Standard review and update for tropical comfort shift of the built environment

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Abstract. The urban building standards recommend adaptable shift on heat and noise criteria as the main issues related to the high-density environment. The previous studies relating to building thermal comfort provided the comparison results between the past and recent conditions. This study reviews the guidelines and regulations of international standard, overseas countries, and specific region of tropical climate research in Indonesia. The evaluation is focused on tropical climate in order to reach the accurate thermal comfort and noise criteria comparison for Indonesia. Furthermore, the field study of the 71 of the tropical built environment respondents was also conducted in order to update and compare to the existing standards. The review results show that compared to 17°C to 31°C thermal comfort range from the World Health Organization, the tropical thermal comfort should be determined with a range of 29.3°C to 31°C. Based on the field studies, for lowland is formulated by 1.4x+29.3 and in highland is 1.5x+29.3 as two representative regions of the tropical environment. For noise criteria, some countries set the policy for determining noise limits which has the same value between day and night condition as the result of the constant number of noise source with the similar level of annoyance. Based on the field study, this study updates the noise criteria which the denser environment, lowland, has limits of noise in 49.9 dBA when in highland is 47.8 dBA. Both of them are lower than 55 dBA of Indonesian Standard. Noise perception by occupants in night-time shows that both in the lowland and in the highland, the vote is lower than daytime. The noise limits are 45.9 dBA and 40.0 dBA for lowland and highland, respectively. In general, the updated standard completes the existing and the detail of Indonesia national standard and the will be useful to guide the tropical building design.

1 Introduction

In high density of tropical urban environment, thermal and noise have a combined effect on the enclosed environment accumulated to the others environmental factors. Indoor comfort standard defines the diverse environmental factors, for instance, thermal, indoor air quality, aural and visual settings comfort [1]. In the tropical naturally buildings, the environment might not be improved simply without automatic method. Anthropologically, occupants in tropical culture preferred to enjoy high wind speeds [2]. Meanwhile, in a tropical noisy situation, annoyance is an indicator of non-acoustical features, such as economic, cultural, and social environments [3, 4]. Their effort on thermal comfort has urgent consequences on adaptable noise and comfort shift.

The adaptable shift in heat and noise criteria are the main issues related to the tropical condition. Actually, the previous standards and studies have provided the comparison results between the past and the recent conditions [5-18]. Therefore, this study evaluates the guidelines of international standard, overseas countries, and tropical comfort researches in Indonesia. Furthermore, it should be directed by updating critical environmental issues, thermal and noise comfort in representative object and climate.

2 Research Method

In addition to the current standard review, this study proposes the updated tropical comfort through analyzing the tropical building occupants' perception and adaptation. Javanese houses are the case of tropical building in the lowland (Surabaya, 0-50m msl) and in the highland (Malang, 440-667m msl). The geographical altitude is typical of the tropical environment representation of Indonesia.

The representative tropical cases are 6x7m^2 in typical dimension and a wood (TL_{wood} = 18 dB) has been used for the walls as acoustical properties (Figure 1). Meanwhile, the thermal properties are U-value = 3.19 W/mK and Tlag = 0.3 hours and it has been used for the walls for thermal and noise barriers. As shown in Table 1, the existence of traditional buildings was 19 houses as signified number both lowland and highland with 71 occupants as respondents (clothing is 0.16 to 0.57 and metabolic rate was 0.8 to 1.7, designates "sleeping to working" activities). Thermometer (for thermal) and

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sound level meter (for noise) were also set up at occupant reference height (1.5 m) and used to measure the 24 hours' conditions and consecutively results with an interview in critical time. The interview was conducted in the hottest time and the noisiest time (12:00 to 18:00). For capturing the comfort shift, the thermal vote setting followed 7 scale standard for both the temperature vote and noise observation (Table 2).

Fig.1. Research location and building profile.

