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Occupants' Thermal Adaptive Behavior Pattern in Indonesian Residential Buildings

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Abstract: Occupants' adaptive behaviors (OABs) can boost thermal acceptability. This study aims to identify the OAB pattern in the hot-humid region of Indonesia and compare the thermal acceptability percentage of the groups with the identified patterns. Data from an online questionnaire with 3000 respondents were adopted for the analysis of air conditioning (AC), fan, and portable fan usage intensities, along with AC set-point temperature, clo-value, clothing adjustment, and window opening intensity. Hierarchical cluster analysis and logistic regressions were used to distinguish and evaluate OAB patterns. Five groups with various patterns for each AC and naturally ventilated (NV) residence were identified, and similar pattern groups with high clo-values and low thermal acceptability percentages appeared in both residences. The highest window opening intensity for the most active patterns in both AC and NV residences was perceived to be 87% and 91% as time intensity averages. These findings imply a great influence of NV lifestyles with active behavior patterns on improving thermal acceptability for both residences. This study suggests an appropriate OAB strategy to promote a better trade-off between energy consumption and thermal acceptability, such as patterns with a ±25 °C set-point temperature and various OABs in AC residences. Additionally, further investigation into the socio-cultural effect of OABs is necessary.

Keywords: occupants' adaptive behavior; Indonesia; thermal acceptability; air conditioning; naturally ventilated; lifestyle

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1. Introduction

Indonesia, one of the tropical hot-humid countries, has several climatic zones. The latest study by Putra et al. [1] allocated eight climate zones based on the similarities in standardized hourly climatic data, namely highland tropical (HT), very highland tropical, equatorial (EQ), sub-equatorial (SEQ), monsoonal (M), sub-monsoonal (SM), savanna (SV), and sub-savanna (SSV). These climate zones spread across the archipelago with various socio-cultural and economic backgrounds. Despite this climate diversity, locations close to the equator bring a relatively stable temperature change during the year in Indonesia. Karyono [2,3] mentioned that long-term acclimatization to the local climates allowed most residents to feel comfortable without overly relying on the air conditioning (AC) systems. A similar finding was also mentioned by Feriadi et al. [4], who mentioned that people in the tropics tend to interpret neutral temperature as an acceptable temperature. However, climate issues are threatening to affect the local climate in Indonesia [5–7]. With economic development in Indonesia and the local climate shift, more people will adopt AC to adjust the indoor temperature. A study comparing traditional and modern houses in North Sulawesi, Indonesia, by Sangkertadi et al. [8] suggested that modern houses tended to have a higher temperature than traditional houses. This might raise another issue regarding energy consumption, especially considering the current behavioral practices of AC users in Indonesia who assign AC the lowest possible set-point temperature [3,9]. In addition, despite the increasing AC prevalence [10], the preference for natural ventilation still plays a significant role in tropical and sub-tropical climates [11–13]. Aside from the possible increase in AC prevalence, Indonesians have also become more modernized by foreign cultural influences; thus, their clothing has started to adopt suits, blouses, long-sleeved shirts, etc., during formal meetings in their workplace, and the number of women who wear hijabs is increasing [3,14]. Consequently, this clothing behavior change has caused an increase in clothing insulation compared to the clothing used in the past.

Uno et al. [9] in 2003 showed evidence that actual air temperature was usually higher than the AC set-point temperature in Indonesia. Despite this discrepancy between actual indoor temperature and AC set-point temperature, Standar Nasional Indonesia (SNI) [15], first published in 2011, expressed their recommended thermal environment using an AC set-point temperature around 25.5 °C ± 1.5 °C for working spaces and 28.5 °C ± 1.5 °C for transit spaces, such as lobbies and corridors in regions with an average monthly temperature around 28 °C. Meanwhile, it was generally not necessary to utilize AC for regions with an average monthly temperature ≤23 °C. Similar conditions are still applied in the 2020 version of SNI [16]. However, Karyono showed a different perspective on the relevancy of this SNI for various types of climates in Indonesia [3,17]. Other studies by Miyamoto et al. [18] and Mori et al. [19] distinguished the schedule of window opening and AC usage by Indonesian respondents. However, these studies did not indicate the relation between the behavior schedule and respondents' thermal perception.

In past decades, researchers have developed approaches to understand people's perception of their thermal condition, as summarized in American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 55 [20] and International Organization for Standardization (ISO) 7730 [21], including the predicted mean vote (PMV) model by Fanger [22,23] and the adaptive thermal comfort models by de Dear, Brager et al. [24–26], and Humphreys and Nicol [27,28]. In ASHRAE [20], the standard parameters in thermal comfort are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. As adaptive models have become popular, researchers have been observing these topics for NV buildings [4,29–31] and AC buildings [32–35]. Several investigations on various occupants' adaptive behavior (OAB) on thermal comfort were conducted [36–39], including the effect of clothing [40–45] and elevated wind speed from ventilation and fans [46–48]. In 2010, Masoso et al. [49] raised awareness of the waste of energy from poor OAB adaptation. Since OAB is taken by an individual occupant, OAB provides a personal control method for the thermal environment. It also triggers the emerging topic of personal comfort models [50,51]. This personal comfort model is a promising approach to achieve improvement in building operation in terms of energy and comfort at the same time. A past study by Kim et al. [39] mentioned that occupants in AC mixed-mode buildings tend to have better satisfaction of their indoor air quality rather than the single-mode buildings, such as NV or AC only. Given that the human thermal physiological state is formed through interactions among human–clothing–indoor thermal environment–outdoor thermal environment, as mentioned by Sakoi et al. [52], the effect of OABs, such as opening/closing windows and wearing/removing clothes, on thermal comfort changes depending on outdoor climate and the surrounding indoor environment. Naturally, occupants' responses when they are exposed to an uncomfortable thermal environment will result in OABs, and the OAB plays a large role in achieving personal comfort. Furthermore, if these OABs are considered carefully, it can help reduce the possible heavy reliance on building mechanical ventilation and AC systems in the future [53–55]. One example of a successful strategy in adopting these OABs is the Japanese COOL BIZ campaign [56–58].

Apriliyanthi et al. [59] conducted an online survey to investigate how Indonesians engaged in adjustments by AC usage, fan usage, portable fan usage, and the wearing/taking off of clothing in their residences. With the overall thermal acceptability, AC residences indicated 79% acceptability, higher than that of naturally ventilated (NV) residences at 70%. We clarified that the conventional OABs—the OABs other than AC usage—effectively assisted in the removal of thermal unacceptability, in general, for AC mixed-mode residences. Meanwhile, in NV residences, their effect differed depending on outdoor climate. For the hot local climate group, the conventional OABs usually mitigated the unacceptability but did not remove it. For moderate and neutral local climate groups, the conventional OABs effectively assisted in removing thermal unacceptability. These results suggested that there must be indoor condition ranges for conventional OABs in Indonesia to work effectively in removing thermal unacceptability. The study also succeeded in detecting the characteristic difference in OABs based on the climate group, especially in NV residences. In the neutral local climate group, occupants mainly engaged in clothing adjustment. In hot and moderate local climate groups, occupants engaged frequently in fan usage. However, occupants in the hot climate group tended to adjust clothing more than those in the moderate local climate group, and those in the neutral local climate group adjusted it more than the moderate local climate. Regarding the OABs for occupants in AC mixed-mode residences, there were no significant differences between the local climates. Interestingly, the window opening intensities in all of local climate groups were similarly high, with an average intensity around 63–65%. Summarizing these results, the OABs the occupants engaged in differed by climate and AC adoption and the effect on the adjustment of thermal acceptability also depended on them.

