Spatial Perspective on Thermal Comfort and Energy Consumption: a PLS-SEM approach

Bayu Andalas[1,2], Haryoto Kusnoputranto[2], Suyud Warno Utomo[2,3] and Raldi H. Koestoer[2,4]

Jakarta Provincial Government, Jl. Medan Merdeka Selatan Kav.8-9 Jakarta Pusat, Jakarta, 10000, Indonesia[1]
School of Environmental Science, University of Indonesia, Jl. Salemba Raya, Jakarta Pusat, Jakarta, 10000, Indonesia[2]
Faculty of Public Health, University of Indonesia, Depok, Indonesia[3]
Coordinating Ministry for Economic Affairs, Republic of Indonesia, Jakarta, Indonesia[4]

Corresponding author: bayu.andalas@ui.ac.id

Abstract. Jakarta has implemented Environmentally-friendly buildings and Energy-saving act policy. But the energy consumption in a building is moderately increased all the time. It dominated by consumption in building's air conditioner and related to thermal comfort for building's occupants and also the work performance of civil services employees. This research is providing statistical questionnaire-based of subjective answers by a public service employee of Jakarta Capital Government. This study was conducted by concerning spatial perspective or geographic location of the object in six administrative parts of Jakarta Capital City (center, east, north, west, south and Seribu archipelago). The questions is spreads to 367 buildings occupants during the dry-wet season (October-November). The study were performed in 311 Public service facility, then the data is analyzed by Partial Least Square Structural Equation Modeling (PLS-SEM) method to answer research questions about the link between thermal comfort and energy consumption. The results showed a significant result between two variables. A model using those variables was generated to show the link between them and suggested as a tool to conduct better building-related policies in Jakarta Provincial Government.

Keywords: Sustainable Building, Thermal Comfort, Energy Saving, Structural Equation Modelling

1 Introduction

Green building policy exists in Jakarta Capital City Government since 2012, but ironically, the energy consumption in a building is still increased all the time (Pemprov DKI, 2015). In several types of research [1], buildings consuming energy more than 40% in general global energy, and also provide more than 30% CO2 in general. This is mainly caused by the usage of Air Conditioning System which impacted by building occupants' thermal comfort, especially in the tropical region city like Jakarta [2].

Jakarta Provincial Government in this regime is eager to increase civil service employee's productivity (Pemprov DKI, 2017). To provide better services to its inhabitants, Jakarta Provincial Government built standardized 311 regional offices in its sub-district (267) and

ICESSD 2019, October 22-23, Jakarta, Indonesia

DOI 10.4108/eai.22-10-2019.2291485

district (44) to provide any administrative services. The building Indoor Air Quality become a critical part of making the building occupant's comfort [3]. Every district offices and sub-district offices equipped with AC (Air Conditioner) in its service area or the working office, which will consume more energy to provide better services.

The current condition is not compatible with Sustainable Development principles by Salim and UN's Sustainable Development Goals (Salim, 2015). Research conducted by [4] shows a link between Thermal comfort and energy consumptions. Thus variables also appear in research by [5] which show a connection between thermal comfort and work performance also a connection between energy consumptions and environmental-friendly perception of building's occupants.

2 Literature Review

This research expected to examine the link between variables and visioned to develop a policy for environmentally friendly (low energy) state-owned government office to the environmentally-friendly concept and better work performance in buildings occupant.

2.1 Thermal Comfort

According to [6], Thermal comfort is influenced by physical condition of the buildings and also influenced by the individual preference [7]. in this study the seven-point scale of ASHRAE used in the questionnaire based on method developed by [8].

2.2 Work Performance

Work performance of the building's occupants is related to thermal comfort [9] and [10], a modified work performance parameters from [9] deployed in this research is focused on work performance of civil servant employee of Jakarta Capital City Government based on questionnaire survey.

2.3 Environmentally-friendly perception

Environmentally-friendly perception in every building is measured by asking questions to each building occupants or building user, the question is adapted from [11] and [12], the question designed to determine how the building occupants aware and percept to environmentally friendly concept.

