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## Influence of air leakage from building façade on the energy efficiency of air conditioning system in Tropic Asia

To cite this article: Yukiko Mabuchi *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **294** 012051

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# Influence of air leakage from building façade on the energy efficiency of air conditioning system in Tropic Asia

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**Abstract.** Many buildings are being built in Southeast Asian cities due to rapid economic growth. Because large-scale buildings, such as office buildings, in particular, consume a large amount of energy, it is essential to construct environmental buildings for global climate change. Despite the improving airtight performance of building envelopes for effective energy saving, almost no research regarding them in Southeast Asia is done at present. Therefore, this paper aims to determine the current state of energy conservation effects of office buildings in Asian cities. This research adopts on-site measurement and energy-simulation methods to evaluate the sealing performance of the office building envelope in Bangkok, Hanoi, Hong Kong, Singapore, and Taipei. In the field survey, the CO<sub>2</sub> leakage rate from the building envelope, covered with a vinyl cloth, is investigated using the tracer gas method. In addition, air quality, internal and external differential pressure, and energy consumption are measured. Furthermore, indoor environmental quality such as temperature, humidity, wind speed, CO<sub>2</sub> density, clo value and MRT are measured. The evaluation of the energy conservation performance of the target buildings is multifaceted. In the energy simulation part of this study, actual data are used with simulation software to calculate the energy performance of the heating and cooling load. This research is focused on energy conservation in Hanoi because the amount of air leakage was higher there than the other cities in Tropical Asia. Furthermore, we verified how much of the energy conservation is realized by changing the performance of the air leakage in the model. This paper discusses the current situation of Asian buildings in terms of the results and suggests an appropriate energy conservation model for Asian tropical office buildings.

## 1. Background and purpose of research

Energy consumption in the world is projected to increase by 30% by 2040, and the reduction of energy consumption is a problem to be solved. The rapid rise in population and economic growth in recent years, particularly in Tropical Asia, has increased the density and stratification of buildings [1]. Meanwhile, the National Institute of Standards and Technology (NIST) showed the possibility of a dramatic reduction of 37% of annual cooling and heating expenses by improving the air leakage of the building's outer surface [2]. Although temporary energy-saving effects, due to the improvement of air leakage, are seemingly small in temperate climatic conditions, in the long term they are highly likely to be effective for reducing greenhouse gas emissions. In addition, improvement of the leakiness of the outer surface of the building can alleviate various problems caused by air leakage such as deterioration of indoor air quality and thermal comfort, as well as the deterioration of building materials due to moisture. Therefore, in this research, actual measurements are carried out in office buildings in



Tropical Asia, the tendency of environmental performance is clarified, and the effect of the improvement of airtight performance is discussed. The focus is on Tropical Asia because construction technologies related to airtight performance improvement are inferior to those in developed countries, and energy consumption is high. Furthermore, based on the building conditions of the cities where high air leakage volumes were observed, a building simulation can clarify the energy reduction effect of improvement of airtight performance. The research aims to elucidate the actual condition of airtight performance in the hot areas of Asia and to verify the energy-saving effect by improving airtight performance.

## 2. Overview

We conducted an actual survey of 18 office buildings in five cities, Bangkok, Hanoi, Singapore, Taipei, and Hong Kong, in 2013 to 2018. In all cases, the whole-building air conditioning and mechanical ventilation systems were studied. There are winter seasons in Taipei, Hong Kong, and Hanoi, but summer data was used for the analysis in order to compare cities under similar conditions.

