Research Article

Annual Variations of Environmental Conditions in Naturally Ventilated Classrooms in a Tropical Environment: Comparison with Proposed Guidelines

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Received May 21, 2015; Accepted September 3, 2015

Abstract

Internal classroom conditions are important aspects of the learning environment of students. A suite of relevant guidelines for acoustic, visual and thermal comfort parameters in naturally and/or mechanically ventilated classrooms in tropical environments is proposed. Data measured during winter and rainy seasons in a typical provincial school in central Thailand were then compared. Only thermal parameters, viz. wet bulb globe temperature, air temperature and relative humidity met the proposed guidelines values at all times during the school year. Mean sound levels and signal-to-noise ratios did not meet the requirements at some time during this period. Mean illuminance in classrooms only reached proposed guideline values when all internal lights were operating which occurred mainly during the rainy season. Illuminance in front of blackboards and whiteboards never reached proposed thresholds at any time.

***Key Words*:** Naturally ventilated classroom; Environmental guidelines; Acoustic; Visual, Thermal comfort

Introduction

The school classroom and its environs are important places for human development and providing people with tools and knowledge. Students spend at least a quarter of a day, 6-7 hours, and normally not less than 5 days a week but unsuitable environmental conditions can affect the learning efficiency, attention and comprehension of students (Wong and Jan, 2003)

Most classrooms in developing countries in tropical areas, particularly in provincial areas, employ natural ventilation and/or mechanical ventilation by fans. Annual variations in environmental conditions in such classrooms have not been reported. Although monsoonal tropical environments typically do not exhibit annual variations of factors such as temperature as large as temperate environments, variation does occur. It is important to investigate variation in environmental conditions over sufficiently long periods so that seasonal or annual variations can be determined and compared this data with guidelines appropriate for these climatic conditions. However, such relevant guidelines including all together illuminance, acoustic and thermal comfort parameters for such a long period of time in classrooms in a tropical environments do not currently exist.

Annual data for illuminance, acoustic and thermal comfort parameters were obtained in a school on the outskirts of a provincial town in Thailand. Many schools in rural or semi-urban environments in Thailand and other tropical countries would be similar. Wet bulb globe temperature (WBGT), which is nowadays the most widely used general index of heat stress and it has been subsequently adopted as the basis of heat-stress standards by US occupational heat authorities and other national and international agencies (Budd, 2008), was also

ISSN 1905-9159
doi: 10.14456/sustj.2016.19

measured in this study. In addition, the response of classroom occupants to prevailing environmental conditions in terms of their behavior, e.g. opening of windows was assessed using an observation checklist.

The objectives of this study were to:

(1) propose environmental requirements or guidelines for naturally and/or mechanically ventilated classrooms in tropical areas

(2) investigate the variations of environmental conditions during teaching periods in a typical provincial school in Thailand

(3) compare monitoring results from this school with proposed guidelines in order to understand the general situation in classrooms

The results from this study may provide useful general information for naturally ventilated and/or mechanically ventilated schools in rural or semi-urban tropical regions with similar teaching and learning styles.

Materials and methods

Study site

The study was conducted in Watnongpho School in Nakhon Pathom Province, Thailand. It is located in the tropical area between latitudes 13^o 56' 29.6" N to 13^o 56' 35.2" N and longitudes 99^o 55' 21.0" E to 99^o 55' 30.2" E. It has a total of approximately 300 students of both sexes in a combined primary and secondary school. The school (total area 27,400 m^2) faces a main road with the closest building (Building 4) about 27 m from this road and is surrounded by grove wood, agricultural fields and residential areas, as illustrated in Figure 1. In this study, classrooms were defined as rooms used for instruction for at least 75% of a teaching week. Based on this criterion, 9 classrooms were selected for investigation, viz. 3 on the 1st floor of Building 3 (35 years old) containing secondary school students, 3 on the 2nd floor of Building 2 (25 years old) and 3 on the 2nd floor of Building 4 (16 years old) for primary school students.

These classrooms were of a standard size for public schools in Thailand, with an area of 54 m^2 (6 m x 9 m) and approximately 3 m in height. Each was illuminated internally by 6 fluorescent lights (120 cm long, 36 Watts) and equipped with 2 centrally mounted electrical ceiling fans (Figure S-1). The walls of all buildings were made of brick and coated with cement. The floors of Buildings 2 and 4 were made of wood and cement respectively and that of Building 3 was made of cement and covered with tiles. The classroom buildings were oriented in such a way that the main axes of Buildings 2, 3 and 4 were NE-SW, NW-SE and NE-SW, respectively (Figure 1). The detailed layout and orientation within these classrooms are shown in Figure S-1. During teaching periods, each classroom was naturally ventilated by opening doors and windows and mechanically ventilated by the two ceiling fans. The teaching period was between 8.30 am and 3.30 pm from Monday to Friday. Each student spends one hour in each room before moving to another room in the same building for another subject.

Data collection

The results about suitable environment condition for naturally and/or mechanically ventilated classrooms in tropical areas from previous studies were collected. Then, relevant guidelines including illuminance, acoustic and thermal comfort parameters were summarized in Table 1.

