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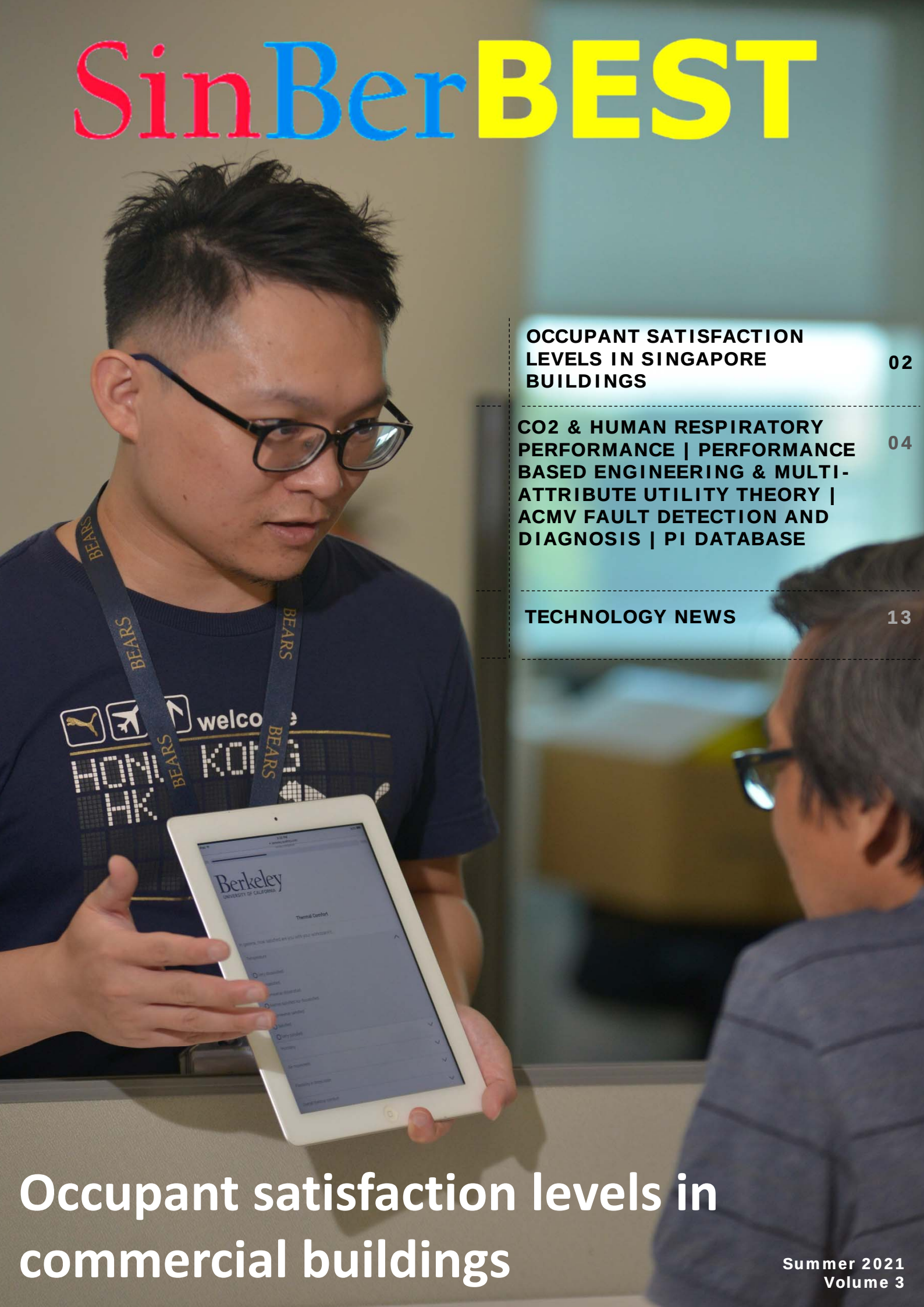
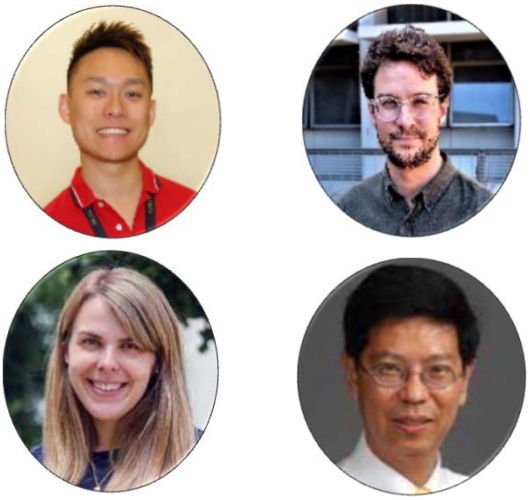


Occupant satisfaction levels in commercial buildings

Summer 2021
Volume 3

Occupant satisfaction levels in Singaporean commercial buildings

Toby Cheung, Stefano Schiavon, Lindsay T. Graham, Kwok Wai Tham



Sustainable buildings must be energy efficient and able to satisfy occupants. Singapore is known for its sustainable and high-quality build environment. We wondered how satisfied building occupants in Singapore are.

To answer this question, we surveyed seven Green Mark certified air-conditioned commercial buildings in Singapore with 666 valid survey responses. We aimed at understanding (i) occupant's satisfaction level with different indoor environmental quality (IEQ) parameters; (ii) the reasons that caused environmental dissatisfaction; and (iii) which IEQ parameters have higher impacts on the overall workspace environment satisfaction using a modified version of the Center for the Built Environment Occupant Satisfaction Survey.

Figure 1 below shows the distribution of satisfaction responses for 18 IEQ parameters. The respondents were more satisfied with the flexibility of dress code (S = 86 %), artificial light (S = 84 %), and cleanliness (S = 82 %) of their workspace. These were the only three parameters that can achieve the satisfaction target (> 80 %) suggested in Green Mark. The three most dissatisfied parameters were sound privacy (D = 42 %), level of personal control (D = 32 %), and air temperature (D = 30 %). These results are comparable with an earlier study conducted in the US (Altomonte et al., 2019; Karmann et al., 2017). It suggests that some environmental parameters are harder to achieve higher satisfaction levels than the others, which further reveals applying a singular satisfaction rating (i.e., 80 % satisfaction target) to all IEQ satisfaction parameters is ineffective. Also, our investigation revealed that occupants were dissatisfied with the workspace thermal environment mainly because of too weak air movement (29 %) and too cold temperature (24 %), suggesting that increasing airspeed and temperature setpoint could lead to higher satisfaction as proven earlier (Lipczynska et al. 2018). We also observed that occupants in open-plan offices were unhappy with the noise produced by their nearby colleagues (68 %).