2.4 Spatial Perspective

Several researcher had discovered a link between geographical location to thermal comfort such as research by [13] or research by [14] in Jaipur India and [15] in Vietnam, mention how urban heat and temperature will be different based on locations and elevation of the measured object. In figure 1. below shown the location of each objects of each public building facility in Jakarta, Indonesia.

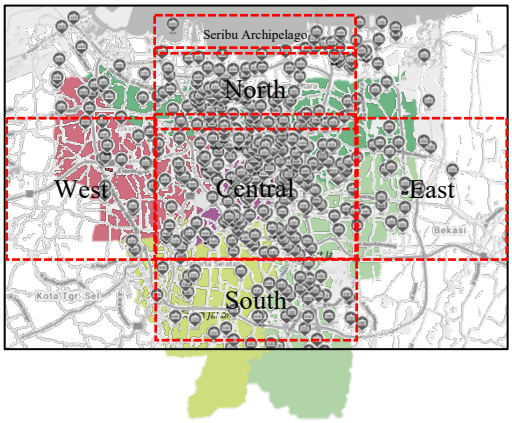

Fig. 1. State-Owned Buildings locations in Jakarta Capital City

2.5 Building Energy Consumption

This research has is focused how human interacted with its building and impacted to building energy consumption, so the research focused in its human interaction based on research by [16] and also research by [17] a set of questions is arranged to measure people's perception to building energy consumption.

3 Hypotheses

The hypotheses of this research is to examine:

Ha1: Thermal comfort influencing Building Energy Consumption
Ha2: Building perception to sustainable has a correlation to energy consumption
Ha3: Thermal comfort in government building influencing building occupants work performance
Ha4: Thermal comfort has a correlation to work satisfaction
Ha5: Public facility building will be environmentally sustainable if consider thermal comfort and work satisfaction

4 Materials and methods

This study is consist of: Subjective questionnaire survey to examine thermal comfort, work performance and environmentally friendly perception of 367 building occupants by adapting the questionnaire method of [8]. The variables compared to the energy consumption of 311 administrative office buildings by determine the Building Energy Consumption.

Population in this research is divided into 2(two) kinds as follows following method developed by [18]: (a) Building Occupants is a civil service employee who work in a state-owned (Jakarta Provincial Government) building counted 67.809 peoples consist of 33.477 (49.36%) males and 34.332 (50,63%) females and (b) State-owned buildings counted 311 buildings located in several locations (North, Central, South, East, West and Seribu Archipelago) of Jakarta Capital City Territory. Based on Slovin's equation in [19] a minimum 367 samples of civil service

employee and based on Tabachnick's equation [20], 58 buildings should be examined to conduct the research with a typical condition and shape like in the figure below:

Fig. 2. Typical Government Office in Jakarta

To compare the answers by the individual building occupants with the physical conditions of the buildings, this research using direct measurement of the physical condition of the building while the e-questionnaire spread during the office hour in each building.

Link between Environmental friendly perception and work satisfaction is appeared in several research like [21] and [22], then a connection between Environmentally friendly perception and energy consumption appear in many researh such as [5], [12], [23] every research mentioned above show a direct relation and mutual relationship between both variables, the rest variables such as Thermal Comfort, Energy performance and work satisfaction is appeared in several research such as: [4], [9], [10], [17], [24]. Based on literature review studies to understand link and connection between variables, a chart is established in figure below:

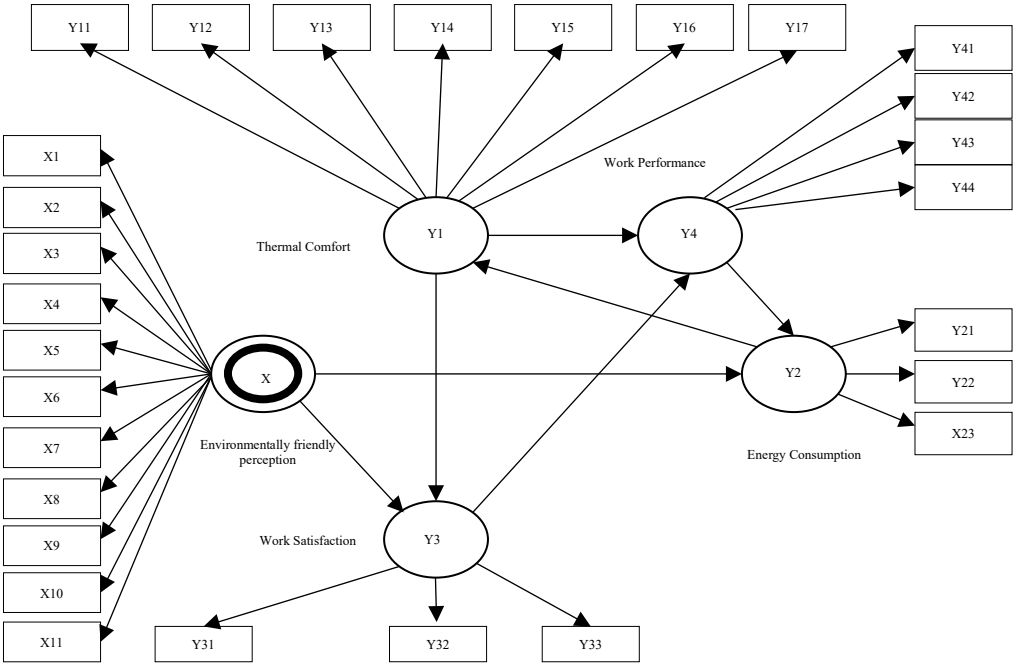

Fig. 3. PLS-SEM model

to examine quantitavely between variables so Partial Least Structural Equation Modelling (SEM) were used to understands link using subjective questionnaire as shown in Figure 2. Those variables are measured in PLS-SEM using these assessments criteria based on research question in each criteria based on research by [25] in Table.1:

Table 1. Variables and Questions

No	Objectives
Independent Variables	
X	**Environmentally-Friendly Perception**
X_1	Environmentally-friendly material
X_2	Water Conservation
X_3	Water Conservation and Rain Harvesting
X_4	Energy Diversity
X_5	Ozone Friendly Material
X_6	Energy Efficient Lighting and Air Conditioning
X_7	Domestic Waste Water Management
X_8	Waste Separation
X_9	Indoor Health Quality
X_{10}	Sustainable Site
X_{11}	Disaster Risk Facilities
Dependent Variables	
Y_1	**Thermal Comfort in Public Facility/Government Building**
Y_11	Indoor Activity
Y_{12}	Daily Activities
Y_{13}	Clothing
Y_{14}	Thermal Comfort Perception
Y_{15}	Thermal Comfort Desire
Y_{16}	Thermal Comfort Satisfaction
Y_{17}	Thermal Comfort Dissatisfaction
Dependent Variables	
Y2	**Identifying Energy Consumption Perception**
Y21	Knowledge of Energy Consumption
Y22	Understanding of Decreasing/Increasing Energy Consumption
Y23	Understanding of using air conditioning device in room
Dependent Variables	
Y_3	**Work Satisfaction**
Y_31	My Work
Y_32	Work Evironment Satisfcation
Y_33	Air Environment Satisfaction
Dependent Variables	
Y4	**Work Performance**
Y_41	Presence/Work Disc
Y_{42}	Work Quantity
Y_{43}	Budget Spending
Y_{44}	Behaviour

5 Analytical methods

In this research, the data is analyzed using SPSS Statistics v.24 and SmartPLS v.3.2.2 [26], the PLS is used due to the limitation of the data gathered from the respondents. Variance based PLS-SEM also used because PLS-SEM able to handle reflective and formative model which included in the proposed model of this research [27]. Moreover, PLS-SEM preference are made because of its ability to estimate causal relationship in every latent construct in single time/real-time while a pact with errors of measurement in a structural model.

[28] also suggest measurement model should be evaluated in different way while evaluating the structural model. Moreover, in order to make sure the data consistency and quality of structural model, several other test should be performed while conducting other validity and reliability checks before conducting analysis of PLS-SEM.