Environmental conditions in classrooms were investigated over one calendar year, i.e. the 2nd semester in the 2010 academic year (November 2010 – February 2011 during the winter season in Thailand) and the 1st semester in the 2011 academic year (May 2011 – September 2011 during the rainy season in Thailand). Two classrooms were randomly sampled in each of these buildings during each sampling period. Illuminance, sound level, WBGT, air temperature, relative humidity (RH) and air movement were measured. Sampling for these parameters was carried out on the basis of a grid pattern (Figure 2) in the morning and again in the afternoon during the teaching period. Data were normally collected in classrooms weekly, except for some periods when the school had special activities and teaching was cancelled. Background noise levels were measured intermittently in three unoccupied classrooms a day (sampling point S_5 in Figure 2) over a total of 8 measuring days. This was only during the rainy season due to restrictions arising from the school schedule.

During the sampling period, observation checklists (Figure S-1) of the reaction of occupants to the environmental conditions such as number of fluorescent lights and fans operating, and the number of open windows and doors were completed by a researcher. Observations of weather or particular activities that could affect the results were also recorded.

Measurement procedures

Environmental conditions within classrooms were measured at sampling points as shown in Figure 2 in accordance with the procedures recommended by the Thailand Department of Labor Protection and Welfare, Ministry of Labor (TDLPW) (2006) and the American National Standards Institute, Inc. (ANSI) (2002) and at the height of seated students (1 m above the floor) by instruments as shown in Table S-1. For example,

doi: 10.14456/sustj.2016.19

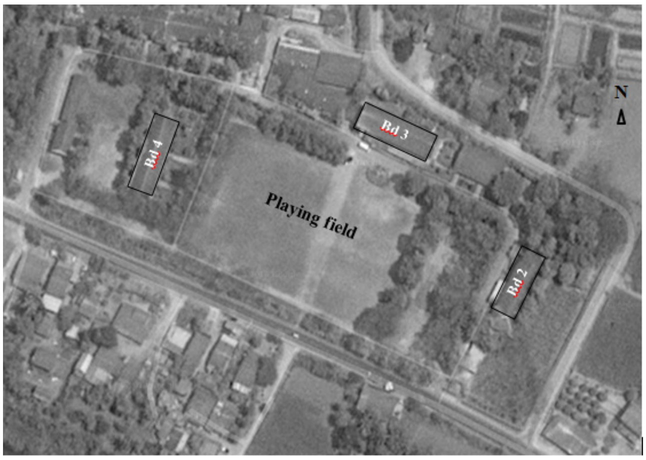


Figure 1 Site location of Watnongpho School (modified from Google Map)

Table 1 Summary of proposed environmental condition requirement guidelines in naturally and/or mechanically ventilated classrooms in tropical areas

Environmental Parameter	Requirements	Source
Noise level (Leq, 30 min)	Noise level with opened windows ⩽ 55 dB (A)	Japanese standard as quoted by Chiang and Lai, 2008; Wong and Jan, 2003
	Signal-to-noise ratio ⩾ +10	ANSI, 2002
Illuminance	In classroom ⩾ 300 Lux In front of blackboard ⩾ 300 Lux	TDLPW, 2006
Temperature	WBGT ⩽ 34^{o}C	TDLPW, 2006
	Air temperature 25-31.5^{o}C	Chenvidyakarn, 2007
Relative humidity (RH)	60-90%	Chenvidyakarn, 2007; James and Christian, 2012
Air velocity	0.05-0.25 m/s	Bradshaw, 2006

the time-average A-weighted sound level (Leq, 30 min) was measured over each of consecutive 30-second intervals for 30 minutes at each sampling point in order to exceed for 10% of the observation hour (50 min for each subject) as recommended by ANSI (2002).

Data analysis

Values of measured parameters were expressed as mean and standard deviation. The mean values were compared with the relevant proposed guideline values. The significance of difference between means of measured parameters with the proposed guideline values was assessed by using Independent Sample t-test at the significance level not less than the 0.05. External factors affecting these parameters could include the orientation of the main axes of the buildings (NW-SE and NE-SW), locations of the buildings relative to the position of the playing field and season (winter (November – February), rainy season (May – September)). The significance of differences between means of measured parameters with respect to season was assessed by using Paired-Samples t-test at the 0.05 significance level. Differences between means with respect to the orientation of the main axes of the buildings and locations of the buildings relative to the central playing field were assessed by using the analysis of variance (ANOVA) and Tukey's honestly significant difference (Tukey HSD) at the 0.05 significance level.

doi: 10.14456/sustj.2016.19

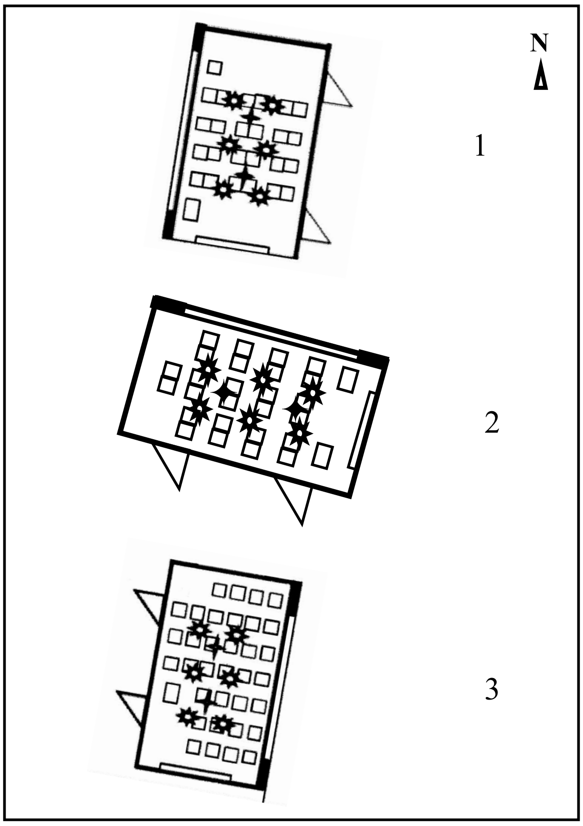
Preliminary Survey for Watnongpho School

Classroom No…………………….Date………………….. Time…………………

Please mark (x) one of these.