A recent study by Apriliyanthi et al. [59] found an effective method to remove thermal unacceptability. However, effective OAB patterns to obtain acceptable thermal environments based on the percentage of occupants perceiving thermal environments as acceptable or unacceptable in general were not proposed. This study aims to clarify the relations between OAB pattern groups and the thermal acceptability of hot-humid climate of Indonesia—a large-population country with a specific lifestyle, building, and clothing style. In this study, we used the collected online questionnaire data in a previous study [59]. First, we identified the typical OAB patterns in NV and AC residences. Next, we investigated the OAB pattern effect in achieving thermal acceptability based on the acceptability percentage of a certain group. We also investigated the effect of local climate on the effectiveness of each OAB pattern. Then, we compared the effectiveness of each OAB pattern in achieving an acceptable thermal environment for AC and NV residences considering the local climate in Indonesia. This study explored the effective OAB patterns to reach thermal acceptability for developing countries with socio-culture and climatic aspects of the hot-humid climate in southeast Asia. The findings in this study can be used in developing a practical and appropriate OAB strategy that promotes a better trade-off between energy consumption and thermal acceptability.

2. Methodology

According to ASHRAE [20], "environment, acceptable thermal" is defined as "a thermal environment that a substantial majority (more than 80%) of the occupants find thermally acceptable". Additionally, we believe that the indoor environment is formed in relation to AC operation, building insulation, and local climate, especially in NV residences. Thus, we reached a hypothesis that thermal acceptability differs depending on OAB patterns, local climate, and AC ownership, based on our positivist epistemology. To validate this hypothesis, this study re-analyzed the data obtained from a cross-sectional survey which used a web-based online questionnaire survey. As a mono-method quantitative study, the survey collected 3000 responses from Indonesian working-age samples from December 2021 to January 2022 [59]. In this study, we conducted three steps of quantitative analyses using the collected data: The first was to define pattern groups in which we grouped the occupants engaged in similar OAB patterns (GOP) through a hierarchical cluster analysis. The second was to analyze how the thermal acceptability changes depending on GOPs through logistic regressions. The third was to compare the effectiveness of each GOP in NV residences to the overall AC residences in achieving an acceptable thermal environment.

2.1. Survey Summary

The survey was carried out after obtaining approval from an ethics committee of Hiroshima University (ASE-2021-74) with the informed consent asked at the beginning of the questionnaire. The online questionnaire was designed with several multiple-choice answers and some open-ended questions where respondents could add their personal answer if necessary. We focused the sample on Indonesian working-age adults who worked in an indoor environment during the majority of their work. Both perceived thermal acceptability and OABs in their workplace and residence were collected in the survey; however, the current analysis focused on their perceived thermal acceptability and OABs in residential buildings only. This was to ensure minimal effect from respondents' socio-culture and the societal norm in general. Each respondent was allowed to submit only one response to the questionnaire. The questionnaire was a survey for residents and workplaces. The detailed survey methods were reported by Apriliyanthi et al. [59].

The data analyzed in the current study included respondents' general residential perception of thermal acceptability, most frequent clothing ensembles worn, usual OABs, AC ownership, AC set-point temperature, and personal attributes, including age, weight, height, gender, and residence province. The respondents were categorized into 2 cases: AC case composed of AC owners in their residences, and NV case composed of the remaining respondents. As was reported by Apriliyanthi et al. [59], data of residence provinces were converted into 7 climate zones as proposed by Putra et al. [1], namely EQ, SEQ, HT, M, SM, SV, and SSV. These climate zones were further classified into 3 large climate groups, namely neutral, moderate, and hot climate groups, to represent the local climates. The classification reflected the common tendency of the relations between OAB and thermal acceptability in the NV residences. SSV and SM, with the highest 25 °C CDD based on Putra et al. [1], shall be referred to as the hot climate group. For this group, OABs were not effective enough in removing thermal unacceptability. The second group was composed of

EQ and M and is referred to as the moderate climate group. For this group, OABs were effective in removing thermal unacceptability. The last group was composed of only HT, where thermal acceptability did not evidently change by OABs. The CCD of HT was lowest for the 7 climates of EQ, SEQ, HT, M, SM, SV, and SSV. This group shall be referred to as the neutral climate group. SV and SEQ were excluded from the current study analysis because of the lack of significant trends between thermal acceptability and OABs coming from the sample number shortage in the previous study [59].

The perceived daily thermal environment in residences and working places is reported as thermal acceptability. The thermal acceptability was asked for using a 6-level scale, namely "acceptable", "slightly acceptable", "neither, but if I have to choose, I would say acceptable", "neither, but if I have to choose, I would say unacceptable", "slightly unacceptable", and "unacceptable" [59]. In the current study, we considered that acceptability should be most prioritized. Then, the 6-level data were converted to 2 levels: "acceptable" or "not acceptable". "Acceptable" included "acceptable" and "slightly acceptable" in the 6-level scale. "Not acceptable" was composed of the rest of the 6 levels. A dummy variable 1 was assigned for "acceptable" and 0 was assigned for "not acceptable".

2.2. Occupants' Adaptive Behavior

Respondents reported OABs for adjusting their thermal environment based on their perception. The OABs in their residence and workplace were reported as a perceived percentage of the respondents' intensity of exhibiting the behavior based on daily time for the past one year. These OAB intensities consisted of the percentage usage of cooling devices, including AC, fans, and portable fans, and the opening time percentage of the window. In order to report them, respondents chose a value from 0% to 100% at 10% intervals for each OAB. Respondents were also asked to report their clothing adjustment intensity and the typical clothing combination in their residence and workplace. The clothing adjustment intensity was reported using a 4-point Likert scale, where 1 represents "never", 2 represents "rarely", 3 represents "sometimes", and 4 represents "often". The clo-value was estimated from the reported typical clothing combination by referring to ISO 9920 [60] and other databases [61,62], as was reported in a previous study [59]. While the each OAB was reported for residences and workplaces, this study focused only on OABs in residences.

AC set-point temperatures in AC residence data were collected as a selection input from 16 °C to 30 °C with 1 °C intervals, "no set-point temperature", and "others: ...", which respondents could write using the nominal value. Respondents with more than one unit of ACs in their residences were asked separately for each room in which AC was installed; however, in this study, only the average set-point temperature for the common bedroom and living area of the residence where respondents usually conduct activities was assigned as the representative AC set-point temperature for a respondent. Therefore, the analysis did not consider AC in the guest rooms or other unique or private rooms. Additionally, the respondents who live in AC residences but did not disclose their AC set-point temperature were excluded from the analysis. Through this data validation, the total number of 3000 samples reduced by 49 samples, resulting in 2951 samples to be analyzed.

2.3. Analysis Methods

The analyses in this study were conducted using IBM SPSS Statistic version 25. The current study utilized hierarchical cluster analysis and logistic regressions, namely binomial logistic regression (BLR) for the binomial outcome variable. Categorical or nominal data, such as GOP introduced later and climate groups, were converted to binary 0 or 1 dummy variables within each item prior to BLR. The BLRs resulted in adjusted odd ratios (AORs) of the investigated variables. The adjusted variables used in these calculations were the respondents' age, weight, height, and sex. All analyses were carried out for AC and NV cases, respectively, to reflect the evidently different relationship between OABs and thermal acceptability [59].

2.3.1. Hierarchical Cluster Analysis

A hierarchical cluster analysis using Ward's method was conducted to identify the GOPs for AC or NV cases. Then, we observed the thermal acceptability percentage for each GOP. Variables included in the analysis for the NV case were fan usage intensity, portable fan usage intensity, window opening intensity, clo-value, and clothing adjustment intensity. Meanwhile, additional variables included in the cluster analysis for the AC case were AC usage intensity and AC set-point temperature. The analyzed valuables were standardized by transforming them into z-scores prior to the cluster analysis.