**Table 1.** Descriptions of office buildings for the actual survey

City	Hanoi					Taipei		Hong Kong		
Building name	CA	CE	OC	PV	VN	LP	UR_NE, UR_NW	C		
Total stories	23 floors, 3B	27 floors, 2B	19 floors, 2B	26 floors, 2B	27 floors,2B	12 floors	23 floors, 6B	118 floors, 4B		
Total area [m <sup>2</sup> ]	37000	10105	34640	61400	40000	9158	42712 (Basement: 4108)	260200		
A/C system	Central	Central	Central	Central	Central	Individual	Individual	Central		
Typical floor area [m <sup>2</sup> ]	1195	833.5	1224.5	2092	1550	544.7	2347.11	565.3251763		
Ceiling height [m]	2.6	2.65	2.65	2.7	2.7	3	2.75	2.8		
Number of occupants	36	40	54	152	35	62	61(NE), 61(NW)	41		
A/C time	7:00-17:00	7:00-17:00	7:00-17:00	7:30-17:00	8:00-17:00	9:00-20:00	8:00-18:00	8:00-20:00		
Buisness time	8:00-18:00	8:00-18:00	8:00-18:00	8:00-18:00	8:00-18:00	9:00-18:00	8:00-18:00	8:00-20:00		
Actual measurement period	2014/7/14~	2013/12/29~	2013/12/21~	2014/6/14~	2014/7/10~	2016/9/6~14	2018/6/26~29	2018/5/23~25		
City	Bangkok					Singapore				
Building name	CP	SC	SS	DK	SD	PS	SB	TQ	PR	
Total stories	31 floors,1B	22	41 floors, 5B	5 floors	9 floors	42 floors	5 floors	5 floors	6 floors	
Total area [m <sup>2</sup> ]	51726	-	99415	6961	-	81756	-	9636	5516	
A/C system	Central	Central	Central	Individual	Central	Central	Individual	Individual	Individual	
Typical floor area [m <sup>2</sup> ]	411.78	971	1090	1139.35	550	1608.842	425.70388	1493	628	
Ceiling height [m]	3	2.9	2.95	3	3	2.8	2.9	3	3	
Number of occupants	55	47	142	175	32	92	3rd: 20, 5th: 21	68	48	
A/C time	8:00-18:00	5:30-18:00	7:00-18:00	8:00-12:00, 14:00-17:45	8:30-17:00	8:30-17:30	6:30-18:30	8:00-18:00	9:00-18:00	
Buisness time	8:00-18:00	8:00-18:00	8:00-17:00	8:00-12:30, 12:30-18:00	8:30-17:00	8:30-17:30	9:00-17:30	8:00-18:00	9:00-18:00	
Actual measurement period	2017/3/7~10	2018/9/17~19	2017/6/25~31	2018/9/17-19	2017/10/30~11/1	2017/11/2~6	2018/3/12~14	2018/3/15~19	2018/5/30~6/1	

We conducted outdoor and indoor environment measurements for each target building listed in Table 1. The measured parameters were outdoor weather during office hours, temperature and humidity in the office space, CO<sub>2</sub> concentration, and wind velocity. The equipment in the office was installed 10 representative points for air temperature and humidity, 3 points for vertical temperature distribution, 2 points for outlet temperature, 6 points for manual measurement, and 2 points for CO<sub>2</sub> concentration in each building.

In order to understand the thermal environment near the workers at the time of the measurements, other data such as manual measurement, electricity consumption, and the number of pieces of equipment were collected. At the same time, the amount of leakage and the number of leaks in the entire office were calculated from the decay of exhaled breath, as measured by CO<sub>2</sub> densitometers installed in the office. The amount of air leakage is the leakage volume divided by the room volume and indicates the degree of air exchange due to leakage.

For the airtight performance measurement of the outer skin, a CO<sub>2</sub> attenuation measurement using CO<sub>2</sub> as a tracer gas was performed in a vinyl tent in building DK in Bangkok. The amount of leakage from the outer skin was calculated from equation (1) [4].

$$\bullet \quad Q = \frac{V}{t} \log \frac{P_1 - P_0}{P_2 - P_0} \quad (1)$$

( $Q$ : The air leakage volume [m<sup>3</sup>/h]  $V$ : The volume of the room [m<sup>3</sup>]  $T$ : The measurement time [h]

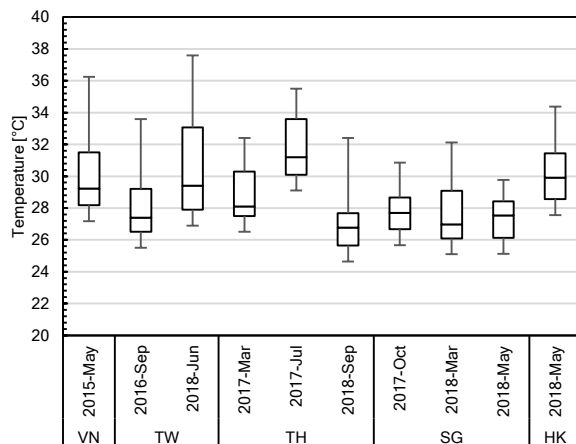
$P_0$ : The CO<sub>2</sub> density of the outside [ppm]  $P_1$ : The CO<sub>2</sub> density when starting [ppm]  $P_2$ : The CO<sub>2</sub> density when finishing [ppm])