Based on guideline performed by [26] an evaluation to assessment criteria should be made to consider each questions be made correctly, the assessment criteria are shown in Table 2.

Table 2. Assessments criteria

Evaluation	Indicators	Assesment
Outer Model	1.Indicator reliability	Outer loading value 0,5 to 0,7 due to exploratory research
	2.Discrimninant validity	Variable indicator to latent variable Cross loading value should be higher rather than another latent variable Fornell-Lacker of every latent variable should be higher than latent variables correlation
	3. Internal consistency	Composite reliability ≥ 0,6 Cronbach's alpha ≥ 0,6 Composite reliability ≥ 0,8
	4.Convergent validity	Average Variance Extracted (AVE) should be higher than 0,5
Inner Model	Determinant Coefficient (R^2)	R2> 0,75 value is good
	Structural Model Coefficient	Significant

6 Respondent Demographic

By examining the Location, educational level, and the age of the respondents specific understanding of thermal comfort and its supporting factors based on each geographical locations could be examined. Complete details about the respondents' demographic attributes are listed in Table 3.

Table 3. Demographic of Respondents

Age years old (yo)	Sum	%	Location	Sum	Percentage

Under 18 yo	0	0%	Central	61	17%
18-24 yo	5	1%	North	62	17%
25-34 yo	83	23%	East	86	23%
35-44 yo	115	31%	South	103	28%
45-44 yo	134	37%	West	53	14%
55-64 yo	30	8%	Thousand	2	1%
	367	100%		367	

During the survey, most respondents has an undergraduate degree education (Undergraduate/equal 54% and graduate degree 31%), so the questionnaire question confirmed to be understandable by the respondents. In the survey, respondents given a set of questions using a digital questionnaires in a cellphone applications with each questions asked individually. The questionnaire spreads during office hour GMT 07:30-17:00 and under specific month (September-October), these month is an intermediary month between dry-wet season in tropical area region like Jakarta (BMKG, 2018) recorded during these month the outdoor humidity level will be higher than other months. Hopefully, The objective to understand the thermal comfort will be achieved.

By using bootstrapping in PLS-SEM, each questions is measured and resulting value as follow:

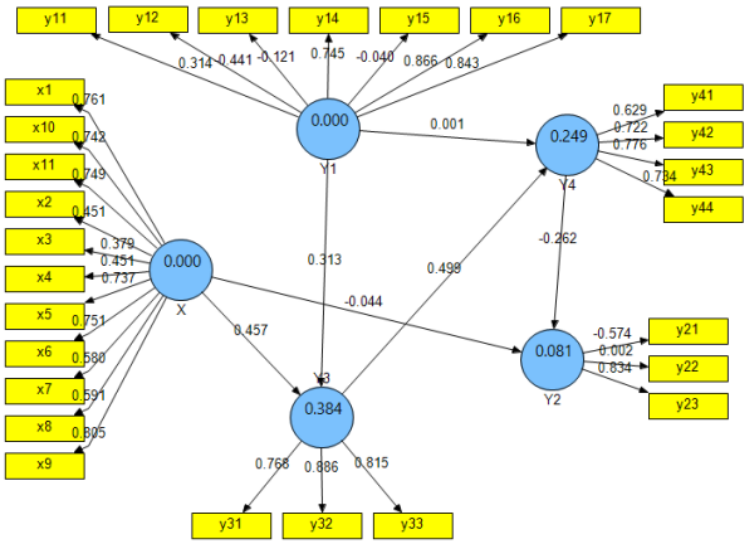

Fig. 4. Bootstrapping in PLS-SEM

7 Results and Discussions

Each variables (independent and dependent) divided into several objectives and questions as follow, every questions in the variables is merged to the PLS-SEM model as appeared in Fig.1, with several question reflecting every objective in the questionnaires. The result show Thermal

Comfort and Energy Consumption variables did not meet the criteria of Internal Consistency with the value of Composite reliability ≥ 0,8, the result shown in Table 4.