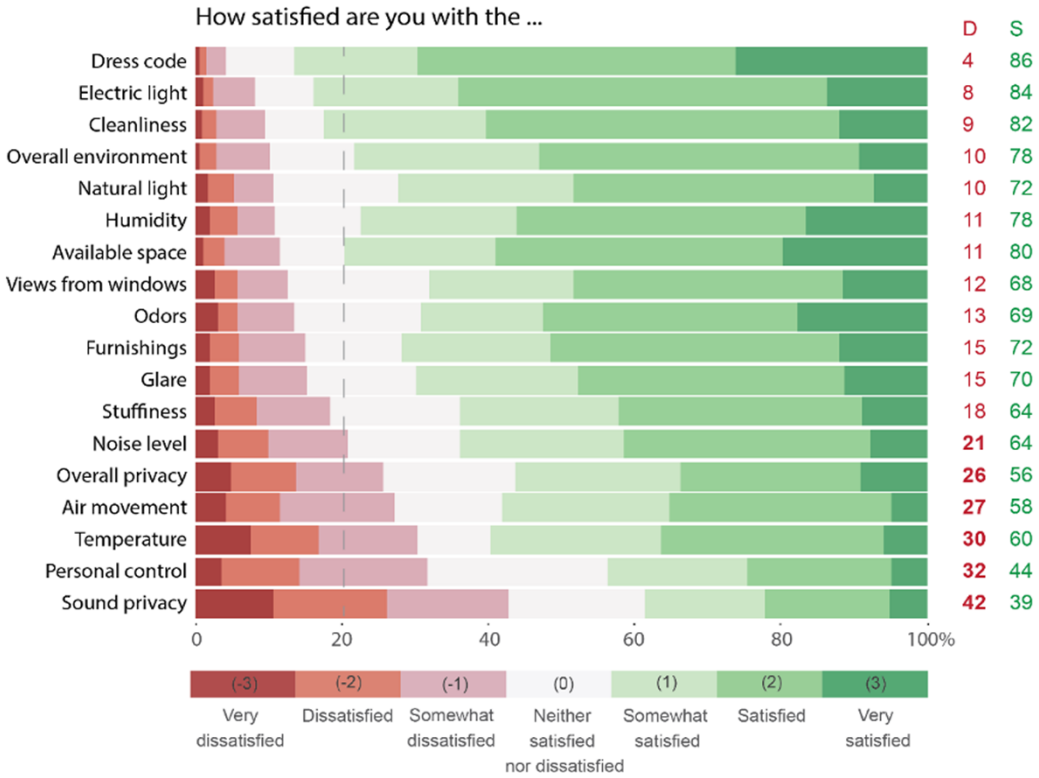


FIGURE 1 Distribution of occupant satisfaction responses for all IEQ categories. (D) and (S) are respectively, the dissatisfaction and satisfaction rate (%). The grey dotted line indicates the 80 % satisfaction target.

Using proportional odds ordinal regression, in Figure 2, we analyzed the impacts of different IEQ satisfaction parameters on the satisfaction with the overall workspace environment. Data points in blue means the corresponding parameters are significantly contributing to overall workspace satisfaction. Interestingly, satisfaction with workspace cleanliness was the most important parameter that contributes to overall workspace satisfaction (OR = 2); this was not found in US buildings (Frontczak et al., 2012). An odds ratio of 2 means that the occupant who stays in a cleaner environment is 2 times more likely to be satisfied than the one who is occupying a less clean workspace. Perhaps a cleaner working environment could, to some degree for Singaporeans, reduce the effect of dissatisfaction caused by other environmental factors, leading to higher overall workspace satisfaction.

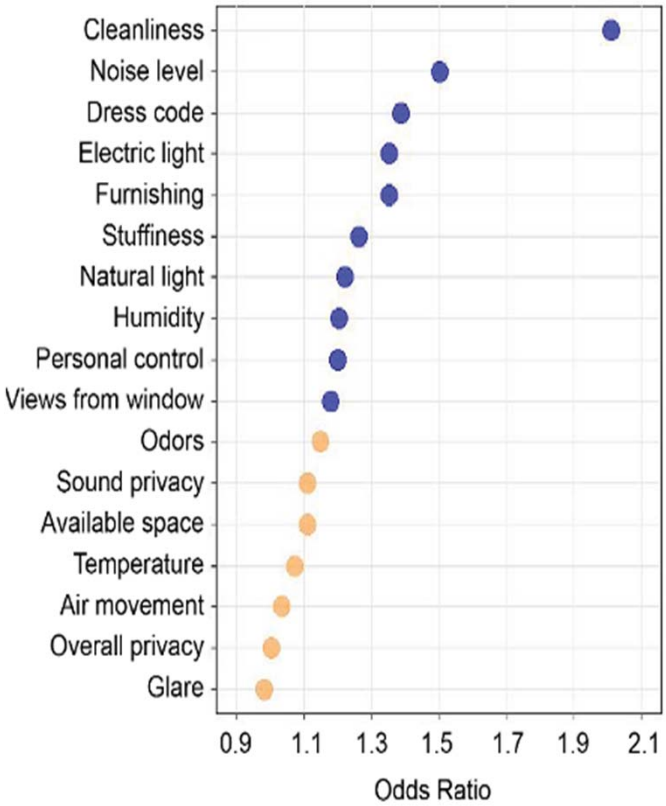


FIGURE 2 The odds ratio for satisfaction with 17 indoor environmental parameters associated with the overall workspace satisfaction

Do you want your building to be part of this dataset? Do you want to compare your building to this benchmark? It is free if the building is in Singapore. Please contact Toby (toby.cheung@bears-berkeley.sg) for more information.

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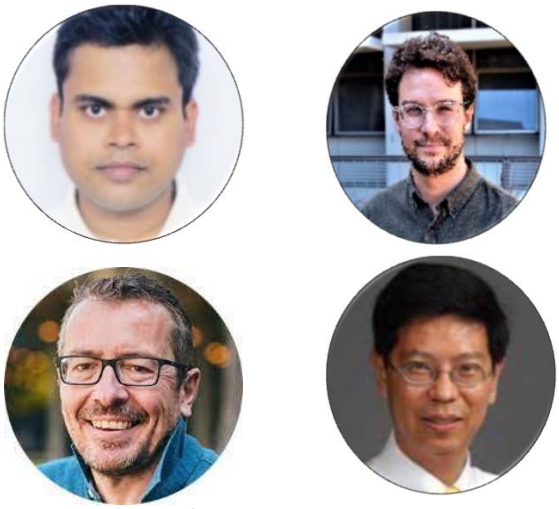
Human respiratory performance during exposure to moderate levels of carbon dioxide



Asit Mishra, Stefano Schiavon, Pawel Wargocki, Tham Kwok Wai

In a recently published study, we describe the unexpected impact on the breathing of study participants due to poorly ventilated environments.

The study examined the effect of exposure to moderate levels of carbon dioxide on respiratory functions of 15 participants, measured via capnography and spirometry. Capnography measures the carbon dioxide concentration in exhaled air (end-tidal CO_2, $ETCO_2$) and respiration rate. Spirometry assesses several lung function parameters such as forced vital capacity (FVC), forced exhaled volume in the first second (FEV1), and the ratio of these two measures. Participants spent 2.5 hours in a controlled chamber modeled as an office space during three different exposures:

1. 900 ppm carbon dioxide (reference, 900-R). This is the baseline condition that may be found in a properly ventilated indoor space.
2. 1450 ppm carbon dioxide (decreased ventilation, 1450-V). This is a situation where the ventilation rate was reduced by ~50%, and it resulted in a higher carbon dioxide concentration.
3. 1450 ppm carbon dioxide (reference ventilation with added pure CO_2, 1450-CO_2). We kept the same ventilation rate as in the reference (900-R) and artificially added pure carbon dioxide in the chamber to disentangle the effect of ventilation and carbon dioxide.

Our goal was to understand two key aspects: (1) Do reduced ventilation rates or increased carbon dioxide concentration affect the respiration rate, exhaled carbon dioxide levels, and respiratory performance? (2) How do the respiration rate and exhaled carbon dioxide levels change during the exposure to the three conditions?