Furthermore, a questionnaire survey of office occupants was conducted in all measured buildings. The questions asked about the amount of clothing, the comfort level, and the thermal sensation of the office worker. Regarding comfort level, we asked for answers from five options: "comfortable," "slightly comfortable," "neutral," "slightly uncomfortable," and "uncomfortable." The clothing amount was calculated using the numerical clo scale in ASHRAE standard 55 [3].

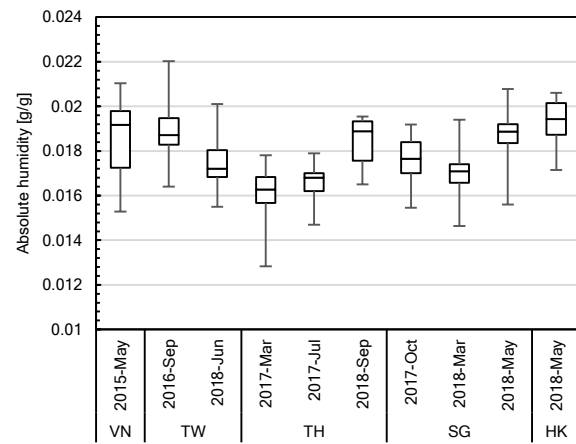
### 3. The results of the field survey

#### 3.1. Outdoor weather conditions

In all cities, the median temperature (Figure 1.) was 27 to 32 °C and the median absolute humidity (Figure 2.) was 0.015 to 0.019 kg / kg [DA], which shows the hot and humid environment that is characteristic of the hot Asian area. For Hanoi, it can be seen that the environment is hot and humid compared to other cities, and because it rains from May to September, the humidity increases considerably. For Bangkok, the maximum temperature was 35.6 °C in July of 2017. The lowest temperature is 27.8 °C in July, the maximum temperature is 35.5 °C in July, and the lowest temperature is 27.4 °C, which is almost the same except for the temperature. Although it was sunny in July in Bangkok, the humidity was a bit high. It's thought that it was the rainy season.



**Figure 1.** Outdoor air temperature frequency distribution



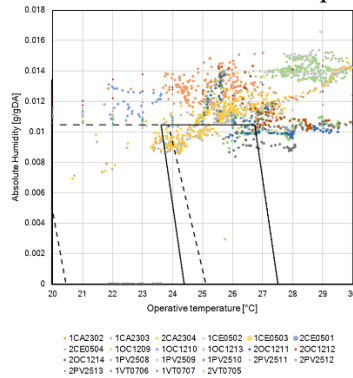
**Figure 2.** Absolute humidity frequency distribution

#### 3.2. Thermal environment in the office space

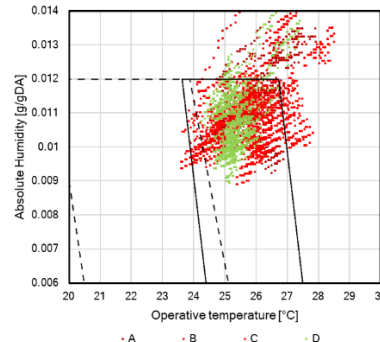
The indoor thermal environment is evaluated by the diagram of the absolute humidity and operative temperature calculated by measured data at representative points in the offices. The diagrams were shown for Figure 3. to Figure 16. The area surrounded by the dotted line in the figure is the comfort range by ASHRAE 55 [3] when wearing winter clothing (suit), and the area enclosed by the solid line is the comfort range when summer clothes (slacks and short-sleeved shirt) are worn. In an indoor environment where there are points within this range, it can be considered to be comfortable for many office workers.