The GOPs were then renamed based on the number of frequent OABs. Here, we set the threshold of frequent OAB to the average time-based intensity >50% for fan usage intensity (f), window opening intensity (w), portable fan usage intensity (pf), and AC usage intensity (a). Meanwhile, for clothing adjustment (c) that used the Likert scale, we set the threshold of the frequent OAB to Likert scale values ≥3.0. The Clo-value and AC set-point temperature were not considered as a frequent OAB, because they did not express the frequency. However, they were included as OABs to explain how clothing adjustment and AC usage were performed. GOPs with more than two frequent OABs were later defined as an active GOP and are referred to as AC active (ACA) and NV active (NVA) for AC and NV residences, respectively. GOPs with two or fewer frequent OABs patterns were later defined as a passive GOP and are referred to as AC passive (ACP) and NV passive (NVP) for AC and NV residences, respectively.

2.3.2. Binomial Logistic Regression

BLR analyses were conducted to compare the perceived thermal acceptability percentage among GOPs. This study used three types of BLR analyses. The results from these 3 BLR analyses are presented in Section 3.1, Section 3.2, and Section 3.3, respectively.

The first BLR analysis compared the thermal acceptability percentage of a GOP with the average of the other GOPs without considering the climate effect. The analysis was conducted separately for NV and AC cases. In the analysis, a dummy variable to express GOP was used along with the adjusted variables as input variables. Meanwhile, the outcome variable during the analysis was the thermal acceptability dummy variable. An AOR significantly greater than 1, determined in this analysis, means that the acceptable percentage of the investigated GOP was higher than that of the rest of the respondents within NV or AC cases.

The second BLR analysis compared the thermal acceptability percentage of a certain GOP in a particular climate with that of the remaining respondents in the NV or AC case. In this analysis, the product of dummy variables representing the GOP and climate were used as input variables along with the adjusted variables. Meanwhile, the outcome variable was thermal acceptability. An AOR significantly greater than 1 from the second BLR analyses means that the thermally acceptable percentage of the investigated GOP in the particular local climate group was higher than that for the remaining respondents within the NV or AC cases.

The third BLR analysis compared the acceptability percentage of a GOP in the NV case in a particular climate with that of the overall AC case of 79%. It was aimed to investigate the potential of OAB patterns in the NV case that can achieve a similar level of acceptability of 80% (≈79%). The analysis was repeated for each GOP in each climate group.

A significantly greater AOR than 1 corresponds to a higher thermal acceptability percentage of the investigated GOP in the NV case of the investigated climate group compared to that for overall AC respondents. Similarly, a significant AOR of less than 1 indicated the opposite fact.

3. Results

Table 1 presents the respondents' attributes collected from the online survey. Several respondents were excluded from the analysis due to missing information of AC set-point temperature. Details of the collected OABs are indicated in the next section.

Table 1. Respondents' attributes overview.

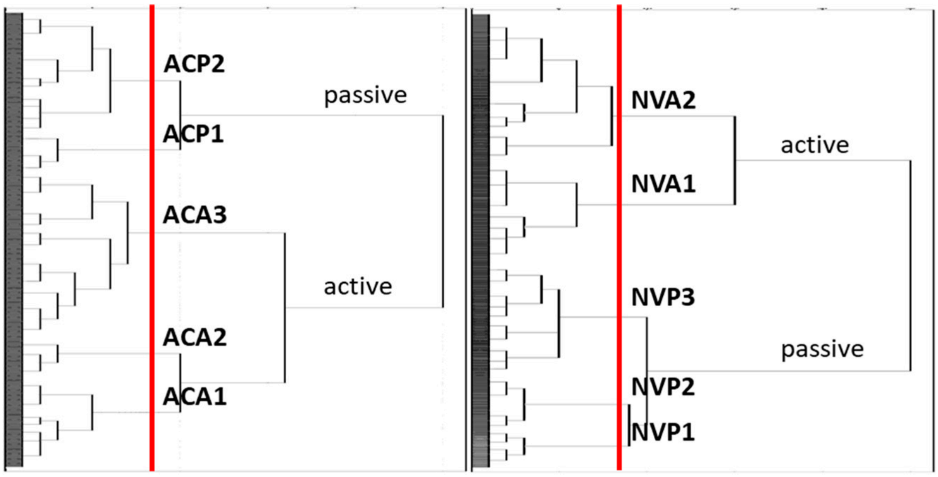
Variable		Sample Number (Avg ± Std/Percentage of Data)
Variable Item Name	**Value Labels of Categorical Data**	
Age (year)		2951 (32.0 ± 7.2)
Weight (kg)		2951 (60.6 ± 11.4)
Height (cm)		2951 (163.4 ± 7.8)
Sex (n.d.)	0: female 1: male	1428 (48.4) 1523 (51.6)
AC ownership (n.d.)	0: no 1: yes	1506 (51.0) 1445 (49.0)
Climate zone (n.d.) Converted from province	1: highland tropical (HT) 2: sub-savanna (SSV) 3: savanna (SV) 4: sub-equatorial (SEQ) 5: equatorial (EQ) 6: sub-monsoonal (SM) 7: monsoonal (M)	563 (19.1) 414 (14.0) 24 (0.8) 84 (2.8) 679 (23.0) 366 (12.4) 821 (27.8)
Thermal acceptability (n.d.)	1: acceptable 2: weak opinion 3: unacceptable	2194 (74.3) 501(17.0) 256 (8.7)

3.1. OAB Patterns

The hierarchical cluster analysis resulted in five pattern groups with a similar OAB (GOPs) for each NV and AC residence. The number of GOP was decided by considering the respondent size in each GOP and the distances between the GOPs. The hierarchical cluster analysis result also distinguished active GOPs, namely NVA and ACA, and passive GOPs, namely NVP and ACP, at the first two main branches of the dendrogram, as indicated in Figure 1.

3.1.1. OAB Patterns in NV Residences

Table 2 presents five GOPs for NV residences. The total number of samples was 1506, and 70% of them perceived the daily thermal environment as acceptable, which was lower than the respondents of the AC case. Opening the window was a common frequent behavior in all GOPs, with the average of all NV respondents being 67 ± 33%. All NVA patterns and NVP1 also used fans as their frequent OAB. Meanwhile, using a portable fan was frequently practiced only by NVP1. Clothing adjustment was the frequent OAB for NVA2 and NVP3. The average clo-value for people who live in NV residences was 0.37 clo. However, NVP2 had an exceptionally high clo-value of 0.64 clo as the average.



(**a**) (**b**)

Figure 1. Dendrogram from hierarchical cluster analysis of OABs for (**a**) AC residences and (**b**) NV residences. Note: red lines indicate the selected cluster division.

Table 2. Indonesian OAB pattern in NV residences.

(a) Part 1: OAB Values and Thermal Acceptability						
GOPs	**Thermal Acceptability (%)**	**Fan**	**Window**	**Portable Fan**	**Clothing Adjustment**	
		Average OAB Intensity				**Clo-Value (Clo)**
		(0–100%)	**(0–100%)**	**(0–100%)**	**Likert Scale (1–4)**	
NVA1	65	68 ± 27 *	74 ± 24 *	55 ± 21 *	2.9 ± 0.7	0.34 ± 0.10
NVA2	67	89 ± 14 *	91 ± 13 *	16 ± 19	3.6 ± 0.4 *	0.32 ± 0.10
NVP1	73	55 ± 36 *	56 ± 40 *	3 ± 8	1.7 ± 0.4	0.34 ± 0.10
NVP2	54	29 ± 34	51 ± 33 *	24 ± 30	2.9 ± 0.7	0.64 ± 0.14
NVP3	83	35 ± 37	52 ± 36 *	3 ± 8	3.0 ± 0.8 *	0.33 ± 0.10
overall	70	58 ± 37%	67 ± 33%	21 ± 27%	3.0 ± 0.8	0.37 ± 0.14

(b) Part 2: Attributes of GOPs						
GOPs	**Samples**		**Sex Ratio (%)**	**Thermal Preferences**		
	Size	**Ratio (%)**	**Male/Female**	**Prefer Cooler (%)**	**Neutral (%)**	**Prefer Warmer (%)**
NVA1	355	23.6	54:46	66	26	8
NVA2	372	24.7	47:53	75	22	3
NVP1	202	13.4	56:44	54	42	4
NVP2	170	11.3	40:60	64	29	7
NVP3	407	27.0	56:44	53	39	8
overall	1506	100	51:49	63	31	6

Notes: (*) is the frequent OAB.

