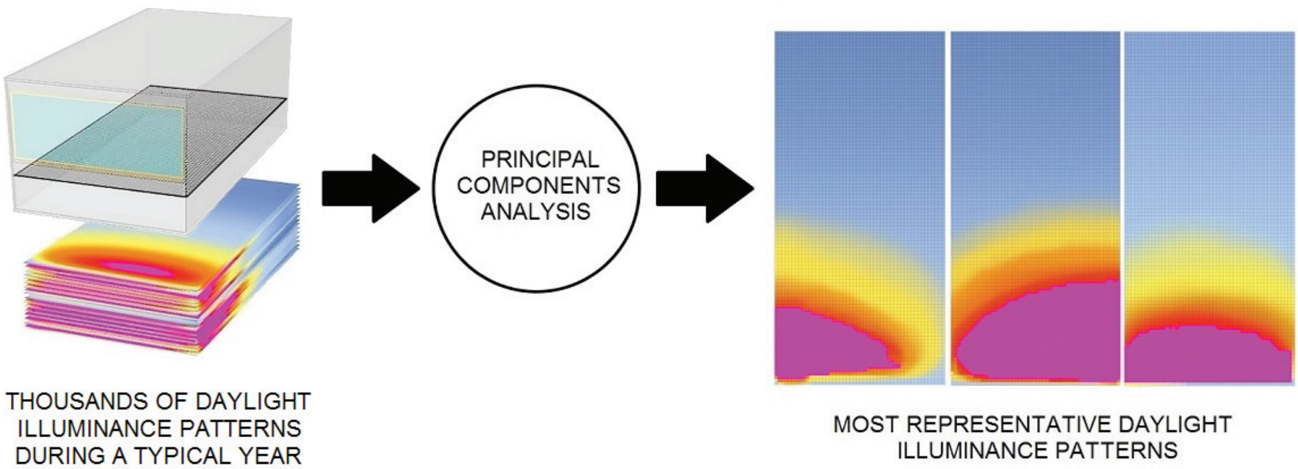


Fig. 1 Concept of how thousands of illuminance patterns from an annual daylight simulation can be reduced into representative cases using principal.components analysis.

We propose another method, whereby one single analysis can evaluate all possible daylight distribution patterns produced from an annual simulation (Fig. 1). To demonstrate our approach, we utilised two different models (Fig. 2) and simulated horizontal daylight distribution patterns using the software DIVA (Solemma LLC, 2020). Annual simulations were performed in two different locations (Oakland, California and Singapore) with an office-based occupancy schedule. When considering the daylight distribution patterns that occur at every hourly interval, over three thousand different temporal conditions were created and needed to be evaluated.

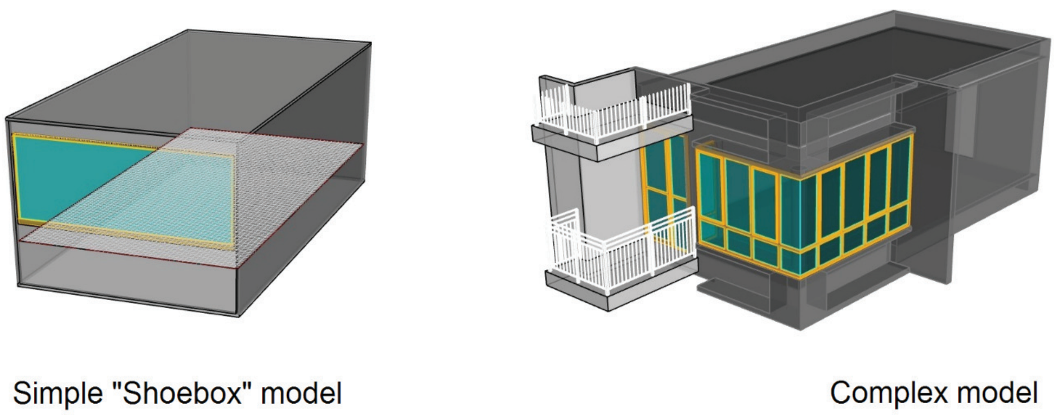


Fig. 2 A simple "Shoebox" model (left) and complex model (right) used to perform annual daylight simulations and to demonstrate how well our new analytical approach worked.