For Hanoi, there were only two representative points for each case, Figure 3. summarizes the distribution of absolute humidity and working temperature in the office for the questionnaires of five cases in Hanoi. In the figure, it can be seen that the humidity and the working temperature tend to be

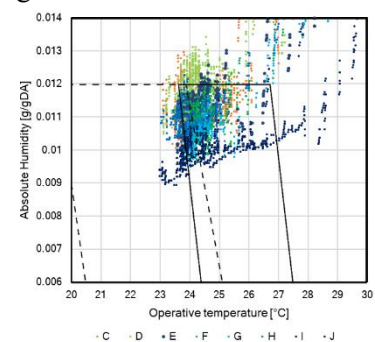
higher in Hanoi than for the comfortable range. It can be expected that the indoor environment satisfaction level from the questionnaire described below will not be high.



**Figure 3.** Thermal environment in office at Hanoi

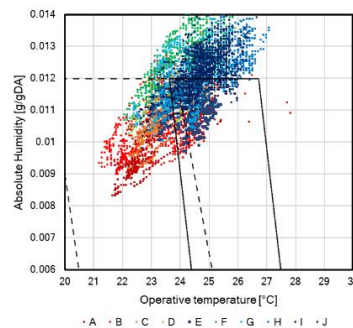


**Figure 4.** Thermal environment at Taipei (LP building)

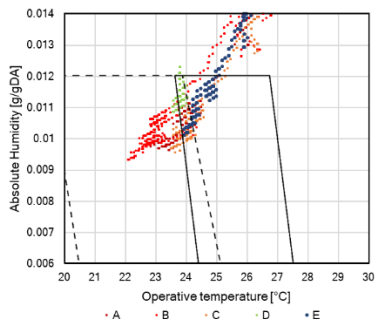


**Figure 5.** Thermal environment at Taipei (UR\_NE building)

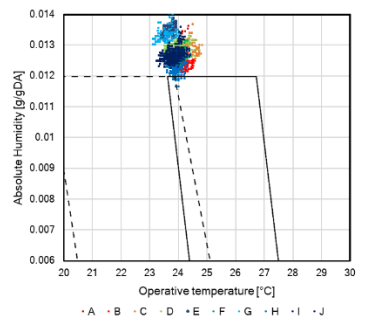
Figure 4. indicates the indoor environment measurement results in the LP building in Taipei. The measurements are almost all included in the comfortable range for wearing summer clothes, and the actual clo value is also close to 0.5, so it can be said that the building is kept in an appropriate indoor environment. Figure 5. and Figure 6. show the distribution of absolute humidity and working temperature in the office space during the actual measurement period at UR\_NE (northeast part of building UR) and UR\_NW (northwest part of building UR) in Taipei. Regarding UR\_NE, in most cases the environment falls within the comfortable range with a clo value of 0.5. By contrast, although there is no variation in the overall distribution for UR\_NW compared to UR\_NE, it can be seen that there is a difference in the distribution depending on each representative point.



**Figure 6.** Thermal environment at Taipei (UR\_NW building)



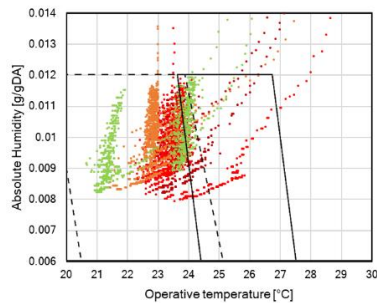
**Figure 7.** Thermal environment at Bangkok (SC building in 2017)



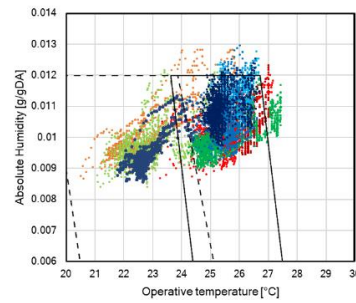
**Figure 8.** Thermal environment at Bangkok (SC building in 2018)

The correlation diagram of building SC in Bangkok in 2017 is shown in Figure 7. Only the representative points denoted A (Dark red dots) are located in the interior. The change in the air temperature during the workday at each point is 1.5 K, and the change in the absolute humidity is 0.003 kg/kg [DA]. The indoor environment at the representative points of building SC in 2018 is shown in Figure 8. This is a high humidity environment compared with the measurements of 2017, and the change in temperature and humidity of the interior and the perimeter is reduced. For office CP at Bangkok depicted in Figure 9., the environment is generally within the comfortable range when the clo value is 1. However, since the actual clothing amount of the office workers was about 0.5 clo, there is a possibility that the indoor temperature setting was too low. In the office DK shown in Figure 10., the distribution difference among the representative points is remarkable compared with other