3 Review of tropical comfort standard

3.1 Building Standard of Overseas Countries

3.1.1 Thermal environment standard of overseas

Thermal comfort reference for warm climates based on WHO recommendation is on the range of tropical neutrality temperatures, resulting from combined many temperature parameters in different world environments [5]. The acceptable thermal comfort for without health impacts is higher than 17°C and lower than 31°C. In addition, ISO 7730 as an International Standard considered the adaptation for existence in different climates and air velocity to offset the warmness perception [6]. Then, 23.5°C for the lowest and 25.5°C for highest are the neutral temperature during the summer season which has a similar state to tropical climates. Furthermore, European Standards and Research Projects suggested that the estimation takes place only in full hours, the tolerance is 3%, up to 5%. Meanwhile, the outdoor temperatures during summer period should be more than 15°C.

Table 1. Respondents profile.

No.	Information	Lowland	Highland
1.	Number of Objects	8	11
2.	Number of Occupants:	28:	43:
	a. Adult Males (≥17 years old)	11	13
	b. Adult Females (≥17 years old)	9	17
	c. Children (<17 years old)	8	13

Source: Field Study (July-August, 2012 and April-May, 2014)

Table 2. Vote setting.

THERMAL VOTE in Investigation Time Condition *Indoor Temperature: ......°C*						
Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
(-3)	(-2)	(-1)	(0)	(1)	(2)	(3)
NOISE VOTE in Investigation Time Condition *Indoor Sound Pressure Level: ......dBA*						
Very Quiet	Quiet	Slightly quiet	Neutral	Slightly noisy	Noisy	Very Noisy
(-3)	(-2)	(-1)	(0)	(1)	(2)	(3)

ANSI/ASHRAE Standard for Thermal Environmental Conditions for Human Occupancy presented the different method for defining thermal comfort. PPD<10, -0.5 < PMV < + 0.5 are determined for acceptable thermal environment for general comfort. That standard discounted the special condition for the different climate, involved tropical climate [7].

For defining thermal conditions for comfortable indoor activities, Brazil, Singapore, and Malaysia as a case of tropical countries had a specific and similar guideline. Brazil's Ministry of Labor adjusted both the safety and health for acceptable thermal comfort using standards effective temperature, and it is 20°C to 23°C. They recommended that the air velocity is set up to 0.75 m/s for the acceptable thermal comfort and humidity should be higher than 40%. Meanwhile, Thermal Comfort Guidelines and Policy of Singapore suggested 23°C to 26°C is normal comfortable needs in Singapore when wearing summer dresses. Department of Standards Malaysia, in Code of Practice on Energy Efficiency and Use of Renewable Energy Malaysia acclaimed the same interval temperature indicated by the same environment because of similar latitude site with Singapore.

The collecting of preceding studies both field and thermal chamber test approaches in tropical climate proposed a neutral temperature for calculating/acquiring thermal comfort during the years 1945-2014 (Figure 2). The building studies were subject by residential types. Although there is the global warming issue, the recent conditions of thermal comfort are not always as higher as neutral temperature from the previous associated studies. Those are influenced by the multipart aspects of thermal comfort, both physics and the psychology of the respondent. In general, the neutral temperature is from 24°C to 29°C with average moved from 26°C to 27.5°C. In the same years and tropical area, there is a neutral temperature difference of 5°C. Not only adaptation ability of respondents, the geographical difference between hotter of lowland and cooler of highland, also convinces a different annual temperature and the building inhabitants preference.

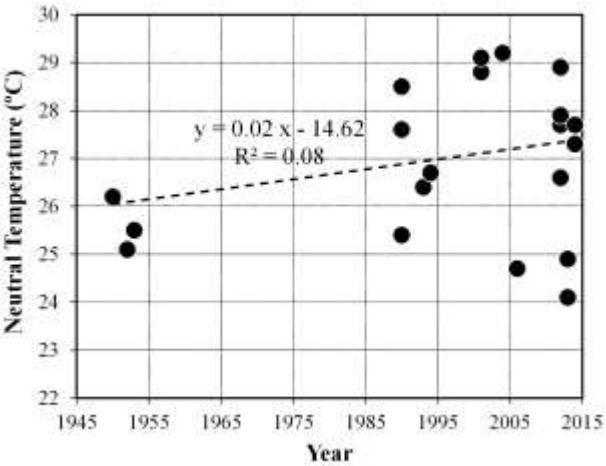

Fig. 2. Neutral temperature of tropical countries.