Figure 2 shows that $ETCO_2$ did not significantly differ across the three exposures and there was no visible evolving pattern to the $ETCO_2$ with time spent in the chamber. However, the 2-1/2 hour exposure to poor ventilation (1450-V) had a negative impact on the lung performance, in the form of an obstructive breathing pattern (Figure 3). Since no similar reduction in lung performance was seen for 1450-CO_2, this was most likely caused by the increased concentration of other pollutants, primarily bioeffluents, and not only carbon dioxide.

FIGURE 1 Chamber configuration with fans and participants.

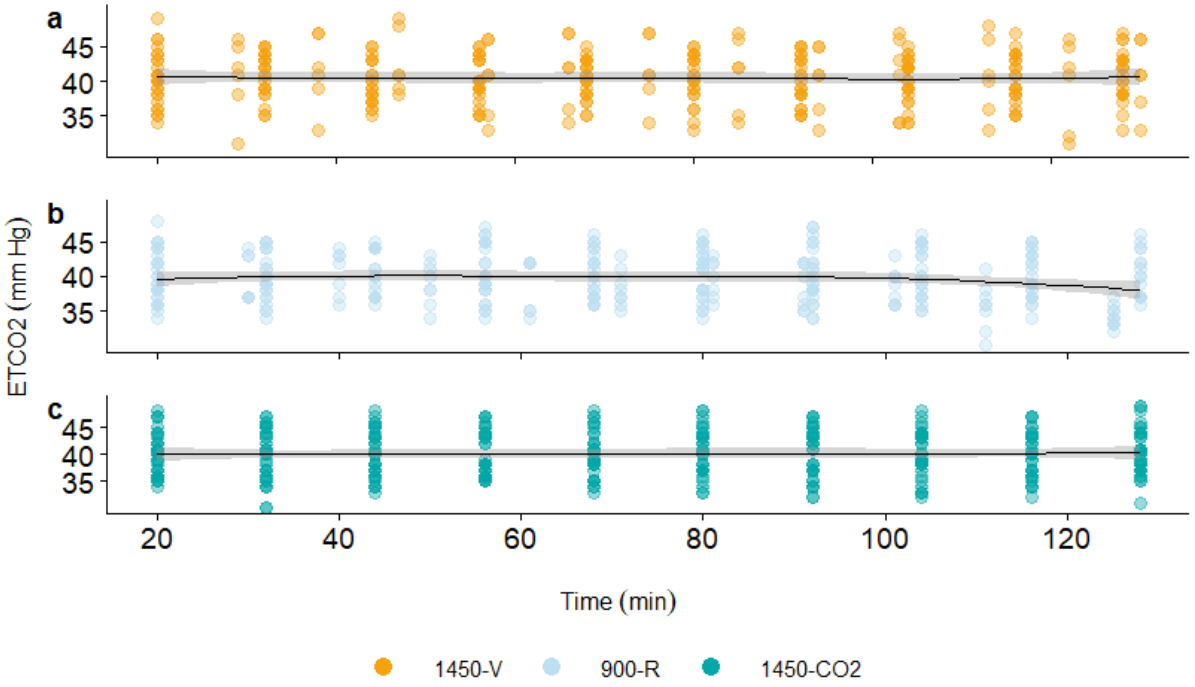


FIGURE 2 Time series for variation of $ETCO_2$ over the time spent inside the chamber for the three different exposures: a) 1450-V, b) 900-R, and c) 1450-CO_2. The trend is depicted using LOESS (locally estimated scatterplot smoothing) curves. .

While this is further confirmation of the health effects of poor ventilation, this is the first work to show physiological impacts of exposures to such moderately elevated carbon dioxide levels (between 800 and 1500 ppm) caused by reduced ventilation. It is concerning that such a short exposure to these moderately elevated indoor pollutant levels is sufficient to measurably impact our breathing. It is not uncommon for people to spend a considerable part of their lives in poorly ventilated buildings, such as classrooms, homes, and even their bedrooms. These findings suggest that this is a matter deserving immediate and further attention.

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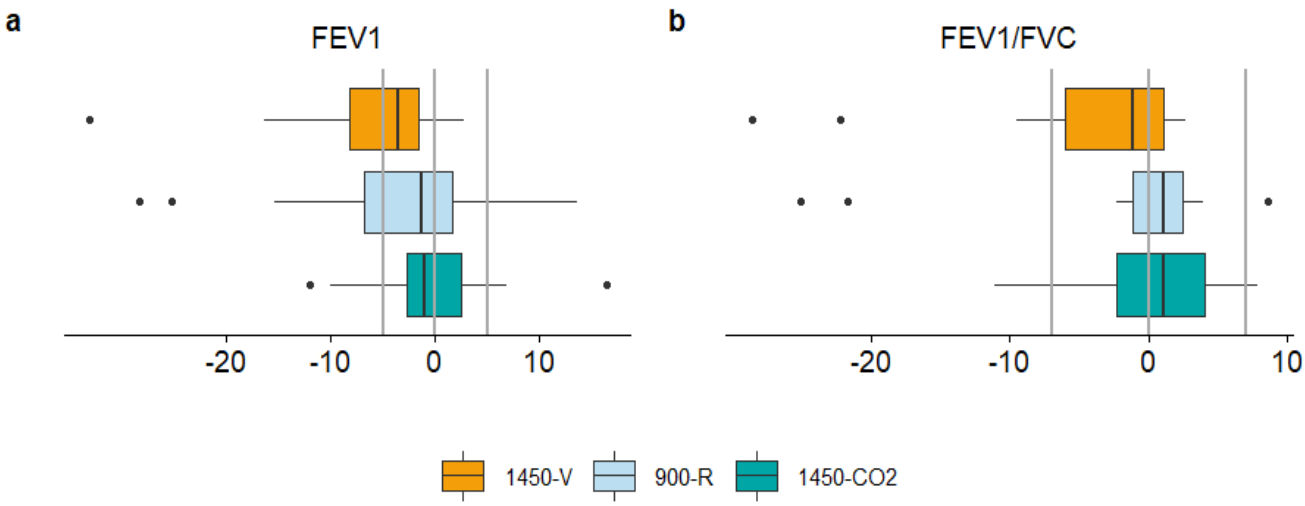

FIGURE 3 Time series for variation of $ETCO_2$ over the time spent inside the chamber for the three different exposures: a) 1450-V, b) 900-R, and c) 1450-CO_2. The trend is depicted using LOESS (locally estimated scatterplot smoothing) curves.

Towards Performance-Based Engineering and Multi-Attribute Utility Theory Using Copula

Yidan Gao, Khalid Mosalam

The Role of Copula in PBE-MAUT

A probabilistic framework of the Multi-Attribute Utility Theory (MAUT) in conjunction with Performance-Based Engineering (PBE) approach, namely PBE-MAUT, was developed in (Mosalam et al. 2018) and was applied for the optimal design of façades in a case study in Singapore. In the PBE-MAUT, correctly capturing the relationship (linear or nonlinear) among different Decision Variables (DVs) is an important step with significant influence on the final selection of optimal façade design. The traditional measure of Pearson's linear correlation coefficient may not adequate in the exploration of complex relationships among different governing DVs. In this case, the copula concept is considered to improve the PBE-MAUT approach for optimal façade design (Gao and Mosalam, 2021).