❑1. All lamps were operating, all ceiling fans were operating at high speed, all windows and doors were opened.

❑2. Differences from results in item number 1. Please circle the number for surveyed classroom layout and mark (x) the position in the layout for non-operating lamps and fans, closed windows and closed doors.



Symbol	Meaning	Symbol	Meaning
✲	Lamp		Window
✦	Ceiling Fan		Door
□	Student Desk		Blackboard/ Whiteboard
▭	Teacher Table		

Please mark (x) other effects were happening during survey period

❒ rain ❒without sunshine ❒ thunderstorm ❒windy ❒breeze

❒noise from other activities ❒power outage

Figure S-1 Preliminary survey checklist for Watnongpho School

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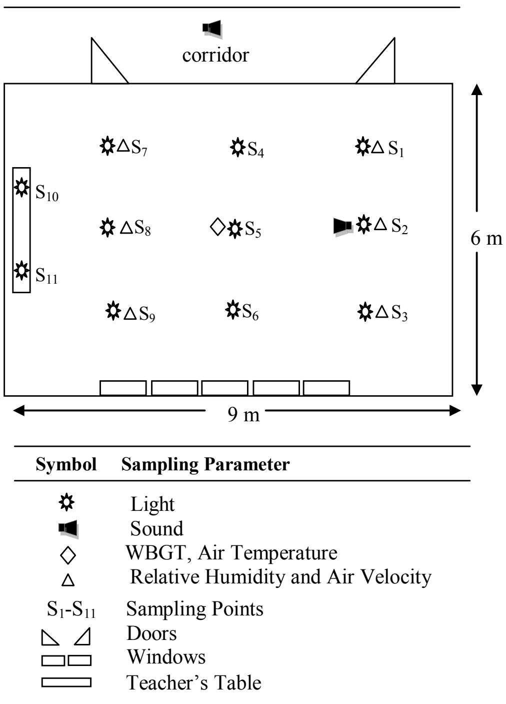

Figure 2 Sampling points ($S_1 – S_{11}$) within classrooms in this study.

Due to time limitation and restriction of the number of instrument, sound level was measured only at the sampling point S_2 in the middle of the last row at the back, which was assumed to be the least sound level compared with other rows in classrooms.

Table S-1 Instruments used for measuring the relevant environmental parameters in classrooms

Environmental Parameter	Instrument	Model/Company/Country; Accuracy within Measuring Range
Illuminance	Lux Meter	Model P-07588-22/Chatchalee Holding Co. Ltd./Thailand; ±3% accuracy for both the measuring ranges 0-200 Lux and 201-2,000 Lux
Noise level (Leq, 30 min)	A-weighted Sound Level Meter	DSP 80/Executive Trading Limited/Thailand; ±1.5 dB (A) accuracy for the measuring range 30-130 dB (A)
Wet Bulb Globe temperature (WBGT)	WBGT Heat Stress Monitor	RSS-214/ IST Co. Ltd./Thailand; ±2°C accuracy for the measuring range 0-80°C
Air temperature Relative humidity (RH) Air velocity	Compu Flow Thermo-anemometer	Model 8585/ Executive Trading Limited/ Thailand; ±0.3°C accuracy for the measuring range -20-75°C; ±2% RH accuracy for the measuring range 0-100%; ±0.02 m/s accuracy for the measuring range 0-0.99 m/s

doi: 10.14456/sustj.2016.19

Results from the observation checklist were analyzed in a similar way using ANOVA and Tukey HSD (Table 3, S-2, S-3, S-4). Every pairs of measured environmental parameters in classrooms were analyzed by Pearson correlation. Then, the correlated pair at the 0.05 significance level were analyzed by linear regression.

Results and discussion

Environmental guidelines

An objective of this study is to propose suitable environmental condition guidelines for naturally and/or mechanically ventilated classrooms in tropical areas. These guidelines are summarized in Table 1.

There is currently no international noise standard for naturally and/or mechanically ventilated classrooms in tropical areas (Shrestha et al., 2009). The noise level for schools recommended by the American National Standards Institute, Inc. (ANSI) (2002) may not be appropriate. Most classrooms in developing countries in tropical areas are naturally ventilated with open windows and doors during teaching periods in order to provide good ventilation. This can cause additional noise from neighboring classrooms and external sources. This would likely not occur to the same extent in classrooms in temperate areas that are usually air-conditioned and closed during teaching periods. Therefore, the noise guideline employed in the current study was derived from a Japanese regulation for classrooms with open windows, as quoted by Chiang and Lai (2008) and the noise criterion of 55 dB (A) for local schools in Singapore based on objective measurements and the subjective rating of noise levels in local schools by teachers (Wong and Jan, 2003). A signal-to-noise ratio of at least +15 dB in classrooms is recommended by ANSI (2002). However this value includes a contribution of 5 dB for limited English proficiency. In the context of the current work, it is likely most instruction would be in the students' first language so a signal-to-noise ratio of at least +10 dB is recommended in Table 1.