We used a widely utilised method of dimension reduction, known as principal components analysis. This reduced the daylight distribution patterns from the temporal conditions into a smaller number of principal components. Each principal component was used to derive a representative daylight distribution pattern, whereby the identified condition was found to be similar to many other cases that were analysed. For the "Shoebox" model, our approach reduced thousands of temporal conditions from an annual daylight simulation in Singapore into three representative distributions (Fig. 3). When combined, these explained up to 99 % of the information that was contained in the original simulation data used to perform the analysis. Similar results were also obtained when considering Oakland, California.

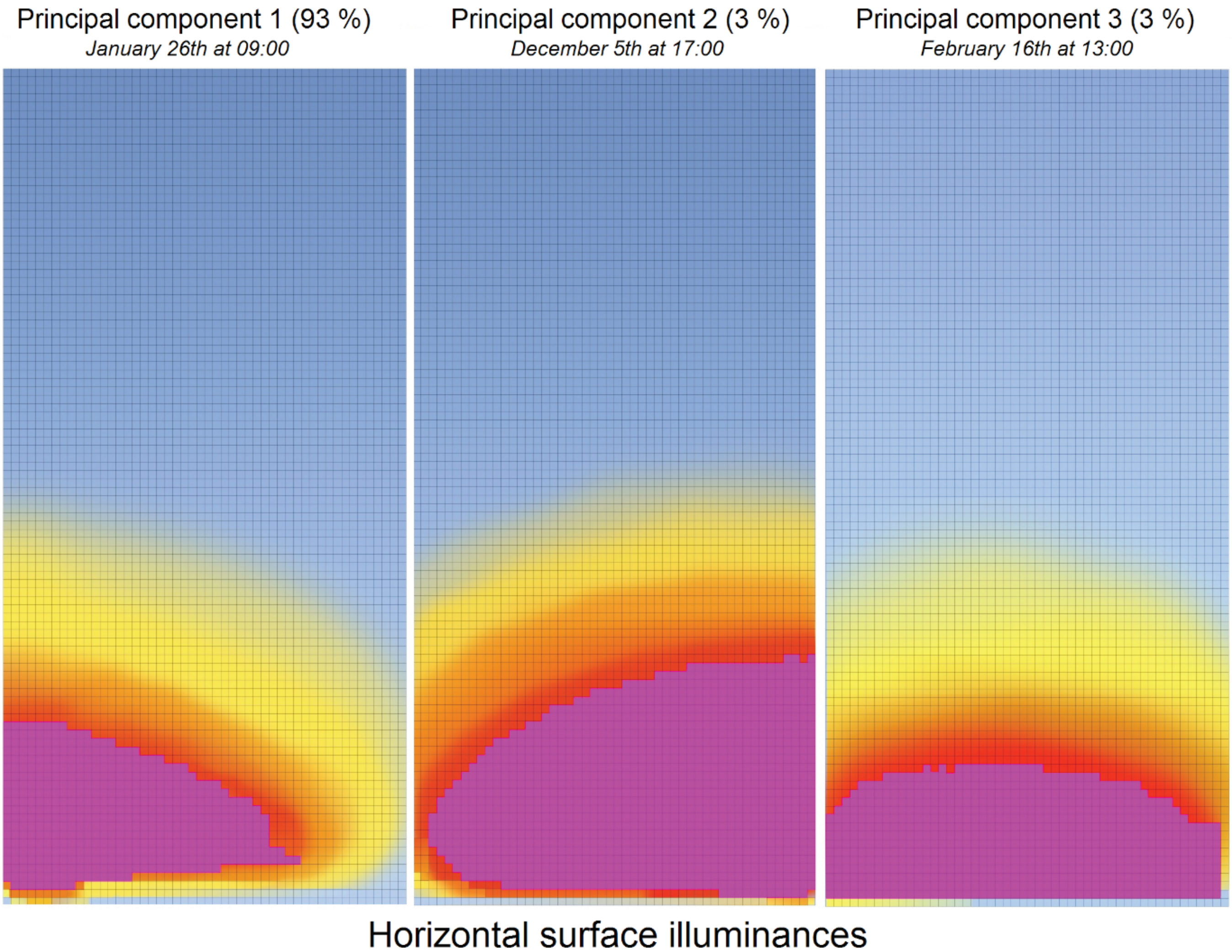


Fig. 3 The three representative daylight illuminance patterns derived from the principal components analysis. These are derived from an annual simulation performed using the simple "Shoebox" model in Singapore.