Despite the lack of frequent OABs, NVP3 had the highest thermal acceptability compared to the rest of the GOPs in NV residences, with 83% of respondents perceiving the daily thermal environment as acceptable. This fact might be attributed to a limitation of our survey method in asking for the acceptability of the general daily thermal environment. Despite the thermal environments that the respondents experienced daily varying with time, we asked for the general perception of the daily thermal environment. Through this method, we did not obtain the perception of the thermal environment which the respondent experienced at the time of their response. Thus, the data must be influenced largely by the individual difference in consciousness of the daily thermal environment. The respondents composing NVP3 were 27% of the total NV respondents.

These respondents would be unconscious of the hot environment, which could explain the infrequent OABs and high acceptability. Considering this limitation and the importance of sensitivity to the hot environment, we considered that the GOPs other than NVP3 provided more meaningful information to investigate the relationship between the OAB pattern and thermal acceptability. The lowest thermal acceptability percentage of 54% was observed in NVP2, which was the GOP with the highest clo-value and infrequent OABs. For all NVAs, less than 70% of thermal acceptability was observed despite them exhibiting more frequent OABs. As discussed later in Section 3.2.1, we considered that this could be attributed to climate characteristics.

Figure 2 presents the AOR of each GOP to the thermal acceptability percentage determined from the first BLR. The result showed that NVA1 had an AOR significantly less than 1, which indicated a less acceptable percentage of NVA1 than that of the other NV respondents. A similar significant AOR result can also be found in NVP2. The result for NVP2 can be expected by considering that this GOP had the highest clo-value, which is marked with (*hc*), of all GOPs. However, the similar result for NVA1, which had three frequent OABs, was unexpected. To clarify the reason, we conducted further analysis to consider the climate effect as shown in Section 3.2.1. NVP3 had an AOR significantly greater than 1, which means a higher acceptable percentage of NVP3 than that of the rest of the NV respondents. As indicated above, the respondents of NVP3 might be unconscious of the hot environment and this unconsciousness may explain this result.

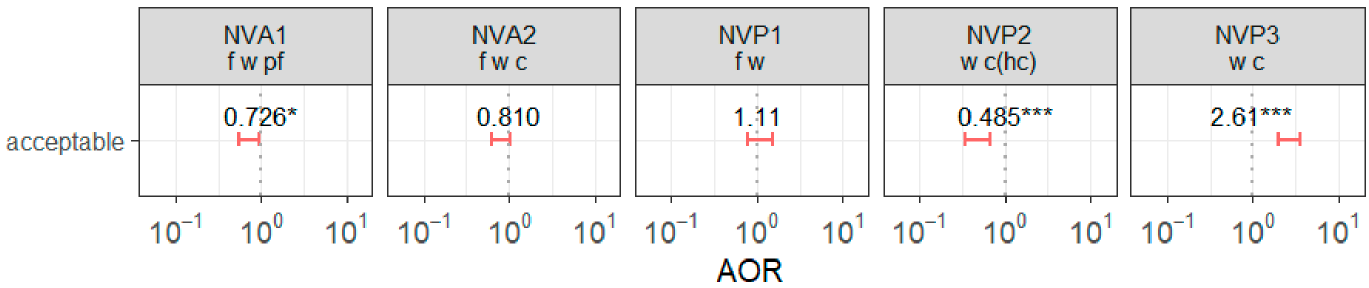


Figure 2. AOR of thermal acceptability for each GOP in NV residences. Notes: (1) values under pattern name are the frequent behavior: f: frequent fan; w: frequent window; pf: frequent portable fan; c: frequent clothing adjustment; hc: high clo-value; (2) *** p-value ≤ 0.001; * $0.01 \leq p$-value ≤ 0.05.

3.1.2. OAB Patterns in AC Residences

Table 3 presents five GOPs for AC respondents. The total number of samples was 1494, and 79% of them perceived it as thermally acceptable. Using a fan and opening window behaviors were frequent OABs in all ACAs. From the average of AC usage, window opening, and fan usage intensities, it can be concluded that most respondents in ACAs used AC with opening windows and using a fan simultaneously. Thus, most residences in ACAs can be regarded as mixed-mode buildings. Meanwhile, using a portable fan was frequently practiced only in ACA2. AC usage and clothing adjustment were considered the most frequently practiced OABs since they were frequent OABs for four GOPs. The average and standard deviation of clo-value for people who lived in AC residences were 0.39 clo and 0.17 clo, respectively. However, similarly to NVP2, ACP2 had an exceptionally high clo-value, averaging 0.65 clo.

Unlike in NV cases, where all NVAs (active GOPs) indicated a lower thermal acceptability percentage than NVPs (passive GOPs), in AC cases, all ACAs (active GOPs) indicated a higher thermal acceptability than APCs (passive GOPs). ACP1 had 76% thermal acceptability. Meanwhile, all ACA groups had >80% thermal acceptability despite different AC set-point temperatures. On the other hand, ACP2, which had the highest clo-value, showed the lowest thermal acceptability percentage of all GOPs. Only 57% perceived it as thermally acceptable, similar to the NVP2 in NV cases.

Table 3. Indonesian OAB patterns in AC residences.

(a) Part 1: OAB Values

GOPs	Thermal Acceptability Percentage (%)	AC		Fan	Window	Portable Fan	Clothing Adjustment	
		Set-Point Temp.(°C)	Average OAB Intensity					
			(0–100%)	(0–100%)	(0–100%)	(0–100%)	Likert Scale (1–4)	Clo-Value (Clo)
ACA1	81	24.6 ± 2.7	61 ± 20 *	66 ± 21 *	78 ± 19 *	29 ± 28	3.4 ± 0.6 *	0.44 ± 0.17
ACP1	76	23.1 ± 3.6	40 ± 21	29 ± 24	44 ± 29	12 ± 17	3.0 ± 0.8 *	0.35 ± 0.11
ACA2	88	21.2 ± 2.7	91 ± 13 *	89 ± 15 *	87 ± 16 *	75 ± 21 *	3.5 ± 0.6 *	0.44 ± 0.18
ACP2	57	20.2 ± 2.5	57 ± 25 *	28 ± 27	40 ± 32	24 ± 24	2.9 ± 0.7	0.65 ± 0.14
ACA3	82	19.6 ± 2.5	68 ± 24 *	57 ± 30 *	69 ± 27 *	18 ± 24	3.2 ± 0.8 *	0.31 ± 0.09
Overall	79	21.7 ± 3.5	60 ± 26%	55 ± 30%	63 ± 30%	24 ± 28%	3.2 ± 0.8	0.39 ± 0.16

(b) Part 2: Attributes of GOPs

GOPs	Samples		Sex Ratio (%)	Thermal Preferences Percentage (%)		
	Size	Ratio (%)	Male/Female	Prefer Cooler	Neutral	Prefer Warmer
ACA1	273	18.9	57:43	80	17	3
ACP1	385	26.6	57:43	74	22	4
ACA2	128	8.9	41:59	74	21	5
ACP2	125	8.7	30:70	56	38	6
ACA3	534	37.0	52:48	74	23	3
overall	1445	100	52:48	73	23	4

Notes: (*) is the frequent OAB.