Table 4. Variables and result

Latent Variables	Composite Reliability	Cronbachs Alpha	Results
Environmentally-friendly perception (EF)	0.886	0.869	Meet Criteria
Thermal Comfort (TC)	0.501	0.280	Not Meet Criteria
Energy Consumption (EC)	0.034	0.456	Not Meet Criteria
Work Satisfaction (WS)	0.864	0.765	Meet Criteria
Work Performance (WP)	0.808	0.692	Meet Criteria

Furthermore, each question in every variable also measured to understand the validity of each questions to fit the proposed model, the results are shown below in Table 5:

Table 5. Variables and conclusion

Variables	Indicator	Objective	Loading Factors	T Statistics	Conclusion
Environmentally friendly perception	X1	Knowledge of Environmentally friendly material	0,5284722	24.736	Valid
	X2	Indoor Water Conservation	0,3131944	6.941	Invalid
	X3	Rainwater Conservation	0,2631944	5.105	Invalid
	X4	Energy Diversification	0,3131944	6.652	Invalid
	X5	Ozone Friendly Air Conditioning	0,5118056	22.402	Valid
	X6	Energy Saving	0,5215278	26.356	Valid
	X7	Domestic waste water management	0,4027778	10.161	Valid
	X8	Waste Sorting	0,4104167	14.105	Valid

Variables	Indicator	Objective	Loading Factors	T Statistics	Conclusion
Thermal Comfort Perception	X9	Building Occupants health	0,5590278	30.433	Valid
	X10	Site Sustainability	0,5152778	24.198	Valid
	X11	Disaster Resilent	0,5201389	22.652	Valid
	Y11	Temperature Difference between indoor and outdoor	0,2180556	3.192	Invalid
	Y12	Daily personal activities	-0.441	5.489	Invalid
	Y13	Personal Clothing	-0.121	1.418	Invalid
	Y14	Thermal Comfort	0,5173611	15.887	Valid
	Y15	Thermal Comfort Desire	-0.040	0,2951389	Invalid
	Y16	Thermal comfort satisfaction	0,6013889	23.302	Valid
	Y17	Thermal Comfort Disatisfaction	0,5854167	30.523	Valid
Energy consumption perception	Y21	Energy consumption understanding	-0.574	0,6763889	Invalid
	Y22	Incresed/Decreased Energy consumption understanding	0.002	0.005	Invalid
	Y23	Usage of Air Conditioning	0,5791667	1.474	Valid
Job Satisfaction	Y31	Building Occupants job satisfaction	0,5333333	20.582	Valid
	Y32	Work Environment Satisfaction	0,6152778	58.472	Valid
	Y33	Indoor Air Quality Satisfaction	0,5659722	36.168	Valid
Work Performance	Y41	Employee Compliance	0,4368056	11.502	Valid
	Y42	Work Quantity	0,5013889	15.924	Valid
	Y43	Budget Absorption	0,5388889	29.055	Valid
	Y44	Working Behaviour	0,5097222	19.240	Valid

Based on above table, not all indicator of every construct has a loading factor value above 0,5 so it can be concluded those invalid criteria can be put aside or removed to answering the

research questions. In the table 6 below, PLS SEM also measured the path coefficient and Structural Model Test.

Table 6. Path Coefficient and Structural Model Test

	Path	**T Statistics**	**R square**
X -> Y2	-0.044	0.101	0.081
Y4 -> Y2	-0.262	0.214	
X -> Y3	0.457	0.049	0.384
Y1 -> Y3	0.313	0.047	
Y1 -> Y4	0.001	0.063	0.249
Y3 -> Y4	0.499	0.054	

As seen in Table above, A link between Environmental Perception (EP) and Work Performance to Energy consumption is measured 0,081. It means Energy consumption can be explained by Environmentally friendly perception and work performance for 8,1%. The rest of it (91,9%) could be explained by other unexamined variables. Based on other research by [3], [9] this might be related to unexamined variables in this research such as: Personal factors or even outdoor climate during the examination.