When using the same two climates but applied to the complex model, our approach reduced the temporal conditions into a far fewer number of representative daylight patterns. While these identified cases from the analyses can be used for further evaluation by the researcher or designer, our approach significantly enhances the interpretability of – what would otherwise be considered as – an overwhelming amount of daylight simulation data. Implementation of our approach in DIVA-for-Grasshopper is currently under development so that others will be able to make full use of this method in their own work. For more information see the reference below.

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Detection and Diagnosis of Intermediate-Severity Building Faults Using Uncertainty Information from Ensemble Learners

Baihong Jin, Yingshui Tan, Alberto Sangiovanni Vincentelli.

Intermediate-Severity (IS) faults present milder symptoms compared to severe faults, and are more difficult to detect and diagnose due to their close resemblance to normal operating conditions. For Fault Detection and Diagnosis (FDD) applications that are built upon Machine Learning (ML) techniques, the lack of IS fault examples in the training data can pose severe risks to the decision-making process, because the IS faults can be easily mistaken as normal operating conditions. On the other hand, the ability to detect and diagnose faults at their incipient stages is vital in building heating, ventilation and air-conditioning (HVAC) systems including chillers or air-handling units (AHUs). If left undetected, these faults could reduce the operational efficiency and lead to significant maintenance costs.

In our recent research, we have proposed using ensemble learning to tackle the challenge of intermediate-severity faults. Ensemble learning is widely applied in ML to improve model performance and to mitigate decision risks. In an ensemble model, the predictions from a diverse set of learners are combined, for example by calculating the simple or weighted average of their individual predictions, to yield a joint decision. The disagreement among individual learner predictions can be used to estimate the decision uncertainties. However, this approach has not been sufficiently exploited in the literature although this uncertainty information comes “for free” from ensemble models. In our work that was recently submitted to KDD`20 (Knowledge Discovery in Databases, 20), we show how the uncertainty information from ensembles can be leveraged for identifying high-risk predictions and we discussed how to design more effective ensemble models for detecting and diagnosing intermediate-severity faults.

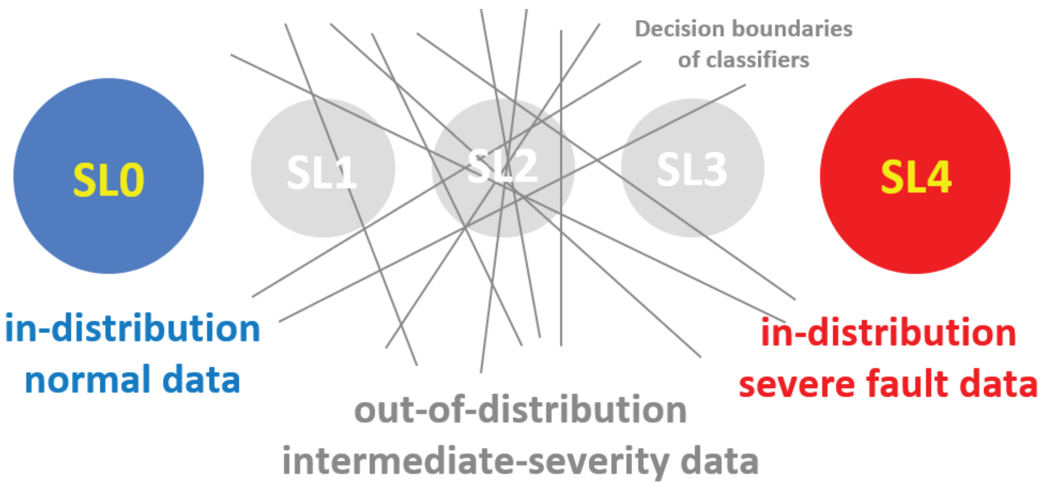

Fig. 1 A visualization of part of the ASHRAE RP-1043 data. The normal condition (SL0) and two fault conditions each with four severity levels are displayed.