Introduction of Copula Theory

In the copula theory, dependent structures are modelled by a copula function. Generally, the concept of copula can be interpreted as functions that link multivariate distribution functions to one-dimensional marginal distribution functions. The mathematical definitions of classical copula are briefly outlined herein. Suppose $\boldsymbol{X} = (X_1, X_2, \dots, X_d)$ is a random vector in the x space with the continuous marginal distributions $F_i(x) = P[X_i \le x]$, $i = 1,2,\dots,d$. Let the random vector $\boldsymbol{U} = (U_1, U_2, \dots, U_d)$ where the application of the probability integral transform to each component implies $U_i = F_i(X_i)$, $i = 1,2,\dots,d$ with standard uniformly distributed marginals. The copula of $\boldsymbol{X}$ is defined as the Joint Cumulative Distribution Function (JCDF) of $\boldsymbol{U}$ as follows:

$$C(\boldsymbol{u}) = C(u_1, u_2, \dots, u_d) = P[U_1 \le u_1, U_2 \le u_2, \dots, U_d \le u_d] \quad \text{.... (1)}$$

We define $\boldsymbol{X} = \boldsymbol{x}$ and $\boldsymbol{U} = \boldsymbol{u}$ as particular vectors of "points" $\boldsymbol{x} = (x_1, x_2, \dots, x_d)$ and $\boldsymbol{u} = (u_1, u_2, \dots, u_d)$ in the basic x and u variable spaces, respectively. All the information in the dependence structure among $(X_1, X_2, \dots, X_d)$ is included in the copula $C(\boldsymbol{u})$ and all the marginal distribution information of X_i is contained in $F_i(x), i = 1,2,, \dots, d$. Conversely, pseudo-random samples can be generated from the copula in a two-step procedure:

1. Generate a sample $(U_1, U_2, \dots, U_d)$ from the copula function in Eq. (1), and
2. A sample $(X_1, X_2, \dots, X_d)$ is calculated as follows,

$$(X_1, X_2, \dots, X_d) = \left(F_1{}^{-1}(U_1), F_2{}^{-1}(U_2), \dots, F_d{}^{-1}(U_d)\right)$$

..... (2)

Sklar's theorem provides the foundation for the application of copula, where the multivariate distribution of $\boldsymbol{X}$ is expressed as a density $f(*)$,

$$f(x_1, x_2, \dots, x_d) = c\left(F_1(x_1), F_2(x_2), \dots, F_d(x_d)\right) \cdot f_1(x_1) \cdot f_2(x_2) \cdots f_d(x_d) \text{.... (3)}$$

where $c = \frac{\partial^d C(U_1, U_2, \dots, U_d)}{\partial U_1 \partial U_2 \cdots \partial U_d}$ is the *density* of the copula, $f_i(x_i)$ is the marginal Probability Density Function (PDF) of x_i, $i = 1,2,\dots,d$. Classical copula has several families. Each family or class of copula has its own characteristics including advantages and disadvantages making it suitable for a certain type of data. Gaussian copula and Student's t-copula are elliptical copulas with their distributions radially symmetric, as defined in Eqs (4) and (5), respectively.

$$C_{\boldsymbol{P}}^{Gauss}(\boldsymbol{u}) = \Phi_{d,\boldsymbol{P}}\left(\Phi^{-1}(u_1), \Phi^{-1}(u_2), \dots, \Phi^{-1}(u_d)\right)$$

..... (4)

$$C_{v,\boldsymbol{P}}^{t}(\boldsymbol{u}) = t_{v,\boldsymbol{P}}\left(t_v^{-1}(u_1), t_v^{-1}(u_2), \dots, t_v^{-1}(u_d)\right)$$

..... (5).

where Φ^{-1} is the inverse Cumulative Distribution Function (CDF) of a one-dimensional standard normal distribution and $\Phi_{d,\boldsymbol{P}}$ is the JCDF of a *d*-dimensional multivariate normal distribution with zero mean vector, unit standard deviations, and a covariance matrix equal to the correlation matrix $\boldsymbol{P} \in [-1, 1]^{d \times d}$, which is symmetric with unit diagonal elements. The subscripts d and $\boldsymbol{P}$ of Φ indicate the number of variables in the vector $\boldsymbol{u}$ and the correlation matrix of the JCDF, respectively. Moreover, t_v^{-1} is the inverse CDF of the standard univariate t-distribution with *v* degrees of freedom (DOF) and $t_{v,\boldsymbol{P}}$ is the JCDF of a multivariate t-distribution with *v* DOF.

Compared with Gaussian copula, Student's t-copula assigns larger weights to the tails. The parameter v controls the heaviness of the tails. When v approaches ∞, $C_{v,\boldsymbol{P}}^{t}(\boldsymbol{u})$ approaches $C_{\boldsymbol{P}}^{Gauss}(\boldsymbol{u})$. Since in Gaussian copula, which is popular in risk analysis, the same linear dependency covers all data within the domain, it is not suitable to model the structural dependence which is not consistent over the entire domain.

Archimedean copula was first studied in the development of probabilistic view of triangle inequality. Compared with triangular copulas which do not have closed form expressions, all commonly encountered Archimedean copulas have explicit formula and are superior to solve asymmetrical problems. The bivariate Archimedean copulas $C_\theta(x_1, x_2)$, namely Clayton copula, Frank copula, and Gumbel copula are also investigated in our research with copula expressions listed in the table below.

Copula	Bivariate copula $C_\theta(x_1, x_2)$	Parameter θ
Clayton	$\left[\max\{x_1^{-\theta} + x_2^{-\theta} - 1; 0\}\right]^{-1/\theta}$	$\theta \in [-1,0) \cap (0,\infty)$
Frank	$-\frac{1}{\theta}\ln\left[1 + \frac{(\exp(-\theta x_1) - 1)(\exp(-\theta x_2) - 1)}{\exp^{-\theta-1}}\right]$	$\theta \in (-\infty,0) \cap (0,\infty)$
Gumbel	$\exp\left[-\left\{(-\ln(x_1))^\theta + (-\ln(x_2))^\theta\right\}^{1/\theta}\right]$	$\theta \in [1,\infty)$

An Illustrative Example

Figure 1 illustrates the comparison of different bivariate copulas using scatter diagrams with each marginal distribution of random variable X_1 and X_2 (10,000 samples) following a standard normal distribution and a linear correlation coeffici 0.8, i.e., $\boldsymbol{P} = [1.0\ 0.8; 0.8\ 1.0]$. Corresponding copulas based on the data are constructed and 10,000 samples of the random variables are generated using the different copula models. It is easily concluded that Clayton copula is more suitable in describing data with strong lower tail dependence, while Gumbel copula is good in describing data with stronger correlations at higher values. Frank copula is more appropriate for modelling data with weak dependence at the tails.