There are suitable Thai regulations and guidelines that can be applied for illuminance in classrooms (TDLPW, 2006), viz. $\geqslant$ 300 Lux for both light intensity in the classroom and light intensity in front of the blackboard (Table 1).

The wet bulb globe temperature (WBGT) is the widely used general index of heat stress. Unfortunately, most of the studies were concentrated on the level of heat stress and conditions of risk in the workplace rather than in classrooms. The current study recommends the WBGT threshold in classroom at $\leqslant$ 34^{o}C. This was based on the value from the TDLPW (2006) for light work that may be regarded as equivalent to learning and teaching activities in classrooms.

Yamtraipat et al. (2005) reported that temperature and humidity in naturally ventilated classrooms did not fall within the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) summer comfort boundaries. This was in agreement with results from the study of De Giuli et al. (2012) who concluded that the thermal comfort range was larger in naturally and/or mechanically ventilated indoor environments than in fully air-conditioned ones. Ibrahim et al. (2013) reported the average air temperature and relative humidity found in naturally ventilated and mechanically ventilated library building in Kuching, Sarawak, Malaysia were in the range of 29.5-30.5^{o}C and 60-80%, respectively. The study by Chenvidakarn (2007) found that the ranges of comfortable indoor temperature and relative humidity for naturally ventilated buildings in Thailand were 25-31.5^{o}C and 62.2-90%, respectively. The work of James and Christian (2012) in a high school in Ghana showed that a high relative humidity has no significant psychological or physiological influence on human response when within the range of 60-90%. Accordingly, it is recommended that suitable air temperature and relative humidity ranges be 25-31.5^{o}C and 60-90%, respectively.

There is some variation among possible acceptable air movement values. For example, the Bureau of Indian Standards (1995) concluded that desirable wind velocities for thermal comfort conditions at various temperatures also depended on relative humidity. Khedari et al. (2000) performed experiments in a classroom without air-conditioning and found that while a relatively low air velocity (between 0.2 and 0.5 m/s) was sufficient to provide acceptable comfort at 28^{o}C, a higher air velocity (> 3 m/s) was required at temperatures above 34^{o}C. However under the latter conditions the noise caused by fans became important and would probably disturb mental tasks. Tantasavasdi et al. (2001) found that to achieve a comfortable indoor environment during the winter (December-February) in Thailand, natural ventilation should provide an indoor air velocity of 0.4 m/s. More generally, Chenvidyakarn (2007) reported that for regions and seasons where the maximum outdoor air temperature did not exceed about 28-32^{o}C an indoor air velocity of around 1.5-2.0 m/s with ventilation could provide comfort. Wong and Jan (2003) suggested a value of < 0.8 m/s in classrooms in Singapore while Wafi and Ismail (2008) quoted the air movement standard of both WHO and the Singapore Indoor Air Quality Guidelines of 0.25 m/s. In

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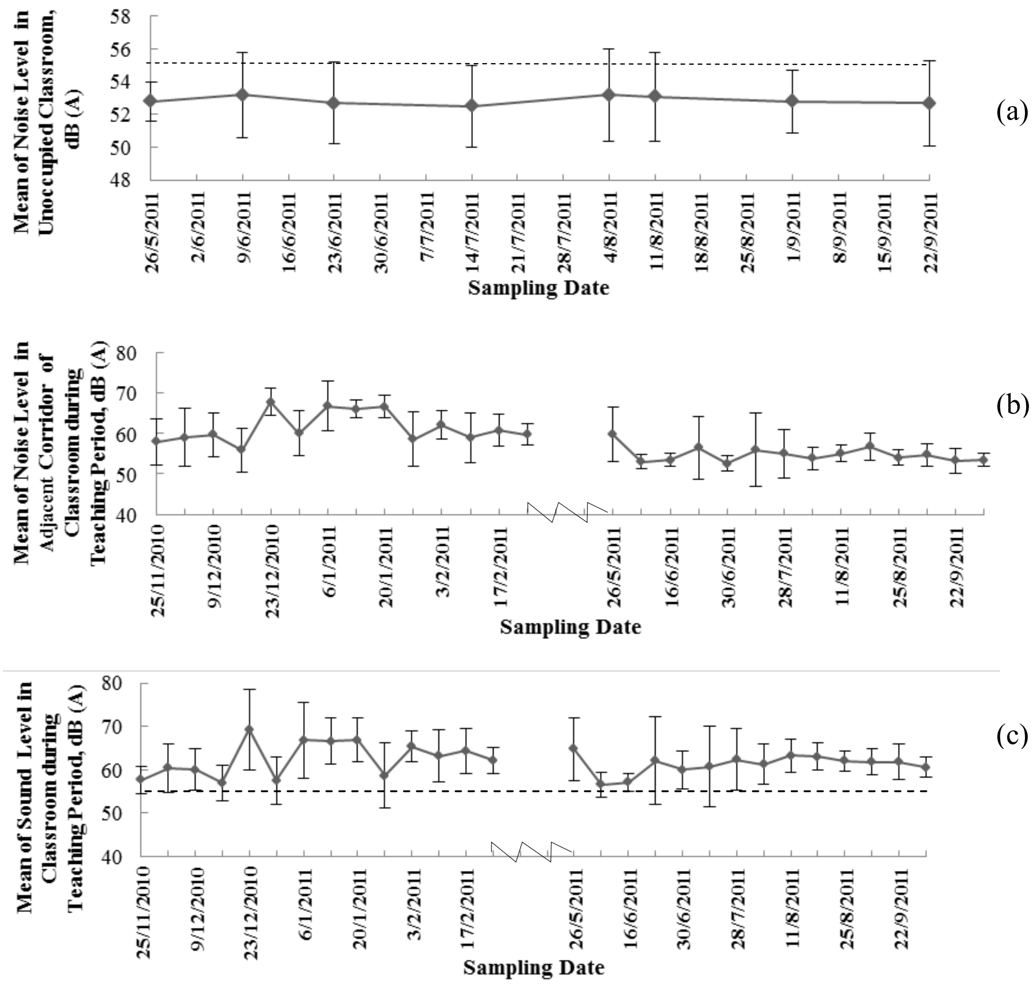