We have conducted extensive experiments using several popular ML models including decision trees and neural networks as base learners in ensemble models on the ASHRAE RP-1043 chiller dataset. A visualization for the reduced condenser water flow rate (FWC) fault data and the reduced evaporator water flow rate (FWE) fault data can be found in Figure 1, in which we can clearly see the distribution of the normal condition (SL0) and faults of varying severity levels (SL1-4) in a reduced-dimension space. We assume in our experiments that the SL1-3 fault data (out-of-distribution data) are absent from the training data; the training data (in-distribution data) only include the normal condition (SL0) and the severe fault condition (SL4). A conceptual illustration showing how an ensemble classifier can help detecting intermediate-severity faults is given in Figure 2, where the gray lines represent the decision boundaries of individual base learners in an ensemble model. A diverse set of decision boundaries tend to agree with each other on the in-distribution data (SL0 & SL4), but not as much on the intermediate-severity faults. By using this property, we design a novel anomaly score function that accounts for both the consensus and the disagreement among base learners, which gives an improvement of over 10 percentage points in the detection rate of intermediate-severity faults, compared to baseline models.

Beyond industrial systems, early identification of incipient anomalies is also critical in the healthcare domain, which shares a similar challenge as the industrial system FDD: accurate labeled training data representing milder symptoms are often hard to obtain. Our preliminary experimental results on the Kaggle diabetic retinopathy dataset have shown deficient performance in detecting low-severity diseases with existing convolutional neural net models, even with abundant data. Motivated by this findings, the team has started to investigate how to extend the proposed ensemble learning approach to improve the diagnosis accuracy of diabetic retinopathy diseases. Interested readers can stay tuned for future updates about our ongoing investigation into this topic for unknown diseases such as the recent COVID19.

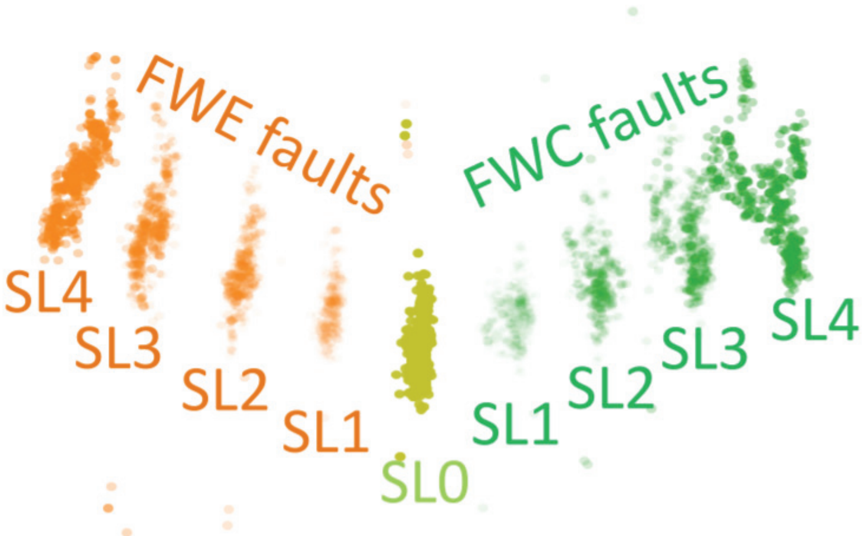

Fig. 2 A conceptual illustration that shows how an ensemble classifier can help detect intermediate-severity faults.

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Building Energy Simulation for Technology Assessment

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Carlos Duarte,
Paul Raftery.

One of the proven ways to assess the performance of new building technologies to reduce building's energy consumption is via building energy simulation. We created a benchmark large (28,000 m2) office building in Singapore and assessed the energy savings of a selected range of developed SBB technologies. The benchmark building meets the Green Mark (GM) version 4.0 requirements at the Certified level that have been in effect since 2010, when the SinBerBEST project began. We defined the characteristics of the benchmark building through an iterative review process involving both Building Construction Authority of Singapore (BCA) and Beca, one of the largest professional services consultancies in the Asia Pacific, to ensure that the model parameters were realistic for the Singapore context. At each stage of this process, we created a whole building energy model in EnergyPlus so that we could review and compare to existing literature and best practice. One additional outcome of this process was that we identified knowledge gaps on Singapore building stock.