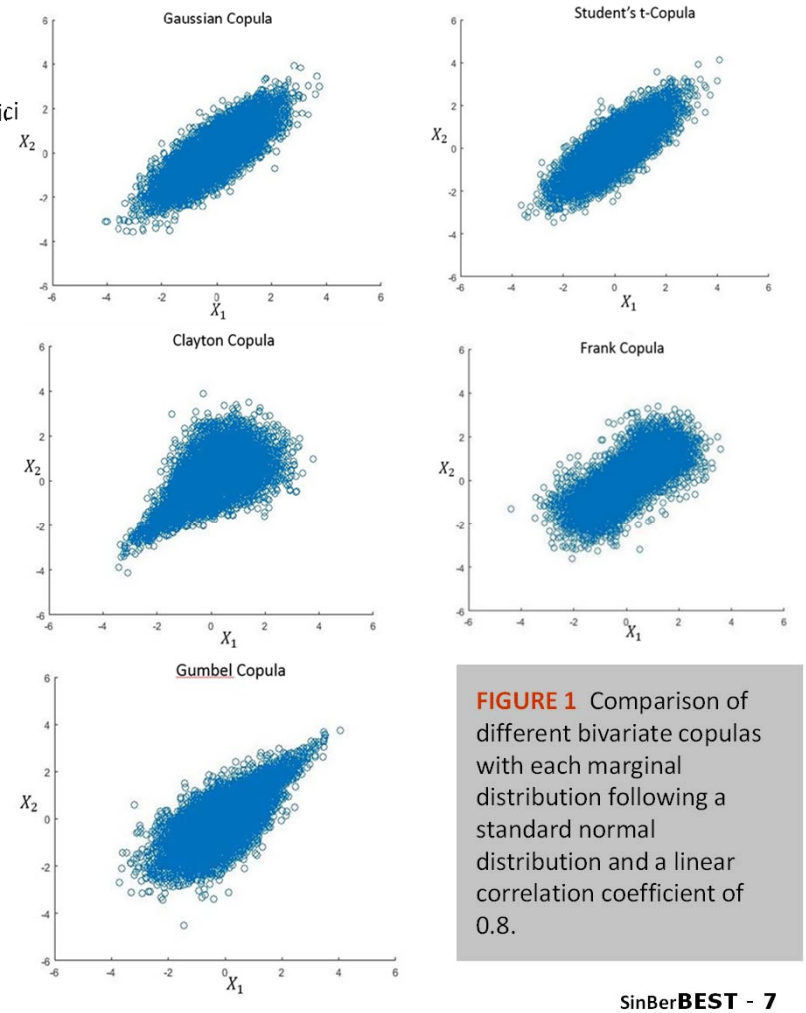

FIGURE 1 Comparison of different bivariate copulas with each marginal distribution following a standard normal distribution and a linear correlation coefficient of 0.8.

Conclusion

With the integration of copula into PBE-MAUT of optimal façade design, the complex inner relationships among the DVs reflecting different design criteria are clearer. This will ultimately improve the PBE-MAUT decision support tools for façade design of energy-efficient buildings.

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Early Fault Detection and Diagnosis in ACMV System by Using Motor Electrical Signals

Hasmat Malik, Sanjib Panda, Kameshwar Poolla, Costas Spanos

Summary

Available online health monitoring systems (HMS) for ACMV tend to detect some of the critical faults only at high severity levels, resulting in higher O&M (operation & maintenance) cost. Moreover, multiple monitoring systems are required for a single equipment, further decreasing the affordability. Motor electrical signals (MES) provide a unique, single and holistic HMS for various critical faults of an ACMV system and its associated equipment. The MES is capable to detect anomalies at an early stage and provides hybrid signals-based efficient condition monitoring and predictive maintenance (PdM) information in advance.

Background

According to the building energy efficiency R&D roadmap of Singapore, commercial buildings consume around 31% of total electricity in Singapore. Cooling (60%) and ventilation (10%), together account for majority (i.e. 70%) of electricity consumption in commercial buildings in Singapore (Fig. 1). Within the ACMV system, the chiller accounts for majority of the electricity consumption (55%), and rest of the consumption is distributed as air handling units (AHU) (35%), pumps (5%) and cooling tower (5%). Moreover, these equipment failures in the ACMV system have two types of effects on its operation, they may lead to additional electrical losses in the system (performance degradation) or complete system shut down, resulting in higher O&M costs and decreasing the stability & reliability of the system.

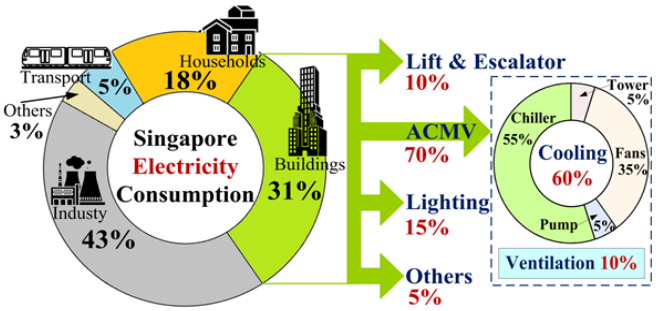


FIGURE 1 Typical electricity consumption by end-use in Singapore and in the building sector [1]

According to NREL (National Renewable Energy Lab.) USA report on "Common Faults and Their Prioritization in Small Commercial Buildings", unexpected failure of ACMV/HVAC (Heating, ventilation, and air conditioning) system leads to downtime and extra energy loss of around 180 trillion Btu/annum for a small commercial building in the US. The financial loss due to extra energy loss is around 7081 million USD/annum. Fig. 2 shows the detailed information of energy loss and its corresponding financial loss, where annual energy loss due to faults and its annual financial loss are represented by annual energy impact (AEI) and annual financial impact (AFI) respectively. Moreover, HVAC Services Market - Growth, Trends, and Forecast (2020 - 2025) represent the maintenance cost for ACMV/HAVC system and its associated equipment could be 7.17 billion USD in 2019, which is a considerable amount and can be saved by doing proper condition monitoring.

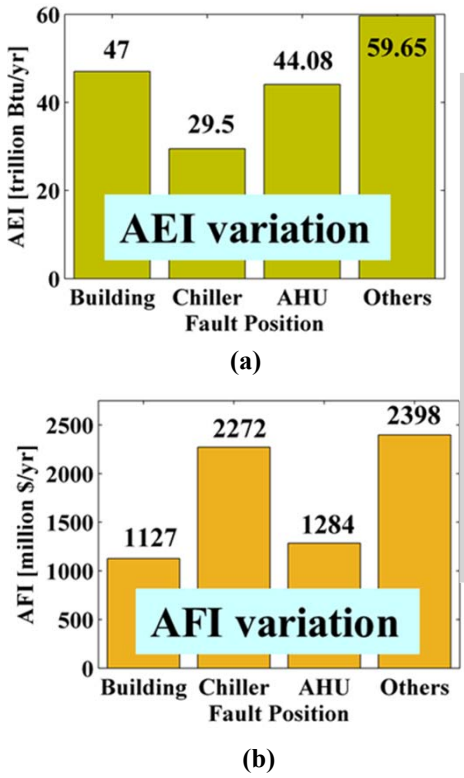


FIGURE 2 The effect of ACMV/HVAC faults representation in the form of (a) Annual energy loss and (b) Annual financial loss [2]

Approximately 50-67% of all air conditioners suffer from improper charge or airflow problems. According to one study conducted by Kim Woohyun & Braun James, the refrigerant charge reduction in 20-25% leads [1]: 1) HVAC average efficiency reduction of - about 15%, 2) HVAC capacity degradation of - about 20%

and 3) Increase in HVAC annual operating cost - USD100 per/ton capacity. Apart of this analysis, the U.S. Department of Energy (DOE) Building Technologies has represented some useful analysis related to AHU faults and its associated extra energy demand. The estimated occurrence of the duct leakage fault is between 50%–80%, which leads to the extra energy consumption of about 13%-26%. The DOE reported that 25%-40% of economizers in the field did not move properly. Due to this malfunctioning, the consumption of extra energy is increase as follows: 1) outdoor damper stuck (closed) - increase 12% energy and 2) outdoor damper stuck (open) - increase 3% energy. Apart of DOE US, NIST USA reported that 10% duct leakage can increase the annual power consumption by up to 12% . Moreover, according to ASHRAE RP-1043 report, anomalies of chiller's sub-component are also responsible for increasing in high cost of repair.