Figure 3 Variation of acoustic parameters in classrooms and outside classrooms

(a) Noise level in unoccupied classroom when there were teaching activities in adjacent classrooms on both sides

(b) Noise level in adjacent corridor of occupied classroom during teaching period when there were also teaching activities in adjacent classrooms on both sides

(c) Sound level in occupied classroom during teaching period when there were also teaching activities in adjacent classrooms on both sides

Dashed line denotes recommended value for each parameter

The break in the time axis represents the main student vacation

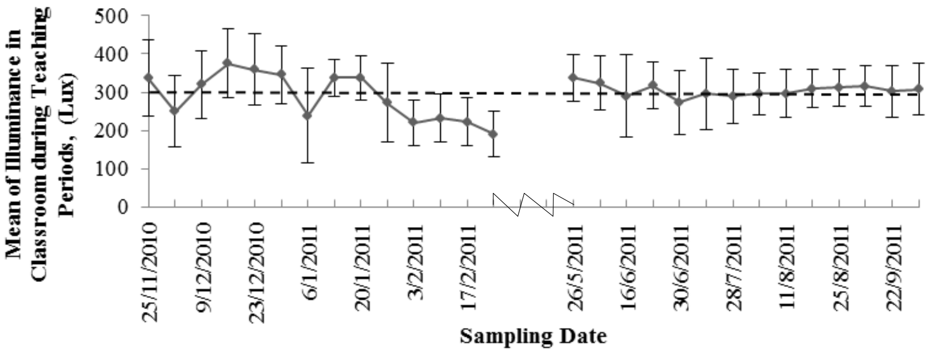
agreement, Bradshaw (2006) concluded air movement in the range 0.05-0.25 m/s resulted in generally favorable occupant reaction. Therefore, the requirement for air movement in this study is proposed to be in the range 0.05-0.25 m/s.

With respect to these guidelines, it is acknowledged that human comfort with regard to environmental conditions is dependent not only on these measured physical conditions but are influenced by many other factors such as location, social setting, physiological acclimation, behavioral and psychological adaptation, expectation and long-term experience in any climate (De Giuli et al., 2012; Djongyang et al., 2010).

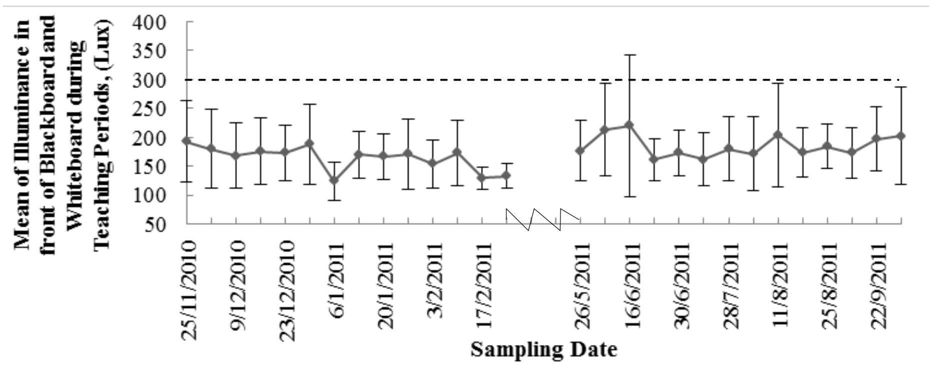
Annual variations of environmental conditions during teaching periods and comparison with relevant guidelines

These results demonstrate the need for data encompassing at least one calendar year for meaningful

doi: 10.14456/sustj.2016.19



(a)



(b)

Figure 4 Annual variation of illuminance in classrooms and in front of blackboard and whiteboard
(a) Illuminance in classrooms during teaching periods
(b) Illuminance in front of blackboard and whiteboard during teaching periods

Dashed line denotes recommended value for each parameter

The break in the time axis represents the main student vacation

comparison. Shorter-term investigations could produce misleading conclusions.

Acoustic parameters

In tropical regions, classrooms' doors and windows are usually opened for energy saving purposes and to provide better ventilation, but this can result in noise interference from neighboring classrooms and external sources. Background noise levels were measured in unoccupied classrooms and found to be quite stable throughout the rainy season, ranging from 52.7-53.2 dB (A) (Figure 3a). The mean (52.9 dB (A)) is significantly lower than the recommended threshold of 55 dB (A) ($p < 0.01$) (Table 1).