Moreover, link between Environmental Perception (EP) and Thermal Comfort to Job Satisfaction is measured 0,384. It means Job Satisfaction can be explained by Environmentally friendly perception and work performance for 38,4%. The rest of it (61,6%) could be explained by other unexamined variables. Based on other research by [3], [9] this might be related to unexamined variables in this research such as: Personal satisfaction or even outdoor climate during the examination.

Moreover, the PLS-SEM measurement is trying to answer the hypotheses shown above, the results can be seen in Table 7 below:

Table 7. Test the hypotheses

ypotheses	**Path Coefficient (Before intervention)**	**t_{count}**	**$t_{critical}$**	**Result (before intervention)**	**Path Coefficient (After Intervention)**	**t_{count}**	**$t_{critical}$**	**Result (After intervention)**
Ha1	-0.044	0,2986111	1,96	Rejected	0.006	0.096	1,96	Rejected
Ha2	-0.262	1.226	1,96	Rejected	-0.221	3.859	1,96	Accepted
Ha3	0,317	9.389	1,96	Accepted	0,327	9.348	1,96	Accepted

Ha4	0,217	6.611	1,96	Accepted	0,209	6.013	1,96	Accepted
Ha5	0.001	0.010	1,96	Rejected	-0.035	0,424	1,96	Rejected

Ha1: Thermal comfort does not impacted Building Energy Consumption
Ha2: Building perception to sustainable has a correlation to energy consumption
Ha3: Thermal comfort in government building influencing building occupants work performance
Ha4: Thermal comfort has a correlation to work satisfaction
Ha5: Public facility building is not related thermal comfort and work satisfaction

Acknowledgements. The authors would like to thank Universitas Indonesia for supporting our research under grand scheme Hibah Publikasi Internasional Terindeks untuk Tugas Akhir Mahasiswa A (PITMA-A) Number: NKB-0886/UN2.R3.1/HKP.05.00/2019

References

[1] Y. Zhang, J. Wang, F. Hu, and Y. Wang, "Comparison of evaluation standards for green building in China, Britain, United States," *Renew. Sustain. Energy Rev.*, vol. 68, no. August 2016, pp. 262–271, 2017.
[2] Y. H. Yau, "Thermal comfort and Indoor Air Quality at Green Building in Malaysia," 2010.
[3] A. Merabtine, C. Maalouf, A. Al Waheed Hawila, N. Martaj, and G. Polidori, "Building energy audit, thermal comfort, and IAQ assessment of a school building: A case study," *Build. Environ.*, vol. 145, no. July, pp. 62–76, 2018.
[4] L. Pomfret and A. Hashemi, "ScienceDirect ScienceDirect Thermal Comfort in Zero Energy Buildings," *Energy Procedia*, vol. 134, pp. 825–834, 2017.
[5] S. Barbhuiya and S. Barbhuiya, "Thermal comfort and energy consumption in a UK educational building," *Build. Environ.*, vol. 68, pp. 1–11, 2013.
[6] P. O. Fanger and J. Toftum, "Extension of the PMV model to non-air-conditioned buildings in warm climates," vol. 34, pp. 533–536, 2002.
[7] M. A. Nico, S. Liuzzi, and P. Stefanizzi, "Evaluation of thermal comfort in university classrooms through objective approach and subjective preference analysis," *Appl. Ergon.*, vol. 48, pp. 111–120, 2015.
[8] M. Kameni, R. Tchinda, and J. A. Orosa, "Thermal comfort and energy consumption in modern versus traditional buildings in Cameroon : A questionnaire-based statistical study," vol. 114, pp. 687–699, 2014.
[9] S. Tanabe, M. Haneda, and N. Nishihara, "Workplace productivity and individual thermal satisfaction," *Build. Environ.*, vol. 91, pp. 42–50, 2015.
[10] M. T. H. Derks, A. K. Mishra, M. G. L. C. Loomans, and H. S. M. Kort, "Understanding thermal comfort perception of nurses in a hospital ward work environment," *Build. Environ.*, vol. 140, no. March, pp. 119–127, 2018.
[11] M. Holmgren, A. Kabanshi, and P. Sörqvist, "Occupant perception of 'green' buildings: Distinguishing physical and psychological factors," *Build. Environ.*, vol. 114, pp. 140–147, 2017.
[12] A. Botelho, L. M. C. Pinto, L. Lourenço-Gomes, M. Valente, and S. Sousa, "Public Perceptions of Environmental Friendliness of Renewable Energy Power Plants," *Energy Procedia*, vol. 106, pp. 73–86, 2016.
[13] S. Hubbard, K. Stewart, and J. Fan, "Modeling spatiotemporal patterns of building vulnerability and content evacuations before a riverine flood disaster," *Appl. Geogr.*, vol. 52, pp. 172–181, 2014.