Therefore, identification of an anomaly in ACMV and its associated equipment is generally diagnosed by using mechanical signatures, such as vibration, temperature, humidity, refrigerant, pressure and flow rate etc. These mechanical signatures are captured by mechanical sensors. Generally, these mechanical sensors are widely used in the big applications of the industry or very large critical system. For the component level or small system application, such mechanical sensors are not financially feasible due to their additional cost. Moreover, mechanical signals are not capable to identify the anomalies at early stage (i.e., incipient level), while electrical signals have such type of capability to identify the anomalies at incipient level, which is represented by several researchers in 3 decades of research in the domain of electrical engineering. Due to this reason, electrical signals come into the picture, which is already being utilized in the protection system of the ACMV, and no extra sensors are required to capture these signals. Therefore, approach based on electrical signals will be sensor less approach. So, there is a big research gap and market to identify an alternative way for ACMV and its associated component's anomaly detection by using electrical signals instead of mechanical signals. For this purpose, a hybrid data-driven approach for health monitoring become more advantageous for ACMV system.

FIGURE 3 EFDD approach for ACMV at Incipient Level

Diagnosis

Motivated by the requirement for early fault detection and diagnosis (EFDD), this project develop a hybrid data-driven health monitoring approach (HMS) for ACMV. Fig. 3 illustrates the main ideas of our EFDD for ACMV. The proposed approach is scalable and efficient in large computational burden. We analyze the performance of the proposed approach on three case studies, i.e., healthy versus 1 fault with 4 severity levels (analyzed 5 conditions), healthy versus 6 faults with 1 severity level (analyzed 7 conditions) and healthy versus 6 faults with 4 severity levels (analyzed 25 conditions). The case study-3 is more complex and we analyze 25 conditions (healthy and 24 faulty conditions (6 faults with 4 severity levels)) for a chiller system by using 16 different recorded signals (i.e., one electrical and 15 non-electrical signals). The graphical representation of the obtained results has been exhibited in Fig. 4. The analyzed six fault conditions with four severity levels are: 1) F1: Reduced Condenser Water Flow (FWC), 2) F2: Reduced Evaporator Water Flow (FWE), 3) F3: Refrigerant Leak (RL), 4) F4: Refrigerant Overcharge (RO), 5) F5: Condenser Fouling (CF), and 6) F6: Non-Condensables in System (NC). The used 16 signals for the analysis are: 1) Pw: Electric Power Consumption, 2) FWC: Flow Rate of Condenser Water, 3) FWE: Flow Rate of Evaporator Water, 4) PRE: Pressure of Refrigerant in Evaporator, 5) PRC: Pressure of Refrigerant in Condenser, 6) TEI: Temperature of Entering evaporator water, 7) TEO: Temperature of leaving evaporator water, 8) TCI: Temperature of entering condenser water, 9) TCO: Temperature of leaving condenser water, 10) CHRR: Calculated Condenser Heat Rejection Rate, 11) WCT: Calculated City Water Cooling Rate, 12) TRC: sub Subcooling temperature, 13) Tsuc: Refrigerant suction temperature, 14) Tsh.suc: Refrigerant suction superheat temperature, 15) TRdis: Refrigerant discharge temperature, and 16) Tsh.dis: Refrigerant discharge superheat temperature. After analyzing the results, we conclude that the performance of diagnosis accuracy based on electrical signal is more preferable. Moreover, the proposed approach is supposed to be more acceptable in implementation as it is sensorless, non-intrusive health monitoring solution, which may provide the diagnosis at the incipient level of 10%.

Reference

[1] Kim, W & Braun, J, "Impacts of Refrigerant Charge on Air Conditioner and Heat Pump Performance. International Journal of Refrigeration" 35, 2012.

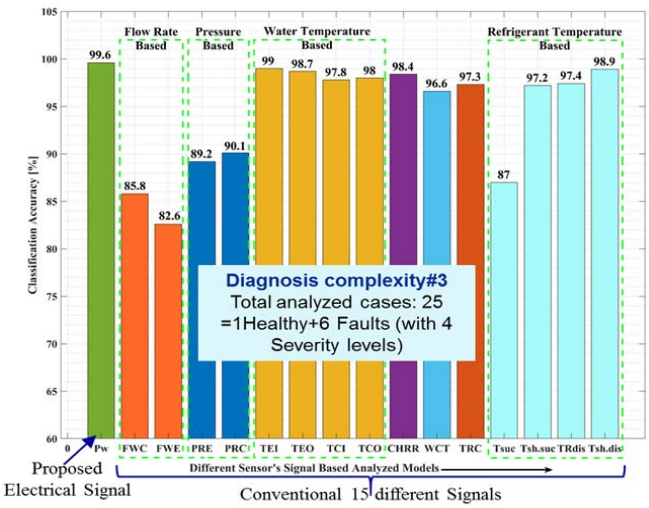


FIGURE 4 Graphical representation of obtained results

Mining and managing SinBerBEST research experiment data with the OSISoft PI System

Christopher Soyza

For an engineering experiment to be successful, a good amount of data needs to be generated. This data needs to be mined in a time sensitive approach so as to preserve the events of the measured quantity as they happen and often many data points are mined at any one time.

At SinBerBEST, moderate to large numbers of data points of measured quantities are mined in the course of experiments carried out within the SinBerBEST Testbed. As SinBerBEST research includes a good amount of computer systems utilizing data acquisition element for many types of sensors and control instruments, it is essential that an effective data mining and managing system solution is adopted to mine, store and offer the ability to extract and review the data in both real time or for historic review purposes. The OSISoft PI System was adopted for this very purpose.

OSISoft or Oil System Information Software is an American incorporated company that develops and maintains the PI System solution or PI as it known in its more common short form. The PI System is essentially what is called in industry a Historian System. It preserves mined data (or operational data) in time series format thus preserving the event chronology of a measured quantity. Within the PI System each measured data point is known as a PI Tag. A typical PI Server will host up to 2000 PI Tags of which are configured for use. PI Tags can be stored as 32 to 64 bit floating point or integer numbers, text strings or the unique to the PI System format call PI Digital states where multiple fixed values represent different fixed state text string representations of the recorded quantity.

The PI System is built on Microsoft Windows dotNET based software technology and heavily relies on Microsoft's Active Directory authentication and authorization features for data security. It is both granular and flexible in use for data read, write security. A typical PI System Installation (Figures 1 & 2) will have multiple server nodes of which, and at least, a PI Data Archive node (which stores all PI Tags), a PI Asset Framework node (a meta data database describing real world objects that are made up of one or more PI Tags) and finally several to many PI Interface nodes (integration application services that integrate industry data acquisition computers) that do the data mining extraction workloads. Being a veteran industry Historian system solution provider, OSISoft have over the years built a veritable arsenal of integration interface services that include most known industry integrations protocols. Examples will be Johnson Controls Modbus, Overlay Process Control (OPC), TCP and HTTP listener services and well known propriety industry Programmable Logic Controllers to name but a few. Apart from this, custom software based integration kits can also be built for this integrating layer through published Application Programmers Interfaces. Small to very large data write rates can be achieved with up to more than 30,000 PI Tag data point write updates a second depending on the type of integration interface used. PI Systems can also be used as deep store data storage service and integrated into bigger data management ecosystems requiring historical trails.