The noise levels in adjacent corridors were found related to the sound levels in occupied classrooms with opened doors and windows ($r = 0.669$) (Figures 3b and 3c respectively), showing the same trends with time. The mean sound level in classrooms during teaching periods is 61.91 dB (A) (Figure 3c), significantly higher than the recommended value 55 dB (A) ($p < 0.01$). Moreover, only 35% of sound level data from the occupied classrooms in this study (Figure 3c) met the proposed signal-to-noise ratio criterion ($\geqslant$ +10 dB) after subtraction of the mean value of background noise level in unoccupied classrooms (52.9 dB (A)).

Illuminance

Lighting affects energy consumption and insufficient lighting in classrooms can cause health problems and impair visual performance, thereby affecting student learning. However there are few studies on the annual variation of light intensity in classrooms, particularly in tropical regions. Light intensity is best considered in terms of illuminance which is a measure of how much incident light illuminates a given surface, wavelength-weighted to account for the relative brightness of different wavelengths as perceived by humans. For the current study, the mean illuminance in classrooms fluctuated between 190 to 375 Lux (Figure 4a). Only 54% of the results met the proposed threshold ($\geqslant$ 300 Lux). Results from the 1st semester in the rainy season showed less

doi: 10.14456/sustj.2016.19

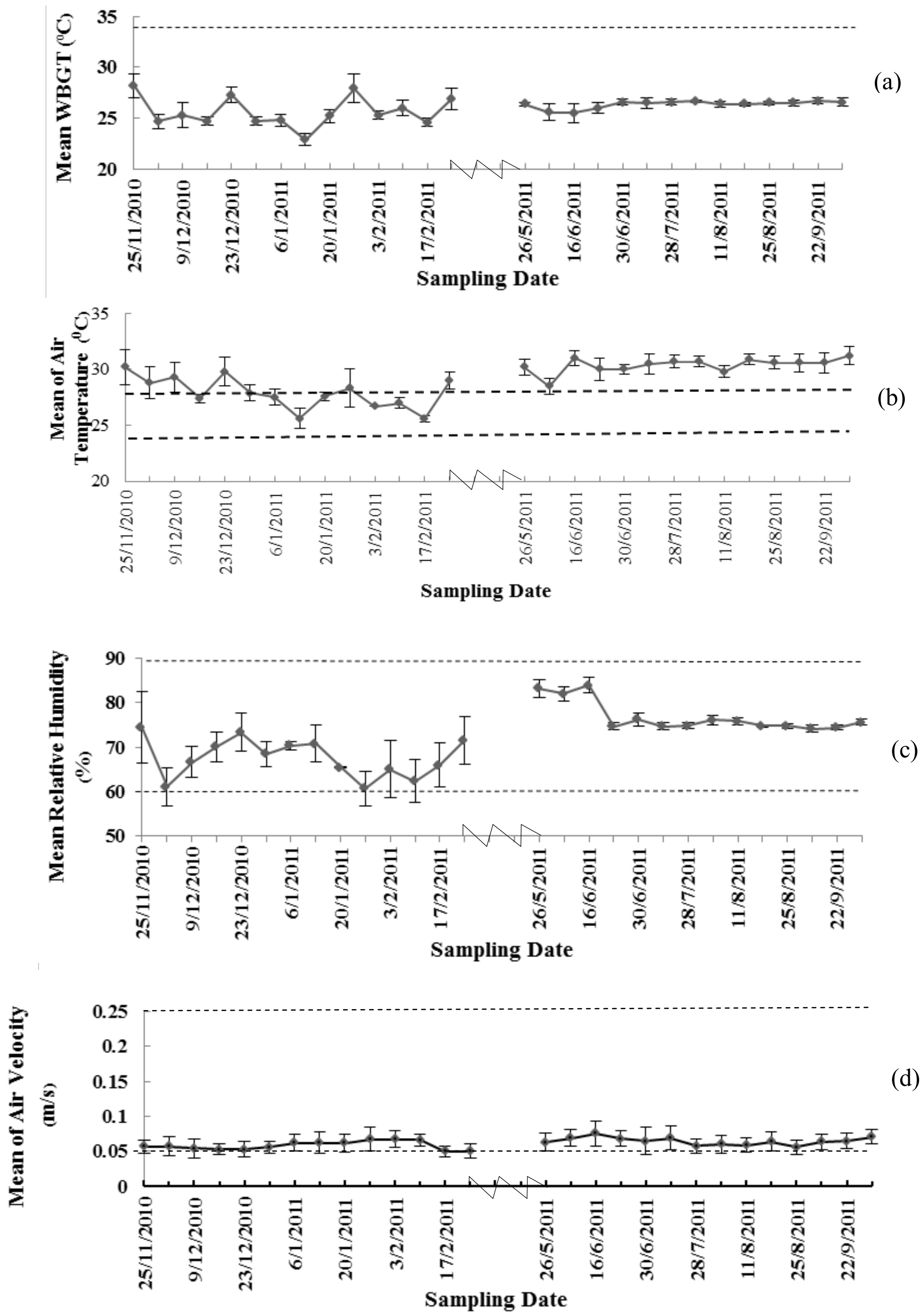


Figure 5 Annual variation of thermal parameters in classrooms

(a) Wet Bulb Globe Temperature (WBGT)