The final model yields energy consumption results at a level of detail that is otherwise difficult and cost prohibitive to obtain from physical measurements. This level of details allows us to identify the key aspects on which to focus in order to improve energy performance. The energy model allows us to quantify the impact of various technologies on whole building energy consumption in a robust manner, accounting for temporal variation in performance and the interaction effects of different solutions. For example, an improved lighting system may provide lighting energy savings as well as savings due to the reduction in heat gains that the air conditioning and mechanical ventilation (ACMV) system must remove from the building. Figure 2 shows the resulting end use distribution and a total annual energy consumption of 146 kWh/m2·a. The auxiliary category includes sources such as exterior lighting, mechanical ventilation in car park floors, miscellaneous domestic water pumps, and lifts. The total EUI value is within the range of what we expected given data from BCA on GM certified buildings and 2014 benchmarking report on the Singaporean building stock. Note that this benchmark model is most usefully compared to other similar sized office buildings as Green Mark v4.0 has a mandatory chiller efficiency requirement based on size that is independent of certification level.

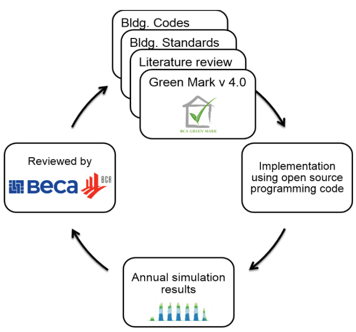


Fig. 1 Model development process involving BCA and Beca

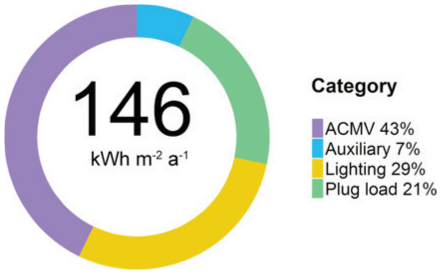


Fig. 2 Annual EUI Model broken into four categories

The results show that the ACMV system is the major energy consumer, and is responsible for 43% of the total annual electricity consumption. A more in depth analysis of the cooling loads that the ACMV system must handle shows that ventilation requirements are the larger driver of energy consumption. This is due to the high moisture content of outside air in Singapore and the associated latent load, which can be up to 85% of the total ventilation load. Figure 3 illustrates this by breaking down the cooling loads during occupied hours into eight categories. It is clear from these results that the technologies with the greatest potential for energy savings are those that address ventilation related loads, either by reducing ventilation rates based on occupancy detection, or by providing a more efficient means of dehumidifying air, or by increasing indoor setpoints. Window assemblies are the second most significant source of cooling load. Given the tendency to design predominantly glass facades in modern office buildings in Singapore, appropriate external shading designs and energy-efficient window assemblies have significant energy savings potential. Technologies that focus on opaque exterior walls have less potential for savings in commercial buildings. The correct balance between window area, shading, and glass types for different orientations of the building will help lower cooling loads, while still providing access to daylight and views to the outside that are beneficial to occupants. Lights and plug loads consume 29% and 21%, respectively, of the overall building energy consumption. These two categories account for 50% of the direct annual energy consumption in the benchmark building. This means that these two categories offer a large impact on reducing the energy needs of a building. For instance, by using efficient artificial lighting systems like LED lights or the ability to control lighting and plug load base on real occupancy.

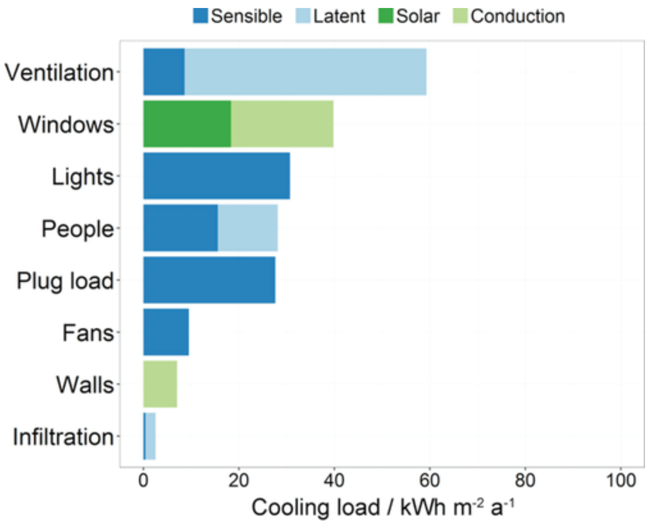


Fig. 3 Total cooling load by source during occupied the hours for benchmark building