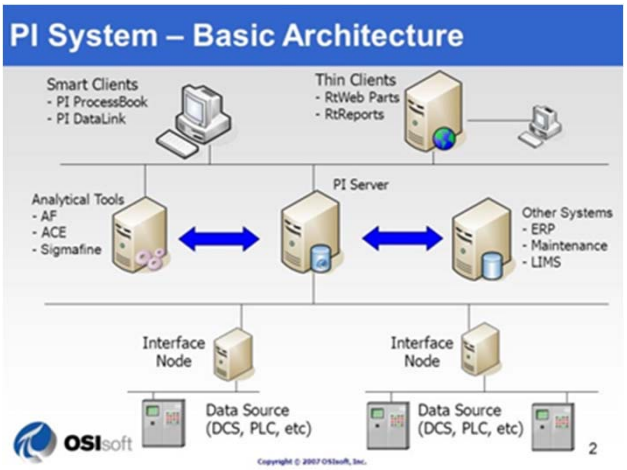


FIGURE 1 Typical PI System architecture

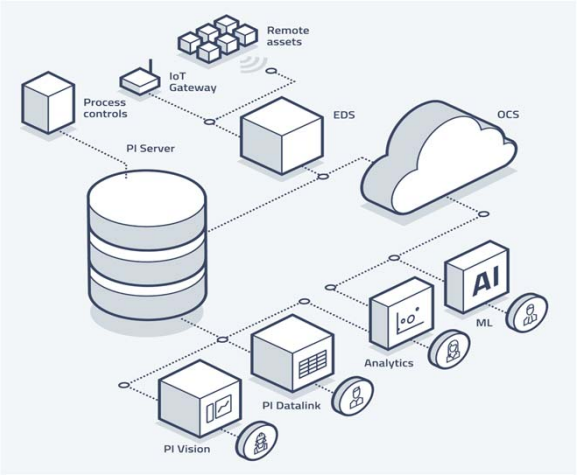
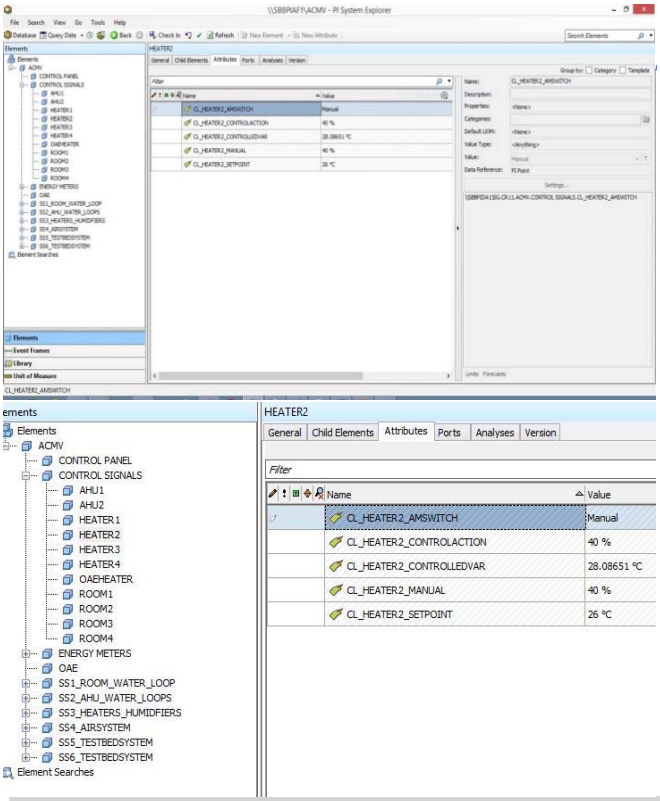


FIGURE 2 how a PI System would fit into a larger data systems services ecosphere

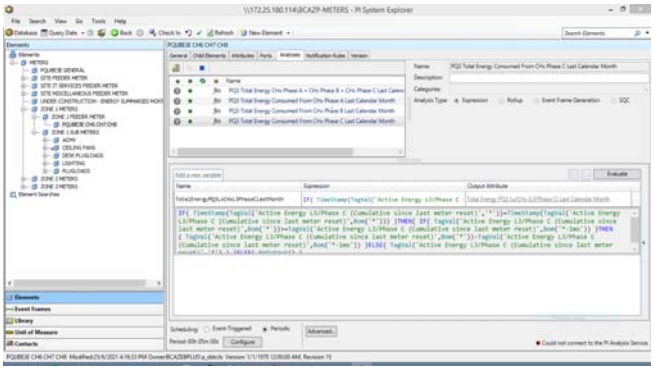
The PI Asset Framework (AF) node is an essential component where multiple PI Tag's that represent raw, time series, measured quantity data can be associated to form logical group representations of real world machines and instruments. Take for example an Air Conditioner Air Handler Unit (AHU). Several PI Tags will store raw data of the AHU's machine components like Motor Speed and Sensory data from inlet and outlet air temperatures. An AF metadata object is then created to represent the AHU as a single machine component object of the Air Conditioner system. Collections of these

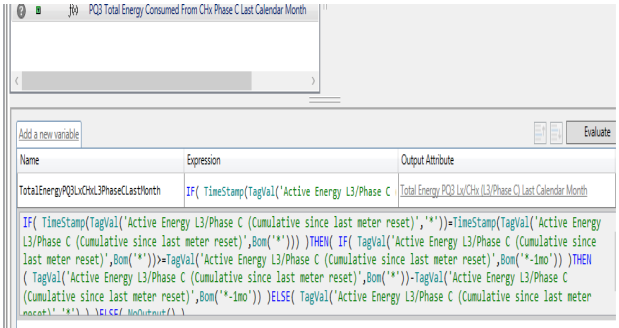
metadata objects are configured as AF Databases that describe and represent the machinery installation. In this way, real world machine objects can be digitally represented with a good degree of context. One can create ontologies of asset objects within an AF database that make up an entire installation. Figures 3 and 4 below show screenshots taken from OSISoft's PI System Explorer tool used for AF database navigation and creation.



FIGURES 3 & 4 Exploring configured AF data assets using PI System Explorer

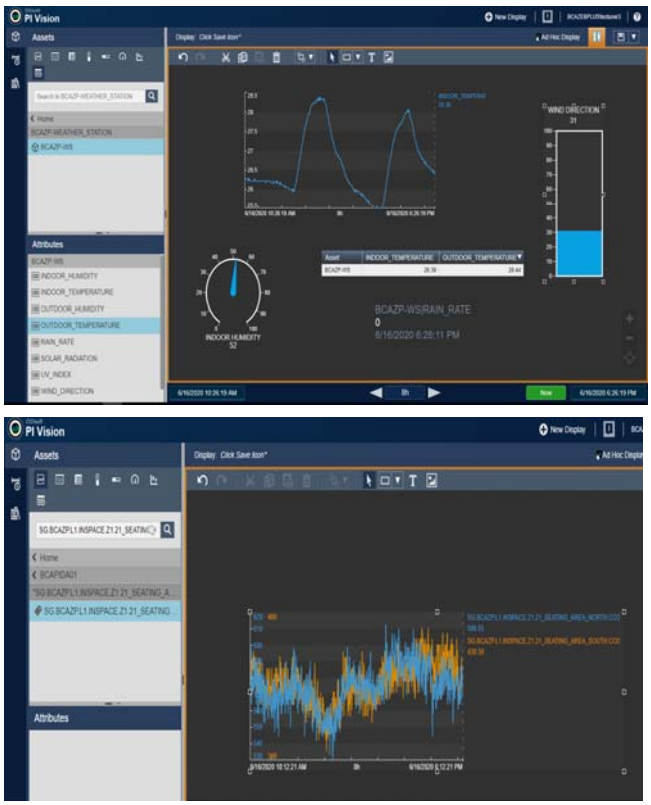
PI AF databases also allow automated Analysis functions which also include model based representations. Analysis functions can be used to generate derived data from existing PI Tags and be stored as PI Tags themselves. For example taking and reporting the cumulative energy measured by a power meter PI Tag on the 1st of a calendar month. The resulting PI Tag data stream from the analysis output will be a plot of cumulative energy data points on the 1st of every calendar month. Analyses can be implemented using syntax expression formats within PI System Explorer. Figures 5 and 6 show screenshots implemented by SinBerBEST.