3.1.2 Noise environment standard of overseas

Accomplishment differently from building thermal guideline, there is no climate difference restrict to building noise mechanism. In the urban environment in the tropical countries, the acoustical propagation is depended on the noise source. Hence, the international standard provided by WHO recommended the requirement for community noise in specific environments [8]. For a residential environment, the highest annoyance in outdoor, the daytime and the evening are suggested up to 55 dB when for a moderate condition is up to 50 dB. The night-time indoor environment is 30 dB, or lower 5 dB compared to the daytime. The WHO standard is useful as a guideline for hearing health and its speech intelligibility performance.

The noise criteria are established by local authorities according to their guidelines as the major international standard, ISO 1996-1:2016 assumption [9]. The noise level standards for a living environment with the road as the main source were formulated by consideration of the daytime and night-time noise (it could be sound pressure level, followed by its source number and type). The interest of noise issue as part of government policy is described by their method from just the guidelines as a recommendation into a national or regional regulation. Because of the different traffic density condition, some countries recommended the evening time noise limits for special environment [10]. The countries with a significant different urban condition such as Australia have different regulation for every state, which provides the detail noise limits only in the daytime and night-time range. For high traffic road noise just as in the USA, regulation for road traffic has hourly noise limits, 67 dB (LAeq,1h). Most of those have indoor noise limits based on the needs for noise comfort. However, in detail, the standard for overseas also indicates different policy for indoor and outdoor for daytime and night-time, 45 dB (indoor) / 65 dB (outdoor) and 40 dB (indoor) / 60 dB (outdoor), respectively. Meanwhile, a long-term ambient sound is considered in a little number of overseas countries to determine the noise limits standard; for example, noise limits at 62 dB in medium noise areas has a long-term ambient sound level between 43 dB and 59 dB for high noise areas.

Comparison between the daytime and night-time noise boundaries is shown in Figure 3. It found that the noise criteria are suggested for daytime is up to 58.7 dBA and night-time noise is limited by 53.7 dBA. It also resulted that the 5 dBA is determined as maximum noise difference. The high scoring regression could be analyzed as an indication of the similar standard difference between daytime and night-time guideline or regulation for all overseas countries. The same requirement between day and night has been taken by many countries. This policy is affected by the similar number of noise source with a constant level of annoyance impact for all times, it could be very density urban transportation movement.

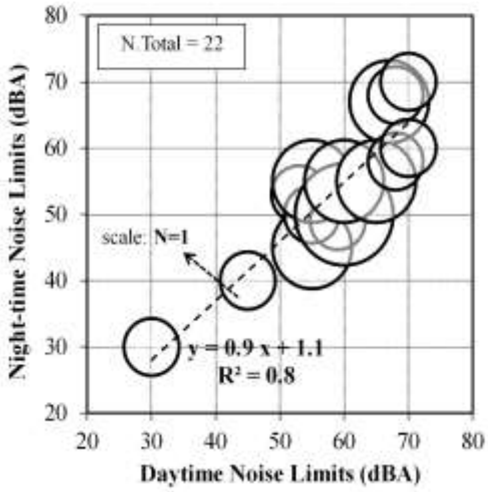

Fig. 3. Indoor noise limits for daytime and night-time from overseas countries.

3.2 Building standard of Indonesia

3.2.1 Thermal environment standard of Indonesia

The Indonesia requirement standard maintains both better indoor air quality and promoting a minimum wind speed for restoring thermal comfort by releasing temperature into the recommended guideline. Therefore, Minister of Public Work Decree for Technical Requirements for Building of Indonesia suggested that in the floor area ratio, the percentage of ventilation should be at least 5% [11]. Based on global warming consideration and compared to ANSI/ASHRAE Standard 62.1-2004, the increasing percentage for minimum ventilation should be conducted [7].