(b) Air temperature

(c) Relative humidity (RH)

(d) Air velocity

doi: 10.14456/sustj.2016.19

Table 2 Effects of season on environmental conditions in classroom during the study period

Parameter	Season				p-value
	Winter		Rainy		
	Mean±SD	n	Mean±SD	n	
Illuminance in classroom (Lux)	281.9±101.3	1,269	304.5±71.5	1,512	0.000*
Sound level [dB (A)]	62.6±6.7	141	61.3±5.6	168	0.062
WBGT (°C)	25.7±1.6	141	26.4±0.6	168	0.000*
Air temperature (°C)	27.8±1.7	141	30.4±7.4	1,175	0.000*
Relative humidity (%)	67.6±6.1	846	76.8±3.5	1,008	0.000*
Air velocity (m/s)	0.063±0.052	846	0.065±0.014	1,008	0.434

* Significant difference ($p<0.05$) by Paired-Samples t-test

variation and were closer to the threshold than those in winter, with the lowest values obtained during February. Results from the observation checklist (Figure S-1) showed that fluorescent lamps were often not all turned on and all the windows were not opened either, especially during winter. The illumination range from this work was greater than that found in a tropical setting by Panjaitan and Hartoyo (2011) but much narrower than that observed by Winterbottom and Wilkins (2009) in a temperate environment in summer with additional artificial illumination. The latter authors investigated the illumination in 90 classrooms across eleven secondary schools in the UK during summer holidays and found illuminance to vary between 145 and 2,500 Lux in classrooms with lights on and blinds open.

Within the classroom, the range of mean illuminance in front of blackboards and whiteboards was from 120 to 220 Lux (Figure 4b) and demonstrated a narrower variation than that in classrooms as a whole (Figure 4a) The criterion for illuminance in front of blackboard applied in the current study is ⩾300 Lux (TDLPW, 2006). None is strictly defined for the whiteboard, but if we assume it is the same, the mean illuminance in front of the blackboard and whiteboards in classrooms in this study (165 Lux) is approximately half that recommended and less than half the values reported in the study of Wong and Jan (2003) of 353 and 389 Lux for two classroom buildings in Singapore.

Thermal parameters

The annual variation of thermal parameters in classrooms is shown in Figure 5. Larger variations of WBGT, air temperature and relative humidity values were generally observed in the winter than in the rainy season. This is perhaps due to variations in the number of open windows and operating fans in the former season. Air movement data did not vary much during the school year.

All mean measured data for thermal parameters in the current study met the recommended guidelines (Table 1 and Figure 5). Air temperatures and relative humidities found in this study were in the range of 25.6-31.2°C and 60.6-84%, respectively. This was in good agreement with what has been found in naturally and/or mechanically ventilated classrooms in other countries in tropical regions. For example, the temperature ranges found in studies from Singapore, Malaysia (Johor Bahru, Kuala Lumpur, Betong, Sarawak) as well as Brazil (Maceio) were 27.1-29.3°C; 26.0-30.7°C, 30.26-32.31°C, 33.2-34.5°C, 30.6-32.3°C; and 26-30.0°C; respectively (En et al., 2014; Salleh et al., 2013; Ibrahim et al., 2014).

The conditions that are experienced in tropical regions require different levels of temperature and humidity for thermal comfort to those prescribed in the ASHRAE 55-1996 standard (Djongyang et al., 2010). Hwang et al. (2006) found that all of the thermal parameters measured in naturally ventilated classrooms in Taiwan fell outside the ASHRAE comfort zone because the atmosphere was more humid than the criteria recommended. Many studies have concluded that comfort temperatures are higher in tropical regions because of the ability to acclimatize and/or physiological variation (Tantasavasdi et al., 2001). Chenvidyakarn (2007) suggested that comfort in Thailand was experienced within ranges of temperature and relative humidity of 25-31.5°C and 62.2-90%, respectively.

Effects of external factors on environmental conditions in classrooms

Two external factors affecting environmental

doi: 10.14456/sustj.2016.19

Table S-2 Effect of orientation of main axes of the buildings and building position on environmental conditions in classrooms during the study period

Parameter	Orientation of the Main Axes of the Building and Building Position relative to central open area in Figure 1						p-value
	NE-SW & Right (Bd 2)		NW-SE & Top (Bd 3)		NE-SW & Left (Bd 4)		
	Mean±SD	n	Mean±SD	n	Mean±SD	n	
Illuminance in classroom (Lux)	284.0[a]±84.9	918	310.1[b]±90.9	927	288.5[a]±83.3	936	0.000*
Noise level [dB (A)]	62.6±7.0	102	61.3±4.7	103	61.8±6.4	104	0.282
WBGT (^{o}C)	26.0±1.3	102	26.2±1.1	103	26.0±1.2	104	0.534
Air temperature (^{o}C)	29.7±1.3	438	30.8±12.1	439	29.9±1.3	439	0.055
Relative humidity (%)	72.9±6.8	612	72.3±6.6	618	72.6±6.6	624	0.209
Air velocity (m/s)	0.065±0.047	612	0.063±0.030	618	0.064±0.031	624	0.743

* Significant difference (p<0.01) by ANOVA and Tukey HSD

Different letter in the same row denotes statistical difference (p<0.05) when analyzed by ANOVA and Tukey HSD