FIGURES 5 & 6 Implementing PI Analysis from with PI System Explorer using syntax expression

To complement the PI Data Archive and Pi Asset Framework, a fourth element typically found in PI System installations will also include a Pi Vision node. As its name implies, the PI Vision node is a visualization service that uses a web based presentation canvass where users can build up visuals representing process workflows and such making the overall data representation of a system visually tangible. Figure 7, 8 and 9 depict this.



FIGURES 7 & 8 PI Vision web canvas with drag and drop elements to building a process flow visuals

At SinBerBEST, the PI System is an entrenched component where Testbed machinery like, the SBB ACMV system within the Testbed physical space rooms are represented digitally for the benefit of experiments and users. Dashboards were created and allow for a view of ACMV operational data as the system is used for ACMV related experiments. Analysis features allow for a reasonably quick

opportunity to add verification test algorithms if needed and can themselves be saved as PI Tags streams. As an example, a SBB project deployment utilized PI AF Analysis features to generate Alarms for ACMV operational alerts.

The PI System is by no means a simple assembly of software applications and does require reasonable IT Administrative skill sets taken up by the SBB Lab support teams. Several data extraction and manipulations tools also are available for researchers to be able to extract recorded data based on the PI Tag name (PI AF Asset names included), date time filters, value constraints to name a few of many filter constraints. The PI Datalink tool is a Microsoft Excel embedding utility that enables non syntax type data extraction query operations to be done from the PI System. Other features include integration for large data science type analysis with tools like Microsoft's Power BI or Tableau by Tableau Software.

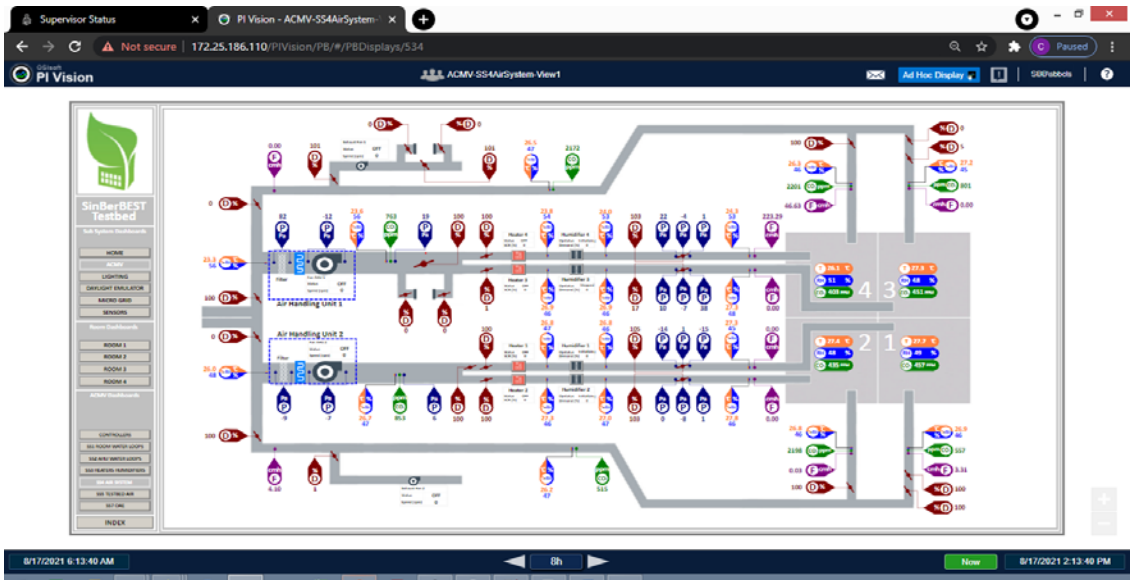


FIGURE 9 SinBerBEST ACMV dashboard implementation

Interview with Miguel Martin

Miguel Martin is a SinBerBEST Senior Research Engineer. He is in the process of finishing a Ph.D. in Building Science from the National University of Singapore and holds a Master and Bachelor's of Computer Science from the University of Geneva in Switzerland. Miguel is investigating the use of infrared radiation cameras and computer vision to analyze buildings at scale.

Can you briefly describe your education background?
I have a Bachelor and Master degree in computer science from the University of Geneva (Switzerland). After being research assistant at the Energy Center of the Ecole Polytechnique Fédérale de Lausanne (Switzerland) and research engineer at the Masdar Institute of Science and Technology (United Arab Emirates), I did a Ph.D. in building science at the National University of Singapore.

How did you get into this field?
Since my Master degree, I have always been interested by interdisciplinary research. I first tried to explore possible applications of computer science in the field of neuroscience. Then, when working at the Energy Center, I saw a great potential in using methods I studied in computer science to solve major challenges related to energy consumption. For this reason, I decided to join the Masdar Institute of Science and Technology, a research institute whose main focus was on renewable energy and urban sustainability. In collaboration with the Massachusetts Institute of Technology (United States), I developed physically-based models to simulate interactions between a building and its outdoor conditions. During my Ph.D. at the National University of Singapore, I formulated a more advanced physically-based models using computational fluid dynamics to assess outdoor conditions.

What drew you to SinBerBEST?
During my Ph.D. at the National University of Singapore, I studied the relation between building energy efficiency and urban microclimates from a modelling approach only. The SinBerBEST program was a unique chance for me to further understand this relation using data collected from a field experiment.

How does your work at SinBerBEST build on your past research?
In the past, and especially during my Ph.D., I conducted field experiments using instruments that are normally used by meteorologist to measure outdoor conditions. In my research at SinBerBEST, I have now the chance to collect measurements of the building surface temperature from infrared cameras, which are instruments more commonly used in the building sector. From measurements collected by infrared cameras, I am trying to establish a correlation between building energy efficiency and outdoor conditions.

How can your research benefit people working in the building and other industries?
The correlation I am trying to establish between building energy efficiency and outdoor conditions using infrared cameras would enable architects and urban planners to better understand the impact of building design on urban sustainability. Architects, in particular, do not always realize how significantly the design of a building might affect its exterior environment. From my research, I hope to provide appropriate guidelines to architects or government agencies to achieve net-zero energy buildings while improving outdoor thermal comfort.

What are your longer term goals?
In the future, I wish to become a faculty member in architecture and the built-environment. I am convinced that my experience at SinBerBEST will help me to achieve this long-term goal.

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 – E) :

A - Human-Building Nexus
B - Smart Technologies and Resilient Buildings
C -Agile Design for Energy Efficiency and Human Comfort
D - Data Analytics
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

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