In Indonesian building instruction, Indonesian National Standard (SNI) has a significant part to guide the standard for the thermal mechanism for the building. The newest SNI for Energy Conservation for Air Conditioning System in Building (2011) releases that thermal comfort requirement for lowland in the maximum of Dry Bulb Temperature (DBT) is 24-27ºC or 25.5ºC±1.5ºC [12]. In the hotter environment, lowland, the air conditioning technique with the criteria above is advised. For highland, with 28ºC as the maximum DBT, the building is not recommended to use air conditioning for obtaining the thermal comfort. In this standard, the considered comfort temperature for a workplace is 25.5°C±1.5°C when for semi-outdoor spaces is 28.5 ± 1.5°C of average temperature.

Figure 4 shows the neutral temperature found by previous studies (1991-2014), especially for Indonesia context [13]. It found that Indonesia has the dominant neutral temperature at 27.5ºC relevant to the tropical environment. The indoor temperature is resulted in the ranges of 24ºC to 28ºC by the outdoor temperature (28ºC). It indicates that the diverse adaptability of respondents and the difference of environment condition. The 0.4 of regression illustrates that outdoor temperature has a low effect on indoor thermal preference. Accordingly, the thermal comfort which is indicated by neutral temperature is affected by difficult factors, not only by outdoor air temperature, but also by the relative humidity, wind speed, mean radiant temperature, and clothing-activities (metabolic rate) combination as occupant indices.

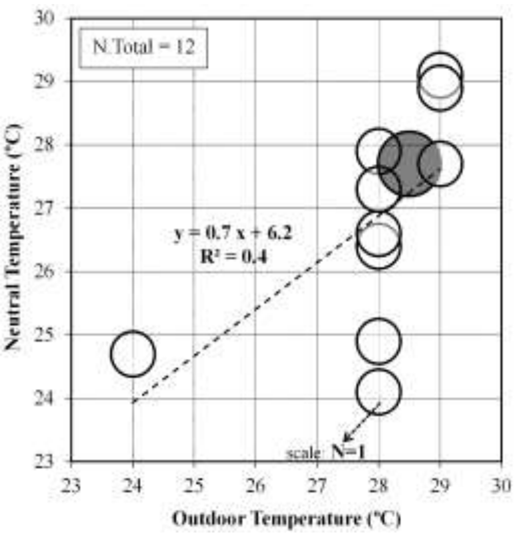

Fig. 4. Temperature standard of previous studies in Indonesia.

The exclusive characteristics of Indonesia environment represent a tendency of preference in lowland and highland. The lowland environment with higher outdoor temperature has a smaller amount trend of neutral temperature. In contrast, a cooler condition of highland has higher thermal preference than outdoor air condition (indicated by 24ºC of outdoor effects 25ºC of neutral temperature).

3.2.2 Noise environment standard of Indonesia

The Minister for the Environmental Decree of Indonesia issued Noise Level Standard (1996). Noise Level Limits for Housing and Human Settlement is recommended not more than 55 dBA. There is no detailed evidence for indoor or outdoor or for daytime or night-time on this guideline [14]. Associated with the foreign countries, it is possible for daytime standard since the high noise propagation affects different criteria compared to the lower sound pressure level in the night-time. The *Guidelines of Construction and Building* suggested that Noise Risk Areas has a width of 0 - 10 m measured from the edge of the roadway [15]. The noise levels over 75 dBA (LAeq) and longtime exposure are the range of 75 dBA to 90 dBA (up to 10 hours per day and the exposure time in the night is not more than 4 hours/day). This guideline is suitable for urban traffic noise control supported by the next guideline for Mitigation of Impacts Due to Road Traffic Noise [16]. For controlling transportation noise, the site barrier has a significant role. The barrier should have a capability in 10-15 dBA of noise reduction and it is each additional 1-meter height above the wave propagation path can decrease the noise up to 1.5 dBA.