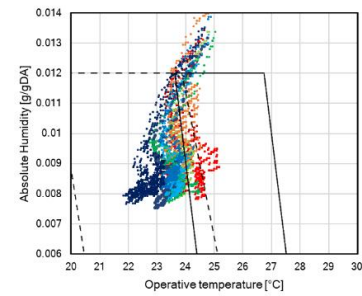
cases. The reason for this is that the air-conditioning system in this office space consists of individual air-conditioning, and there is a large difference in the air outlet temperature for each place.



**Figure 9.** Thermal environment at Bangkok (CP building)

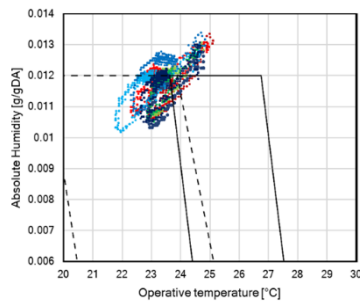


**Figure 10.** Thermal environment at Bangkok (DK building)

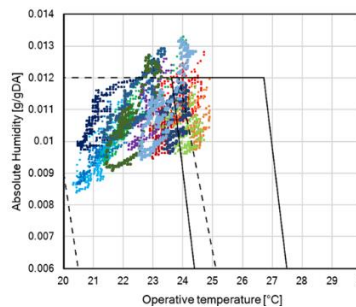


**Figure 11.** Thermal environment at Singapore (SD building)

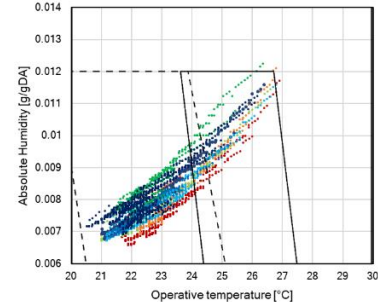
The indoor environment of the office in Singapore is shown in Figures. 11-15. In office SD, the absolute humidity is almost in the comfortable range, but the air temperature is distributed between the comfortable range for clo values between 0.5 and 1. Since the actual clothes amount is about 0.5 to 0.6, there is a possibility that the office space was cooled too much. For office PS, the absolute humidity was high, and temperature was almost in the range of clo 1, which proved to be a humid and cool environment. For office SB, Figure 13. shows that the overall room temperature setting is cool because the actual clothes amount is about 0.5 clo, but the environment is within the comfortable range for clothes amount 1 clo. For office TQ (Figure 14.), the operating temperature showed a lower distribution. The set temperature of the air conditioning in this office was 22-23 °C. In the answers to the questionnaire for this office, many answers of "slightly cold" and "cold" were seen. With respect to office PR (Figure 15.), temperature was within the range of 0.5 clo, and the clothing amount of the workers was about 0.5 clo. The set temperature of the air conditioning was 25 °C, and it was an appropriate thermal environment.



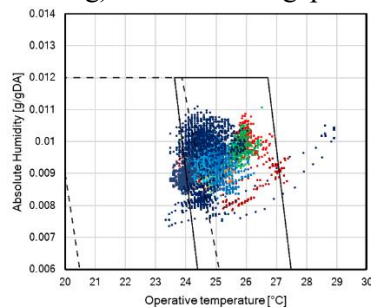
**Figure 12.** Thermal environment at Singapore (PS building)



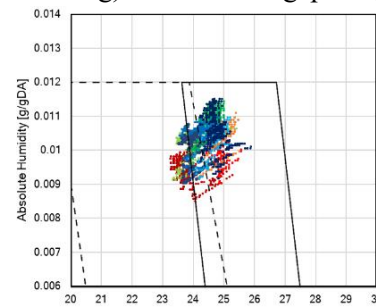
**Figure 13.** Thermal environment at Singapore (SB building)