Table 3 Effect of number of operated lamps on illuminance in classrooms during study period

Number of Operated Lamps	n	Illuminance (Lux) Mean±SD
0	82	191.7[a] ± 72.5
2	18	218.4[a] ± 107.4
4	153	221.4[a] ± 73.9
5	9	214.2[a] ± 56.5
6	1,007	300.2[b] ± 90.0

Different letter in the same column denotes statistical difference (p<0.05) when analyzed by ANOVA and Tukey HSD

Table S-3 Effects of position in classroom on illuminance during study period

Sampling Position	n	Illuminance (Lux) Mean ± SD
Close to door	567	294.8[ab] ± 90.5
Close to windows	927	301.7[b] ± 92.6
The remaining positions (not close to either door or window)	1,287	288.6[a] ± 81.0

Different letter in the same column denotes statistical difference (p<0.05) when analyzed by ANOVA and Tukey HSD

doi: 10.14456/sustj.2016.19

Table S-4 The influence of sampling position on air velocity in studied classrooms during rainy season

Sampling Position	n	Air Velocity (m/s) Mean±SD
Close to door	308	0.063^{a}±0.013
Close to windows	336	0.067^{b}±0.016
The remaining positions (not close to either door or window)	364	$0.064^{a,b}$±0.013

Different letter in the same column denotes statistical difference ($p<0.05$) when analyzed by ANOVA and Tukey HSD

conditions in classrooms were investigated in the current study, i.e. seasons, and the main axes of orientation and locations of the buildings relative to the open area of the central playing field.

Illuminance, WBGT, air temperature and relative humidity all displayed seasonal differences, being higher in the rainy season whereas sound level and air movement did not show significant differences (Table 2).

It is not surprising that WBGT and relative humidity were higher during the rainy season. This trend has been also found in naturally ventilated buildings in hot and humid areas of China (Zhang et al., 2010). External illuminance is typically lowest during the rainy season due to overcast conditions (Choi et al., 2012). The reason for the increased illuminance in the classroom during the rainy season was due to the increase usage of the internal lighting in the classroom.

Of the measured parameters, only illuminance was significantly affected by the main axis of orientation and location of the buildings relative to the open area of the central playing field. The highest illuminance levels were found in classrooms of Building 3 that is oriented in the NW-SE direction and to the NE of the playing field meaning it is surrounded by fewer trees (Table S-2 and Figure 1).

Effects of internal factors on environmental conditions in classrooms

The overall mean measured illuminance within opened windows classroom meet the proposed guideline (⩾ 300 Lux) (Table 3) only when all 6 fluorescent lights were operating. However, there was variation depending on position within the classroom (Table S-3). Those seat positions close to windows (sampling points S_9, S_6 and S_3 in Figure 2) experienced the highest light intensity and met the 300 Lux threshold suggested for naturally and/or mechanically ventilated classrooms in tropical areas (Table 1). But none of the other seat positions met the threshold which was in a good agreement with the results in classrooms in Singapore reported by Wong and Jan (2003).

The number of operating ceiling fans, percentage of open windows and seat positions were not found to significantly affect air movement in classrooms when combined data was analyzed by ANOVA. Some influence on air movement is discernable by focusing on data from specific periods within the year however. During the rainy season nearly all ceiling fans are operated and doors and windows in classrooms opened. Under these conditions the seats closest to the windows (sampling points S_9, S_6 and S_3 in Figure 2) experienced the best air movement (Table S-4).

The correlation between measured environmental parameters in classrooms

It was found that only four pairs of measured environmental parameters in classrooms were correlated at the 0.05 significance level. Then, they were analyzed by linear regression. Results were as follows:

WBGT = 12.958 + 0.450 Air Temperature (r^2 = 0.443, n = 308)

WBGT = 25.283 + 12.686 Air Velocity (r^2 = 0.013, n = 308)

Relative Humidity = 67.830 + 0.016 Light Intensity in Classrooms (r^2 = 0.044, n = 1,853)

Relative Humidity = 71.910 + 10.894 Air Velocity (r^2 = 0.003, n = 1,853)

However, the predictions of these parameters by the parameters in linear regression models were not so high in real situation and may need further studies.

doi: 10.14456/sustj.2016.19

Conclusions

Existing acoustic, visual and thermal guidelines for other climatic regions and for air-conditioned classrooms are not appropriate for naturally ventilated and/or mechanically ventilated schools in tropical regions. A relevant suite of guidelines is proposed and compared with annual measurements from a typical provincial school in Thailand. Only the thermal parameters (WBGT, air temperature, relative humidity and air movement) met the proposed guidelines throughout the school year. The background noise level in unoccupied classrooms met the recommended guideline, however only 37% of sound level samples in classrooms during teaching periods met the proposed signal-to-noise ratio criterion. Also, only half of mean illuminance measurements in classrooms met the proposed threshold. All internal lighting had to be on for this to occur and in the school investigated, this occurred only in the rainy season. Mean illuminance in front of blackboards and whiteboards never reached the threshold at any time. These results suggest attention needs to be paid to visual and acoustic conditions in order to provide a comfortable and productive learning environment in such classrooms.

Acknowledgements

The present study was partly supported by Faculty of Science, Silpakorn University, Thailand. We would also like to thank Department of Environmental Science, Faculty of Science, Silpakorn University for providing instruments and facilities throughout this study.

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doi: 10.14456/sustj.2016.19