[14] S. Khandelwal, R. Goyal, N. Kaul, and A. Mathew, "The Egyptian Journal of Remote Sensing and Space Sciences Assessment of land surface temperature variation due to change in elevation of area surrounding Jaipur , India," *Egypt. J. Remote Sens. Sp. Sci.*, vol. 21, no. 1, pp. 87–94, 2018.

[15] T. N. Phan, "Land Surface Temperature Variation Due to Changes in Elevation in Northwest Vietnam," pp. 1–20, 2018.

[16] J. Student, E. Papyrakis, and P. Van Beukering, "Buildings behaving badly : a behavioral experiment on how different motivational frames influence residential energy label adoption in the Netherlands," *J. Hous. Built Environ.*, vol. 32, no. 1, pp. 107–132, 2017.

[17] J. Langevin, J. Wen, and P. L. Gurian, "Quantifying the human-building interaction: Considering the active, adaptive occupant in building performance simulation," *Energy Build.*, vol. 117, pp. 372–386, 2016.

[18] B. Andalas, H. Kusnoputranto, and R. H. Koestoer, "Developing thermal comfort model through regional budget expenditure analysis towards low energy consumption in public building facility (case object: government building in north and south of Jakarta)," *E3S Web Conf.*, vol. 74, p. 05001, 2018.

[19] H. Boesono, D. R. Setiawan, K. E. Prihantoko, B. B. Jayanto, and A. R. Malala, "Productivity Analysis of Mini Purse Seine in PPI Pulolampes Brebes, Central Java, Indonesia," *Aquat. Procedia*, vol. 7, pp. 112–117, 2016.

[20] B. G. Tabachnick and L. S. Fidell, "Using Multivariate Statistics Title: Using multivariate statistics (Vol. 5)," pp. 1–14, 2007.

[21] S. Kaur, R. Sharma, R. Talwar, A. Verma, and S. Singh, "A study of job satisfaction and work environment perception among doctors in a tertiary hospital in Delhi," *Indian J. Med. Sci.*, vol. 63, no. 4, p. 139, 2009.

[22] Y. Geng, W. Ji, B. Lin, and Y. Zhu, "The impact of thermal environment on occupant IEQ perception and productivity," *Build. Environ.*, vol. 121, pp. 158–167, 2017.

[23] H. Ma, W. Lu, L. Yin, and X. Shen, "Public Building Energy Consumption Level and Influencing Factors in Tianjin," *Energy Procedia*, vol. 88, pp. 146–152, 2016.

[24] J. K. Day and D. E. Gunderson, "Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction," *Build. Environ.*, vol. 84, pp. 114–124, 2015.

[25] M. S. Farooq, M. Salam, A. Fayolle, N. Jaafar, and K. Ayupp, "Impact of service quality on customer satisfaction in Malaysia airlines: A PLS-SEM approach," *J. Air Transp. Manag.*, vol. 67, no. January, pp. 169–180, 2018.

[26] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, "An assessment of the use of partial least squares structural equation modeling in marketing research," pp. 414–433, 2012.

[27] D. J. Ketchen, "A Primer on Partial Least Squares Structural Equation Modeling," *Long Range Plann.*, vol. 46, no. 1–2, pp. 184–185, 2013.

[28] M. S. Farooq *et al.*, "Acceptance and use of lecture capture system (LCS) in executive business studies: Extending UTAUT2," *Interact. Technol. Smart Educ.*, vol. 14, no. 4, pp. 329–348, 2017.