4 Updating tropical standard

4.1 Actual mean vote analysis

In general, the result of actual mean vote analysis shows that a hotter climate than highland and noisier settings of the lowland stimulates the vote in the upper choices (Figure 5). Although the condition is lower in temperature and noise, the environmental conditions result in accumulative effects on votes. Some respondents still feel slightly quiet votes or quiet in a little percentage because of the high distance from the noise source to the receiver.

The neutral vote designates as a comfort circumstance in the general condition when the thermal environment in highland tropical is perceived as the distributed votes. Similar with the thermal, because the buildings are found mostly in the settlement space which further from the main noise source, the noise in the highland is also perceived in distributed options. Although it has ascended trend as low regression of thermal in highland, it is distributed, tends to be hot in the afternoon while cool in the night.

In the peak time, the higher temperature and noise incline to effect in the high option votes (Figure 6). On the other hand, several environments show that the equal temperature and sound pressure level have altered votes. It shows that the inhabitants have the different technique in adaptation, based on their occupancy index as well as on the situation of their living environment and building. Between lowland and highland thermal comfort, the perception consequences 29.3°C as a neutral vote for the indoor temperature Although there is climate and comfort zone difference, the building residents should have a capacity of controlling the temperature.

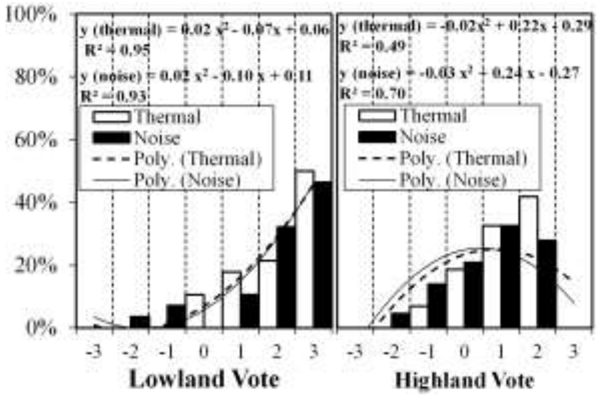

Fig. 5. Annual percentage of occupant's vote.

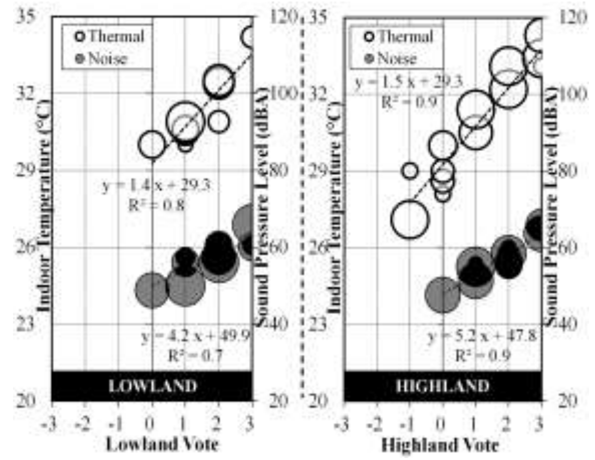

Fig. 6. Anthropological approach on occupant's vote of thermal and noise.

Without the selected option for lower votes (-3 to 0) are the characteristics indicator of the peak form in the noise propagation. The altered noise adaptation in the higher noise source does not always outcome in higher noisy perception. Based on trend line linear equations: for lowland, if the score of x is 0, every number in y coordinate is resulted in 49.9 dBA, while in highland, if x is 0, y will be 47.8 dBA. It confirms that diverse altitude with different urban development consequences in changed noise preference. Additionally, the higher noise level stimulates the higher adaptation. This acceptable noise is adjusted by various means. If slightly noise is supposed as a tolerable election (+1), the noise restrictions will change to 54.1 dBA for the lowland and 53 dBA for the highland daytime. Meanwhile, in the night-time, it could move to 50.5 dBA and 44.9 dBA for lowland and highland, respectively.