Figure 3 presents the AOR of each GOP in the AC case to the thermal acceptability percentage determined from the first BLR. The result indicated that respondents in ACA2 and ACA3 were more likely to perceive their daily thermal environment as acceptable. Additionally, the AOR for ACP2, a group with a high clo-value, indicated that respondents in ACP2 were less likely to perceive their daily thermal environment as acceptable. Unlike the NV case, the ACP2 in the AC case should have a cool thermal environment. However, a similar trend was still observed. The fact that only 6% of respondents in ACP2 preferred a warmer environment suggests that low acceptability was not mainly caused by cold discomfort, and their high clo-value was not a countermeasure to cold discomfort. Additionally, the female ratio in ACP2 was considerably high at 70%, suggesting that that demographic and culture strongly affected this group.

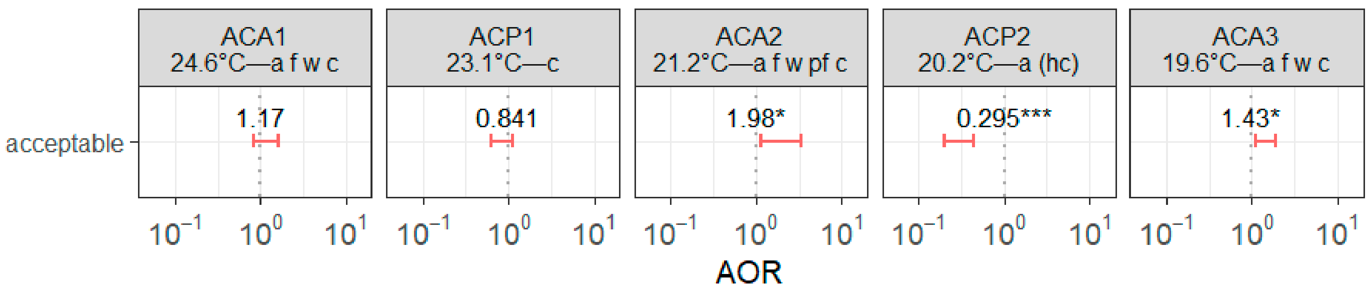


Figure 3. AOR of thermal acceptability for each GOP in AC residences. Notes: (1) values under pattern name are the frequent behavior and average AC set-point temperature: a: frequent AC; f: frequent fan; w: frequent window; pf: frequent portable fan; c: frequent clothing adjustment; hc: high clo-value; (2) *** p-value ≤ 0.001; * 0.01 ≤ p-value ≤ 0.05.

Figure 4 illustrates the density plot of the AC set-point temperature distribution in percentages for each GOP. In the graph, the data respondents reported by using the nominal value by selecting "others" were rounded up to the nearest integer. In general, there were two peaks of AC set-point temperature, namely around 20 °C and 24–25 °C. The OAB patterns with higher set-point temperatures were ACA1 and ACP1, whereas the other OAB patterns tended to have lower set-point temperatures. This distribution indicates that the current AC usage in Indonesia does not comply with the suggestion from the Indonesian National Standard (SNI), which suggests that the set-point temperature should be 25 °C.

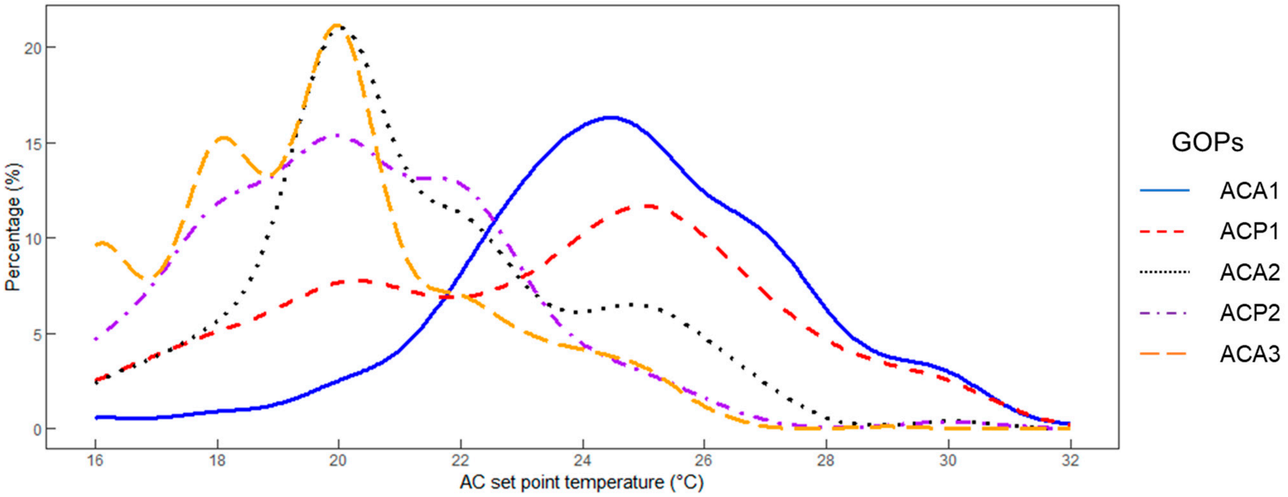


Figure 4. Density plot of AC set-point temperature distribution in percentages for each OAB pattern.

3.2. Effect of Climate Type Groups to Thermal Acceptability on Each OAB Pattern

3.2.1. NV Residences

Figure 5 presents the AOR of each GOP in a certain climate group to the thermal acceptability percentage determined from the second BLR. The AOR results indicated that respondents in NVP3 from any climate group perceived their daily thermal environment as more acceptable than the rest of the respondents did in the NV case. However, the result for this NVP3 would be affected by the limitation, as mentioned in Section 3.1.1. The AOR of NVP2 indicated that respondents were less likely to perceive their thermal environment as acceptable in the neutral and moderate climate groups. NVP2 were for the people with a higher clo-value (*hc*); therefore, we can expect respondents to be less likely to perceive it as acceptable. However, it did not indicate a significant AOR in the hot climate group. This lack of significance for NVP2's AOR in the hot climate group may suggest that the cold retention effect of clothing for the evaporative cooling occurred inside clothing. On the other hand, the AOR of NVP1 did not indicate any significance in any climate group.

The AOR of NVA2 indicated that respondents in moderate climates tended to perceive their daily thermal environment as more acceptable than the rest of the NV respondents did. However, the AORs of NVA1 and NVA2 in hot climates indicated that these respondents were less likely to perceive it as acceptable. This result suggests that respondents with NVA patterns in hot climates still need further help, such as AC adoption, to achieve an acceptable thermal environment for the current NV residences. However, similar behavior patterns in moderate climates were effective. This explains why, in Figure 2, NVA1 was regarded as a less acceptable GOP compared to the other GOPs despite actively engaging in OABs. On the other hand, it was suggested that respondents in the moderate climate groups had a high probability of achieving an acceptable thermal environment with proper OAB patterns. The AORs of NVAs in the neutral climate group also took a value >1, even though the *p*-values were not significant. No significant *p*-value may be attributed to the small respondent sample size in the neutral climate groups.