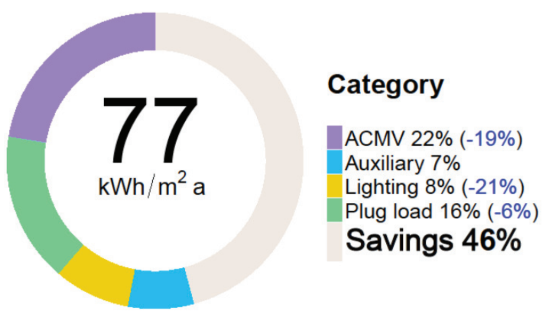
Figure 4 shows the impact of using improved lighting and controls, increased temperature setpoints, and occupant localization solutions. Overall, the results show 46% savings in total annual energy consumption. This demonstrates SBB1 technologies may lead to significant energy savings. Increased temperature setpoints is relatively simple to implement in the existing building stock. It could only require a change in building control and maybe in the cooling coil; it may be inexpensive to implement. Improved lighting and controls are also relative simple to implement but can come at higher cost due to the need for new hardware and labor. Indoor occupant localization systems are still in the research phase and more time is needed to make their way into the building market. However, demand control ventilation is a technology available to reduce ventilation energy costs but carbon dioxide sensors have been cited to have issues with measurement consistency.

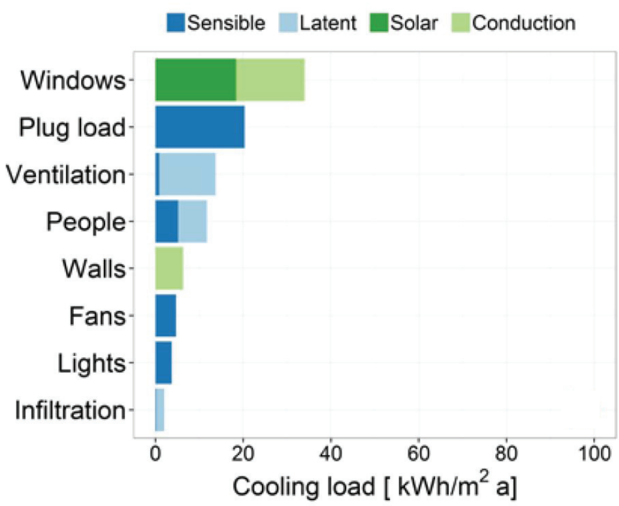
We used the energy model to evaluate all SBB1 technologies in detail within the following constraints: that it was feasible to evaluate within a benchmark model of this type (without modifying the source code of the simulation software); and that the technology and results were sufficiently developed to provide data for evaluation at the time of assessment. This yielded six technologies: 1) improved lighting and controls; 2) increased temperature setpoints with air movement; 3) occupant localization; 4) titanium dioxide coating; 5) ultra-lightweight cement composites (ULCC); and 6) translucent concrete (TC) panels. We restrict our analysis to retrofit scenarios (except for concrete technologies) due to the highest potential that these solutions have in Singapore. Therefore, we do not resize the ACMV system with the corresponding technologies' impact on cooling load reductions. Resizing would also have an effect on reducing initial capital cost and increasing the energy efficiency. We modified the primary benchmark with a concrete exterior wall construction to implement the latter three technologies and analyze their potential energy savings.

Overall, SBB1 technologies can drastically reduce energy use in existing and new buildings. Building stakeholders can use this freely available energy model as an additional tool representing a typical large commercial office building model in Singapore, to test future innovative energy efficiency measures, analyze policy changes in energy code, and other building related studies.