4.2 Analysis of building standard based on field study

4.2.1 Updating thermal environment standard

Based on the field thermal investigation, the tropical houses in both lowland and highland have the same neutral, temperature, 29.3°C. When equated to Indonesian standard, the thermal comfort needs for lowland is DBT is 24 to 27ºC or 25.5ºC±1.5ºC, and for highland, maximum for DBT is 28 ºC, so the active ventilation is not necessary used (Figure 7). It means that based on the field evaluation, the buildings comply with the lowest temperature and relative humidity standards even though it is not in the recommended score by SNI.

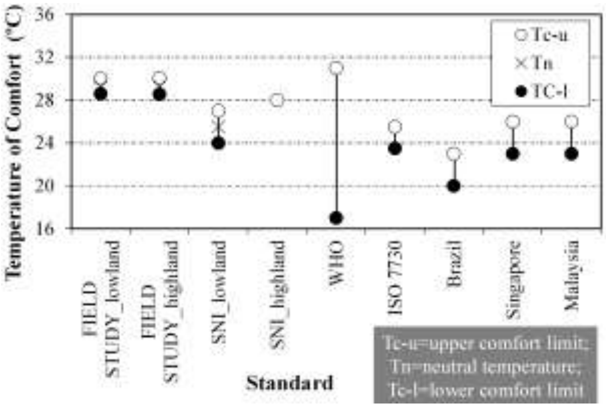

Fig. 7. Updating an existing thermal comfort standards.

Although the typical highland buildings have a cooler atmosphere, in fact, the neutral temperature is the same with lowland. The shifting environment, denser than in the past, affects the colder urban environment of highland. As explained by the occupant adaptation method, the ventilation is very important, especially for lowland building that completely needs artificial ventilation. Consequently, a hybrid ventilation for controlling the energy consumption design of air conditioning treatment should be conducted.

Comparing to the thermal comfort standard by the WHO, the tropical buildings should be articulated in a range of 29.3°C resulted by field study to 31°C as WHO recommended maximum temperature. If it is also related to other tropical building guideline and previous research, the range is 24°C as the minimum and it should be up to 29°C. It has moved from 26°C to the temperature in 27.5°C, the neutral temperature is also higher and the Indonesia traditional building has an effect in better adaptation shift.

4.2.2 Updating noise environment standard

WHO standards have the high noise restrictions because they deliberated the health risk than objective acoustical comfort, away from the general disturbance of noise as almost all countries standards approved (Figure 8). Actually, inhabitants of the tropical building have adequate noise adaptation skill to reach the Indonesian Standard. Taken from analysis of the trend line linear equations, the lowland has noise parameters up to 49.9 dBA where in highland is up to 47.8 dBA for daytime when for night-time, it should be no more than 45.9 dBA and 40 dBA for lowland and highland, respectively.

The characteristic of the tropical noise environment is that the inhabitants have no attention of daytime or night-time noise criteria. Therefore, the daytime and night-time have the same rate of noise parameters for the Indonesian standard. One of the intentions is, usually, the building is occupied for the short period because they intend to have more outside activities. Most the Indonesia cities as developing country have lower traffic movement when compared to the developed one. However, the WHO consideration standard is still accepted by the tropical countries for the planning of the better noise control in the future and it is combined with the thermal problem.

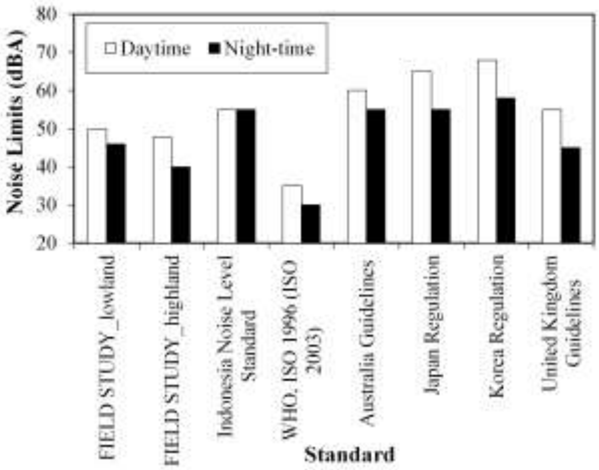

Fig. 8. Updating an existing noise criteria.