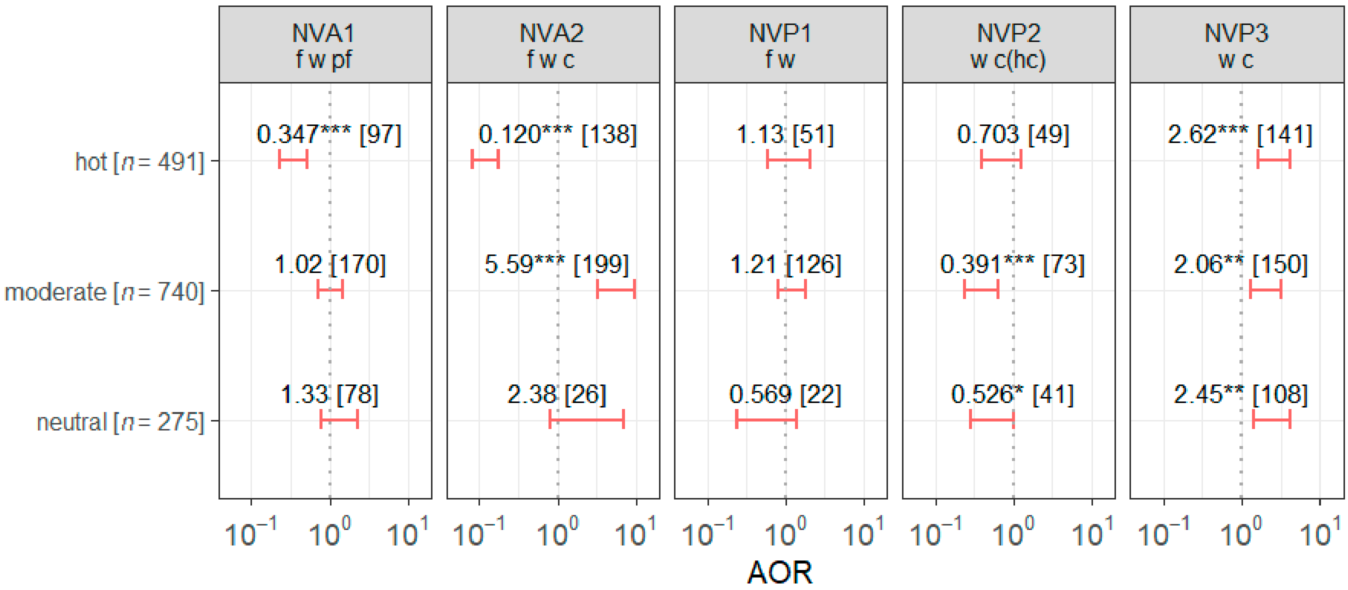


Figure 5. AOR of NV GOPs for thermal acceptability in each climate group. Notes: (1) values under pattern name are the frequent behavior; (2) values in [ ] are the sample size; (3) *** *p*-value ≤ 0.001; ** 0.001 < *p*-value < 0.01; * 0.01 ≤ *p*-value ≤ 0.05.

3.2.2. AC Residences

Figure 6 presents the AOR of each GOP in a certain climate group to thermal acceptability percentage. The result shows that respondents in the moderate climate group mostly show an AOR significantly different from 1. The AOR of ACA2 in the moderate climate group indicates that these respondents had the highest probability of accepting the thermal environment for the AC case. Similar results were observed for ACA3 for the neutral and moderate climate groups.

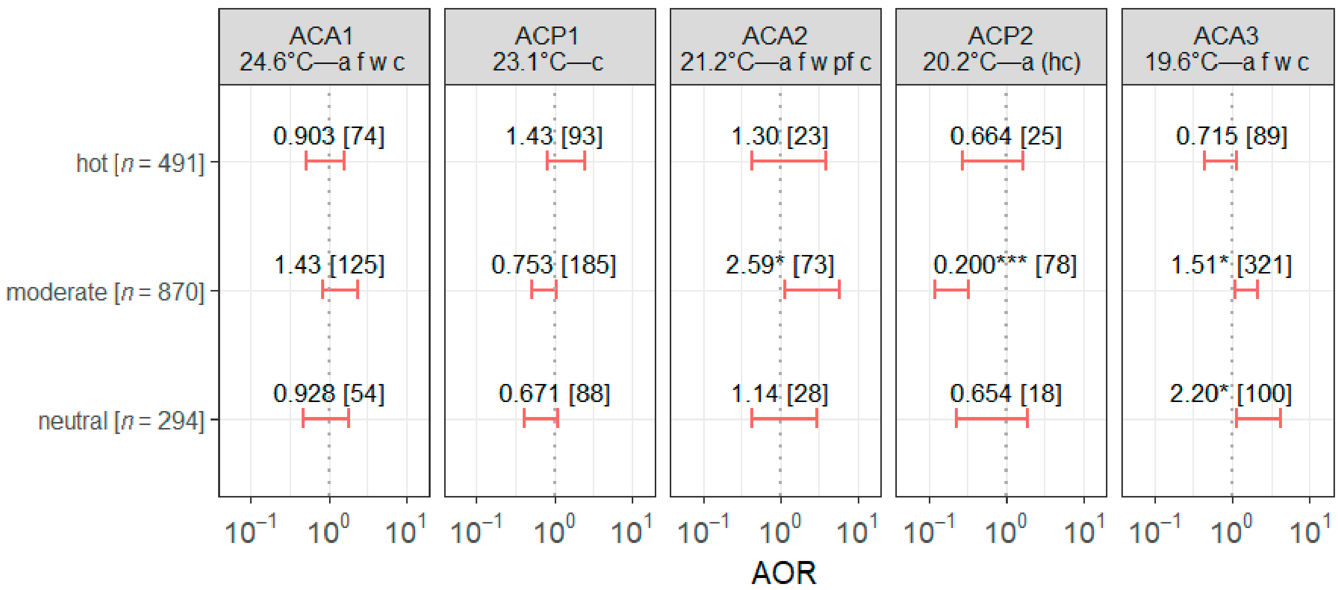


Figure 6. AOR of AC OAB pattern for acceptable thermal environment in each climate group. Notes: (1) values under pattern name are the frequent behavior and average AC set-point temperature; (2) values in [ ] are the sample size; (3) *** *p*-value ≤ 0.001; * 0.01 ≤ *p*-value ≤ 0.05.

The respondents in ACA2 and ACA3 with the lowest AC set-point temperature and infrequent portable fan usage tended to perceive their daily thermal environment as acceptable compared to the average of the rest of the AC residences. Meanwhile, respondents in ACP2 who engaged in a few OABs and who had high clo-values were less likely to perceive it as acceptable. The AORs of the other OAB patterns did not indicate significant *p*-values, due to sample size, such as ACA2 and ACP2 samples in the neutral and hot climate groups, which had fewer than 30 samples. While the sample respondent size in the moderate climate group was large compared with the other climate groups, a significant *p*-value was not provided for ACA1 in the moderate climate. This suggests that ACA1 in the moderate climate maintained the same level of thermal acceptability with the rest of the respondents of the AC residences despite the highest set-point temperature. Another reason that resulted in a lack of significance in AORs of GOPs in the hot and moderate climate groups was the average thermal acceptability in the AC residences of 79% and above, suggesting that the sample size of respondents who perceived it as unacceptable was not sufficient, as indicated in Table 2, in obtaining a significant *p*-value. Therefore, most 95% confidence interval lines were drawn to cross 1 (=10^0), except for ACP2 in the moderate climate group. The AOR of ACP2 suggests the difficulty for respondents with a high clo-value in the moderate group to achieve an acceptable thermal environment through the current OAB patterns.

3.3. Thermal Acceptability in Each OAB Pattern Within NV Residences Compared with Overall AC Residences

Table 4 shows AORs to compare the thermal acceptability percentage of a GOP in a certain climate group in NV residences with that of the overall AC residences. Since the reference for comparison was set to the overall AC residences, the AOR of AC was always 1. The AORs indicated that only NVA2 in the moderate climate group could provide a higher thermal acceptability percentage than that for overall AC residences. The AORs of NVA1 and NVA2 in the neutral climate group and NVP1 in the hot and moderate climates were not significantly different from 1, which suggests that these groups may provide a similar acceptability with the overall AC residences. However, as shown in Figure 5, the sample number of NVP1 in the hot climate group was only 51. The small sample size might make it difficult to detect significance.