We are now in the midst of upgrading this model to meet the Green Mark (GM) standard (GM NRB: 2015). We plan to use this improved model to assess the performance of SBB2 building technologies to reduce energy consumption.

Fig. 4 Annual EUI and total cooling load breakdown by source for a building that implemented a selected number of SBB1 technologies





The Hugo Shuck prize is award annually jointly by nine engineering and math societies (IEEE, ASME, AIAA, AiChe, AIAA, ISA, SIAM, APS, SCS).

Best Paper Award

BEARS Researcher Sen Li and co-PI Kameshwar Poolla along with co-authors Junjie Qin and Pravin Varaiya were awarded the 2020 Hugo Schuck Best paper prize. The prize was awarded for their paper “Distributed Storage Investment in Power Networks” to be presented at the American Control Conference in Denver in July 2020, out of 1300 paper submissions. This paper analyzes the value created by aggregating behind-the- meter distributed energy storage devices for grid services. This value depends on how much storage is in the system, its location, and the power network state. To understand whether market-driven distributed storage investment will result in a socially desirable outcome, the paper analyzes a network storage investment game. By explicitly characterizing the set of Nash equilibria (NE) for two examples, it is shown that the uniqueness and efficiency of NE depend critically on the power network state. Furthermore, it is shown that the NE supports social welfare under two market modifications. These modifications suggest potential directions for regulatory interventions.

Event and Outreach

Talk by Professor Stefano Schiavon. "The future of cooling" at the CREATE Symposium on Climate Change, Singapore. 6 Dec 2019

Up to 60% of the world population would be living within tropical climatic region in 2060 and a large increase of air conditioning use is expected. In the recent CREATE symposium on climate change held on 6 December 2010, Prof. Schiavon introduced an energy efficient cooling strategy with higher temperature set-point (e.g. 27°C) from the air-conditioning system while simultaneously maintaining occupant’s comfort by increasing the air movement using electric fans. Usage of fans is not any new technology and its application is limited especially in commercial buildings, but it is a very useful technology that can employed in the face of climate change challenge. Three major challenges were mentioned by Prof. Schiavon, including technical, regulatory and culture. We all know how to turn on a fan, but do we have the common technique to design, select and evaluate the performance of fan used in office space? A technical guideline is currently missing to inform building practitioners on such cooling strategy. Secondly, the existing Singaporean building standard is designed for air-conditioned office, which limits indoor air speed of not higher than 0.3 m/s. Fans application in office space is thus discouraged. Lastly, the uses of air conditioning is often being advertised as modern, elegant, luxury and comfortable, which may discourage the building designers in considering the usage of fans office space. SinBerBEST has been working hard to promote the cooling strategy of higher indoor temperature set-point together with increased air speed. We found that this strategy did not only reduce cooling energy consumption, but also enhanced occupant’s satisfaction with the indoor environment in both experiment chamber and real office building. We are happy to share more information and looking forward to any collaboration opportunity.

Interview with Dr Jose Ali Porras-Salazar

(1) Can you briefly describe your education background and how did you get into this field?

I am an architect graduated from the School of Architecture at the University of Costa Rica. In this State-run university, the bachelor program’s main focus is on architectural design – similar to most of the architectural schools around the world. However, due to the influence that the Department of Development and Tropical Studies (DDTS) of the Architectural Association had on the creation of the school, we were taught from the early beginning of our career that adapting the building to the site conditions is a must.

Later on, I did my Master’s in Bioclimatic Architecture at the Polytechnic University of Madrid, where I became familiar with concepts, theories, and methodologies related to the indoor environmental quality (IEQ) field. During this period of time, I was inspired by the work of a Hungarian architect named Steven Szokolay and his phrase “Architecture is the art and science of building”. Without diminishing the capital role of art and design, Szokolay sustained that building science was equally important to achieve good architecture.

As I have always liked educational buildings, due to the role that they play in society, I focused my doctorate at the University of Bio-Bio in Chile, on the effects that the thermal environment of classrooms has on the cognitive performance of tropically acclimatized pupils. During this period, I spent a year as a Ph.D. Guest Researcher at ICIEE in Denmark, one of the IEQ’s best-known laboratories, preparing the design of an experiment that was later carried out in Costa Rica.