5 Conclusion

When compared to the thermal comfort standard from the other tropical countries and previous studies, the Indonesian Standard has already reached the suggested neutral temperature. Nevertheless, the lowland buildings have a passive technique prospect even though the buildings have high regular DBT as stated by Indonesian National Standard. The integration between the inhabitants' adaptation and their living environment optimization has effectiveness to solve the problem.

Psychologically, the environmental settings concern in accumulative effects even though the condition is in a low temperature and noise. The neutral votes are confirmed as a leading comfort form in the current research and standards. The altered altitude and urban growth effect different thermal preference and noise votes. Additionally, the higher noise level results in higher adaptation and the noise criteria.

In the near future, in addition to previous studies [17-19], this study will be extended to review air movement requirement and to propose the updating standard of wind speed in restoring thermal comfort. Furthermore, it will be integrated with controlling airborne noise and support the existing guidelines.

This research is part of Excellent Primary Research of Higher Education, *Penelitian Dasar Unggulan Perguruan Tinggi* No. 882/PKS/ITS/2018. The authors gratefully acknowledge this financial and technical support.

References

1. L. Huang, Y. Zhu, Q. Ouyang, B. Cao, Building and Environment, **49** (2012)
2. H. Feriadi, N.H. Wong, Energy and Building, **36** (2004)
3. H.E. Laszlo, E.S. McRobie, S.A. Stansfeld, A.L. Hansell, Science of the Total Environment, **435–436** (2012)
4. G. Winkel, S. Saegert, G.W. Evans, Journal of Environmental Psychology, **29** (2009)
5. World Health Organization (WHO), WHO/EHE/RUD/90.2, *Indoor Environment: Health Aspect Air Quality, Thermal Environment, Light and Noise* (1990)
6. ISO 7730, *Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria* (2005)
7. ANSI/ASHRAE Standard 55-2004 (Supersedes 55-1992): *Standard for Thermal Environmental Conditions for Human Occupancy*
8. Berglund, T. Lindvall, D. Schwela, K.T. Goh, *Guidelines for community noise* (World Health Organization, 2000)
9. 1996-1:2016: *Acoustics - Description, measurement and assessment of environmental noise.*
10. International Institute of Noise Control Engineering, *Final Report of The I-INCE Technical Study Group on Noise Policies and Regulations (TSG 3), Survey of Legislation, Regulations, and Guidelines for Control of Community Noise* (2009)
11. Minister of Public Work Decree, Republic of Indonesia, No. 441/KPTS/19*98: Technical Requirements for Building*
12. Indonesian National Standard (SNI) No 03-6390-2011: *Energy Conservation for Air Conditioning System in Building*
13. T.H. Karyono, Buildings, **5** (2015)
14. Minister for The Environment Decree, Republic of Indonesia, No. 48/MENLH/11/1996: *Noise Level Standard*
15. Guidelines of Construction and Building, Department of Settlement and Infrastructure, Republic of Indonesia, No. Pd T-10-2004-B: *Prediction of Noise Due to Traffic*
16. Guidelines of Construction and Building, Department of Public Work, Republic of Indonesia, No. Pd T-16-2005-B: *Mitigation of Impacts Due to Road Traffic Noise*

17. F.X.T.B., Samodra, Journal of Architecture and Urbanism **41**, 4 (2017)
18. F.X.T.B., Samodra, IOP Conf. Ser.: Earth Environ. Sci., **126** (2018)
19. F.X.T.B., Samodra, International Journal of Technology, **9** (2018)