Table 4. AOR to compare thermal acceptability of GOPs in NV with overall AC.

Climate Groups	NV Residences—GOP					AC Res.
	NVA1 *f w pf*	NVA2 *f w c*	NVP1 *f w*	NVP2 *f c* (*hc*)	NVP3 *w c*	
hot	0.238 ***	0.0962 ***	0.725	0.422 **	1.484	1.000
	(0.156–0.362)	(0.0641–0.145)	(0.385–1.37)	(0.233–0.763)	(0.911–2.42)	
moderate	0.62 **	3.02 ***	0.757	0.245 ***	1.243	
	(0.431–0.892)	(1.784–5.117)	(0.495–1.16)	(0.151–0.399)	(0.798–1.94)	
neutral	0.805	1.51	0.369 *	0.318 ***	1.44	
	(0.475–1.36)	(0.514–4.42)	(0.155–0.879)	(0.169–0.599)	(0.840–2.46)	

Notes: (1) values in ( ) are 95% confidence intervals of the AOR; (2) values under pattern name are the frequent behavior; (3) *** p-value ≤ 0.001; ** $0.001 < p$-value < 0.01; * $0.01 \leq p$-value ≤ 0.05.

4. Discussion

ASHRAE [20] defines "environment, satisfactory thermal" as "a thermal environment that a substantial majority (more than 80%) of the occupants find thermally satisfactory". In this study, we analyzed the change in respondent percentages perceiving daily thermal environments as acceptable in Indonesia within the groups exhibiting similar OAB patterns. Given that the thermal acceptability for the overall AC case was 79%, which was similar to the 80% adopted in ASHRAE, we compared the AOR of the groups for thermal acceptability with that of the overall AC case.

Indonesians tend to prefer an open to outdoor environment lifestyle. Moreover, the GOPs that tend to actively exhibit various OABs indicate the highest thermal acceptability. Mori et al. classified the schedule of occupants opening the window in tropical countries, including Indonesia and Malaysia [19]. The study also mentioned that opening the window is one of the significant OABs for tropical countries. However, Miyamoto et al. [18] suggested that most of the respondents do not open their window frequently. This is due to the respondents in their studies tending to live in an apartment and condominium. Despite this fact, their result suggested that clusters with less window opening intensity tended to have a low comfortability level. Sangkertadi et al. [8] compared the thermal comfort level of modern and traditional houses, which indicated that in the indoor environment condition of modern house was considered unsatisfactory due to the lack of natural ventilation. Our study indicated a similarity to Mori et al. [19], which mentioned a higher percentage of respondents that open the window. It can be observed from the overall cases of Section 3.1 that both AC and NV respondents indicate more than 60% of average window opening intensity.

Generally, in NV buildings, people have a wider range of thermally acceptable environments than in an AC building for the different expectations of the thermal environment [39]. Meanwhile, the trend of frequent OABs improving the thermal environment acceptability agrees well with the OABs in the NV mode in mixed-mode buildings expanding the comfort condition to the same range as NV buildings [38,39,53]. This phenomenon should be applied to our study. NVA2 in the NV case provided a more acceptable thermal environment than the overall AC case in neutral and moderate climate groups, while it was not the same for the hot climate group. From the average OABs in Table 1, NVA2 was characterized as the group where the respondents exhibited OABs most frequently, except for portable fan usage, and wore the lightest clothing for the NV case. According to ISO 9920 [60], a clothing combination resulting in 0.30 clo, close to the 0.32 clo of NVA2, is composed of underwear, T-shirts, shorts, light socks, and sandals. The clothing of NVA2 seems to be very light within daily life. The high acceptability of NVA2, who almost always opened the window, suggests that a natural ventilation lifestyle that exposes the indoor environment to the outdoor environment has a great effect on achieving an acceptable thermal environment. However, establishing the lifestyle of NVA2 might be challenging in central urban areas which have other factors like noise, safety, and health concerns due to air pollution.

In usual conditions, occupants in AC buildings with proper building insulation tend to rely on AC and exhibit less, other OABs than NV building occupants [59,63,64]. This results in OAB patterns of ACP1 in this study, with 26.6% of samples. However, due to the preferential tendency of a naturally ventilated lifestyle, many respondents liked to open their window even in AC-equipped residences, resulting in the mixed-mode GOPs such as ACA1, ACA2, and ACA3. Similarly to NV residences, the natural ventilation lifestyle positively affects the acceptable thermal environment in AC residences. While this study cannot distinguish between AC and NV schedules in their residences, the GOPs with more frequent OABs—ACA1, ACA2, and ACA3—indicated a more acceptable thermal environment than the GOPs with less frequent OABs: ACP1 and ACP2. In addition, among ACA1, ACA2, and ACA3, the highest acceptability percentage was observed in ACA2. Looking at the OAB intensity in Table 2, the respondents in ACA2 might use AC with opening windows.

Several studies also reported that an AC set-point of 20 °C or less was popular, possibly due to the building insulation [2,4,9] and AC cooling performance efficiency [2,9] despite the recommendation of 25 °C by SNI [16]. Along with building insulation, this could occur due to exposing the indoor environment to the outdoor environment while using AC, requiring occupants to use a lower AC set-point temperature to achieve an acceptable indoor condition. Respondents in ACA2 and ACA3 might set the AC to around 20 °C for obtaining better acceptability, as shown in Table 2 and Figure 6. However, in the current findings, the average clo-value of ACA2 was 0.44 clo, which was higher than the clo-value of NVA2 of the NV case, which was only 0.32 clo. This result suggested that the higher clo-value in ACA2 than that in NVA2 occurred due to overcooling by AC usage, which should have been compensated by conventional OABs [59].

Moreover, by considering the preference of the naturally ventilated lifestyle in Indonesia, or the hot-humid climate in general, the relatively low window opening and fan usage intensities of ACA1 than those of ACA2 suggests that the AC usage behavior of ACA1 was not always simultaneous with opening the window and using the fan. This suggested that by exhibiting proper OABs, respondents in ACA1 were able to balance the need of natural ventilation and room cooling, making it feasible to normalize the GOP. Despite the AC set-point around 25 °C, the thermal acceptability percentage of ACA1 for daily thermal environments was around 80%. This GOP had a higher temperature with various OABs, to maintain a proper trade-off between thermal acceptability and energy consumption. Even more importantly, this pattern also satisfies the current SNI suggestion. Studies in hot climates in America and Ghana mentioned that a 1 °C change in AC set-point temperature could provide 7–15% of energy savings [35,55]. Other studies suggested that AC usage with higher temperatures complemented with a fan, portable fan, and clothing adjustment can have similar thermal acceptability [32,33,35].

The use of AC in the future might be inevitable due to increasing temperatures globally and the developing economy. However, we need to be aware of the trade-off between acceptability and energy saving [54]. Regarding building envelope and facility improvement, Sangkertadi et al. [8] indicated that the modern house tends to have better insulation but less air permeability than the traditional house. With the improvement in building insulation, indoor operative temperature will approach AC set-point temperature. This could trigger the OAB pattern change from ACA2 or ACA3 to ACA1. However, with the reduction in energy-related AC operation, the relative energy consumption rate by ventilation to total AC operation energy consumption increases. Natural ventilation through window opening might be reduced and people might rely on mechanical ventilation. Future buildings must maintain the necessary ventilation at a certain level to maintain occupants' health and preference. Indonesia, as a hot-humid country, has a long rainy season during the year. We need to consider AC maintenance carefully. The AC operation in this high-humidity rainy season encourages mold growth [65]. Based on this recognition, the current high opening window intensity in ACA2 might be an unconscious countermeasure for mold contamination of AC.