(2) How did you hear about SinBerBEST and what makes you decide to join the team here?

In the course of my PhD I was looking for recent research done in the tropics. When I found that there was a project underway in Singapore called SinBerBEST, I was surprised. , because of its large investment in R&D in IEQ research. Currently, there is a lack of R&D investment in the tropical region in R&D. However, Singapore appears to be an exception and I was surprised because a tropical country was doing that investment. What impressed me the most, was that they were studying elevated air speed, which is, along with solar shading, the most widely used strategy in warm humid climates such as those prevailing in the tropics.

When you grow up in the tropics you learn about the benefits of elevated air speed since you are a child. It is in your DNA. Without realizing it, it becomes part of the decisions you make at home, school, work, or in the place you choose to sit in the bus or play in the park. However, high air speeds can be unpleasant in moderate and cold climates; therefore, it was neglected by researchers within the thermal comfort field, until SinBerBEST.

The decision to join the project was not very difficult: I like the research that the SinBerBEST team is doing and it is focused on a climate that I know very well and where I will be working with in the future.

(3) What can you tell about your impressions working in SinBerBEST and living in Singapore?

SinBerBEST is the most ambitious research project on IEQ that has been done in the tropics. I can't recall any other IEQ project that has been researching in this region for so long and with such good results. It has been able to bring together people from many countries and different backgrounds giving it a unique blend of expertise. The project outcomes will not only mean a great improvement for Singapore but also for many countries, especially those located in the tropics.

On the other hand, living in Singapore (even under the COVID-19 situation) has been very exciting. I have lived in other countries outside Costa Rica before, but never in an Asian country, making it a completely new cultural experience. Furthermore, it is admirable how Singapore has developed so fast in the last 50 years and has become one of the most prosperous countries in the world. Today, Singaporeans are leaders in many research fields with renowned universities as the National University of Singapore and the Nanyang Technological University. There is no doubt that Singapore has made us, researchers in the tropical regions, begin to look along the global parallels, before beginning to look at higher latitudes.

(4) How can your research benefit people working in the building and other industries?

We spend most of our lives inside buildings. Therefore, the quality of the indoor environment has a big impact on us. It can affect our health, mood, behaviour. This in turn affects, how good we perform at work or at school. I see two main fields from which our research can benefit people, companies, organizations, and nature: (1) determining the indoor environmental conditions where people stay healthy, are satisfied with, and perform well, and (2) providing this conditions with a minimal use of energy. Right now my work is circumscribed into the first one. I am reviewing published studies on effects of thermal conditions on work performance. We want to know if there is a relationship between indicators of indoor thermal conditions, such as temperature and thermal sensation, and how good people perform at office work tasks. Such a relationship would help us to reduce uncertainty in cost-benefit analysis of practical ways to improve office working conditions.

(5) What are your longer term goals?

I am a professor at the School of Architecture of the University of Costa Rica and once the postdoc ends, I will return to my academic duties. From there, I hope to continue working together with the colleagues and friends that this experience has given to me and to awaken the interest of students and architects for the IEQ field. Architecture should be a symbiosis between art and science; however, in architectural teaching, too much effort has been placed on arts leaving little room for science.

It is time for us architects to close our eyes for a second and pay attention to the invisible aesthetics (term coined by Derek Clements-Chrome): The qualities of the environment that affect humans' life inside buildings.

Baihong Received 2019 - 2020 Lofti A. Zadeh Prize

Baihong Jin, a graduating PhD student in the Electrical Engineering and Computer Sciences (EECS) department at University of California, Berkeley, was recognized for his notable contributions to soft computing and its application with the Lofti A. Zadeh Prize. Every year, the EECS Student Awards Committee selects department award winners, many of them are based on recommendations from EECS students, faculty and staff.

A particpant of the SBB2 program, he is advised by Prof. Sangiovanni-Vincentelli and Prof. Poolla. Also, Baihong is a research affiliate at the Lawrence Berkeley National Lab. His research interests include machine learning, fault management, and anomaly detection techniques, focusing on their applications in energy cyber-physical systems and healthcare AI. After graduation, Baihong will continue with the SBB2 program as a postdoc. Congratulations!

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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