In this study, no peak of AC set-point temperature more than 25 °C can be observed in the current data. An example that succeeded in encouraging an AC set-point more than 25 °C is the Japanese COOL BIZ campaign [56–58]. This policy encourages people to wear light clothing, resulting in a low clo-value, and encourages the use of a fan or portable fan to promote convective and evaporation heat transfer. Currently, in Indonesia, many AC units are still non-inverter types; however, inverter ACs in Southeast Asia are becoming prevalent [66]. The replacement of non-inverter ACs to inverter ACs must encourage less-clo-value clothing to be worn, especially where occupants wear high-clo-value clothing in response to indoor temperature fluctuations. Wearing high-clo-value clothing reduces the effect of temperature fluctuations on body heat loss. Inverter ACs provide detailed power control and reduce temperature fluctuation [34]. In the future, there is possibility in Indonesia to increase the AC set-point temperature higher than 25 °C, which is recommended by the Indonesian local standard, the SNI.

The use of OABs, in general, is important in achieving thermal comfort, such as the use of a fan and clothing adjustment, which will be significant. These OABs can adjust the personal comfortable range. Tanabe et al. [58] found that cooling items, such as portable fans and air-conditioned shirts, can help improve self-estimated thermal environment performance. This self-estimated performance correlated well with thermal satisfaction despite being poorly correlated with actual air temperature. The effective OAB patterns proposed in this study provide insight into the development of personal comfort models based on socio-culture and climatic aspects in hot-humid climates. To increase the controllable range of thermal resistance between the human body and indoor environment, airflow around the human body and clothing wearing and taking off control the resistance. Currently, DC fan adaptation is increasing. The DC fan provides detailed power control and enables very mild airflow to be provided to the human body [46]. Such mild airflow prevents performance reduction caused by airflow [67,68]. This encourages simultaneous operations of AC and fans that enables the AC to be set to a high temperature [35,46,69]. When airflow is emphasized, there are further chances for future improvements in clothing performance.

With regard to clothing, there are cultural and social aspects that affect the thermal acceptability in Indonesia [59,70–72]. As a Muslim-majority country, most Indonesian women tend to wear veils and long-sleeved clothes that have little skin exposure. These resulted in the existence of NVP2 and ACP2 in AC and NV residences with a low thermal acceptability, which was attributed to the high clo-value compared to the other GOPs. Replacing the cotton fabric by polyester used for sportswear should enable the prompt increase in moisture and air permeability [32,40,41]. Generating airflow within the environment can encourage the adoption of clothing that has an airflow pathway inside it [45] for increasing clothing ventilation.

As the limitation of this study, we only covered the case for residences. A similar pattern might not be found in the workplace, due to the building construction type, workstyle, socio-cultural restriction, etc. Additionally, the current study may face limitations due to the cross-sectional data collection method through the online survey method used for gathering respondents' perceptions of OABs and the general thermal acceptability for the daily thermal environment. Consequently, we cannot obtain the perception of thermal environment parameters which the respondent experienced at the exact response time and the physical thermal environment data such as air temperature and humidity. Thus, the results were applied in general but could not be applied for the specific case. Additionally, further investigation to compare the OAB pattern in different countries should be considered since there are still a limited number of studies on the effect of socio-cultural factors on OAB differences. The effect of socio-cultural factors on OABs needs to be considered for implementation of the current findings in different countries. In the current study, for some GOPs in hot and neutral climates, the sample size did not exceed 73, to ensure a 5% population with 5% error. However, the main objective of this paper is not to determine the population percentage but to investigate whether GOP provides thermal acceptability through logistic regression; the above consideration is not effective in considering the appropriateness of the sample size. For the sample size effect, we might miss detecting some trends. As a comparison of our findings to previous studies, Miyamoto et al. [18] and Mori et al. [19] indicated a similar trend of window opening and AC usage. However, the OAB pattern schedule was not clarified in our study. On the other hand, our study investigated the effect of local climate on the effectiveness of GOP in achieving thermal acceptability. By observing the GOP, this study discussed an insight for a practical strategy that can be adopted by readers in exhibiting appropriate OABs. Future research addressing these limitations are needed to develop a better energy trade-off for thermal comfort policy in Indonesia.

5. Conclusions

In this study, 3000 samples of self-reported questionnaire data on residential occupants' adaptive behavior from Indonesia were analyzed. In general, AC residences have a higher thermal acceptability than NV residences, which are 79% and 70%, respectively. These occupants' adaptive behavior was then classified into GOPs through hierarchical cluster analysis to identify the popular patterns of OABs. Regarding a 79% (≈80%) thermal acceptability of overall AC residences as the reference, we evaluated the thermal acceptability of GOP through binomial logistic regression (BLR) to analyze OAB effectiveness in achieving thermal acceptability.

In each NV and AC residence, five GOPs were identified. The groups were classified into active occupants' behavior, namely ACA and NVA, and passive occupants' behavior, namely ACP and NVP, based on the frequent behaviors, which were identified by the average intensity that surpassed 50% for the behavior or that was higher than or equal to "sometimes". NV GOPs consisted of 2 NVAs and 3 NVPs, while AC GOPs consisted of 3 ACAs and 2 ACPs.

There was a GOP with a very specific pattern of passive occupants' behavior patterns for both AC and NV residences. In these GOPs, respondents wore high-clo-value clothing, and their thermal acceptability was the lowest of the AC or NV residences. In AC residences, all active GOPs had a higher thermal acceptability than all passive GOPs.

Climate evidently affected the relation between OAB patterns and thermal acceptability in NV residences. For one of the active OAB patterns within NV residences, NVA2, thermal acceptability in the moderate local climate group was revealed to be higher than overall AC acceptability. On the other hand, the same NVA2 in the NV case in the hot local climate group resulted in respondents perceiving it as unacceptable, which suggested that they require AC to achieve thermal acceptability.

In AC residences, all active OABs tend to open their window frequently despite the residences being equipped with ACs, suggesting that respondents still prefer to have a naturally ventilated lifestyle at some point. At the extreme, respondents in ACA2 might even open their window and use AC simultaneously. The high clo-value of ACA2 also suggested that a potential overcooling was taking place despite this GOP exhibiting the highest thermal acceptability. Meanwhile, ACA1, which had lower OAB intensities and a higher AC set-point temperature than ACA2, indicated a thermal acceptability more than 80%. This fact suggests that ACA1 can provide a better trade-off between thermal acceptability and energy consumption.

For both AC and NV residences, the respondents in GOPs that had the most effective OABs for achieving an acceptable thermal environment always use a fan and open the window. For Indonesia, a country with a specific tropical lifestyle, such as naturally ventilated buildings and the lack of the need of significant seasonal clothing changes, exposing the indoor environment to the outdoor environment must have a great effect on adjusting occupants' thermal comfort.

The outcome from the current study can be used by policy makers and building designers to prepare a proper practical strategy to adjust the thermal environment for each climate group. These strategies must help building designers and policy makers in developing better local policies in Indonesia or hot-humid climate regions. By considering a proper adaptive occupants' behaviors strategy, Indonesia can foster a more responsive and inclusive society in the future.

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Conflicts of Interest: We declare that this research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abbreviations

AC	Air conditioner
ACA	AC active occupants' behavior
ACP	AC passive occupants' behavior
BLR	Binomial logistic regression
CDD	Cooling degree days
NV	Naturally ventilated
NVA	NV active occupants' behavior
NVP	NV passive occupants' behavior
OAB	Occupants' adaptive behavior
GOP	Group of the respondents OAB patterns

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