**Figure 14.** Thermal environment at Singapore (TQ building)



**Figure 15.** Thermal environment at Singapore (PR building)

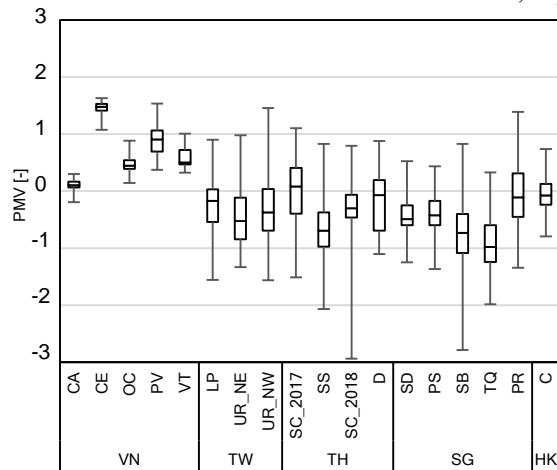


**Figure 16.** Thermal environment at Hong Kong (C building)

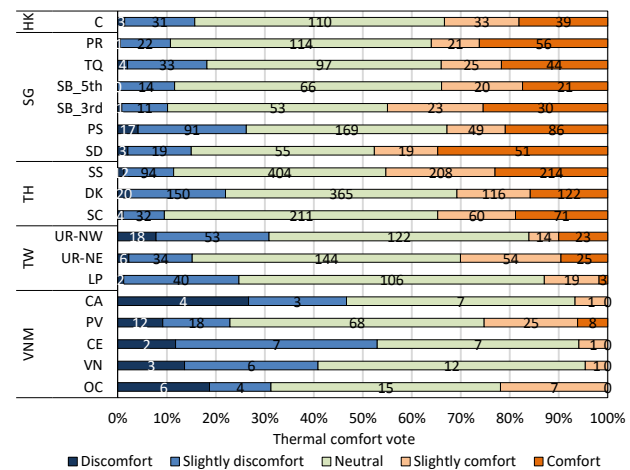
In Hong Kong, there is only one example, office C, and both operating temperature and absolute humidity were in the comfortable range. The clothing amount of the office worker was about 0.5 clo, and it can be said that the working temperature existed in mostly the appropriate range. However, unlike office workers in the other buildings, the workers of office C had quite a large number of standing walks, and even if it was a cool setting, they answered "hot" or "slightly hot" in the questionnaire.

### 3.3. The occurrence frequency of PMV

It's calculated the occurrence frequency of PMV (predicted mean vote) in each case to quantify the thermal environment in each office space. The metabolic rate was 1.1, met in the seated state, and the clothing amount was the value obtained from the questionnaire. The comfortable range of PMV in the ASHRAE Standard 55 is from -0.5 to 0.5 [3]. In the offices in Hanoi, the PMV values indicate a slightly warm environment of 0 to 1, especially in the CE building. In other cities, the PMV values indicate a rather cool environment of -1 to 0, especially Singapore.



**Figure 17.** Frequency distribution of PMV



**Figure 18.** Thermal comfort vote

### 3.4. Questionnaire survey

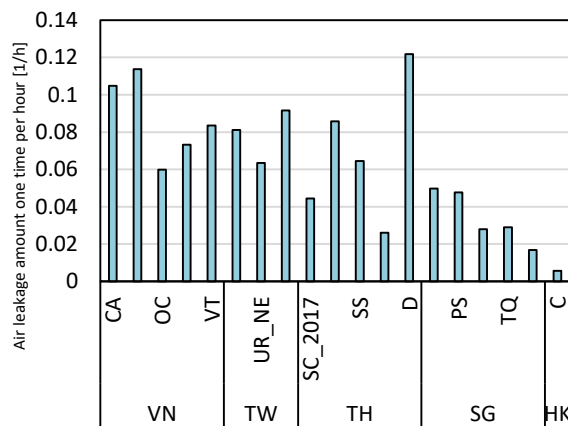
Figure 18. shows the results of the indoor environmental satisfaction questionnaire for each country. Indoor environmental satisfaction is the result of a worker's response to five levels of comfort: "uncomfortable", "slightly uncomfortable", "neutral", "slightly comfortable" and "comfortable". The timing of the reply is three times during the work day: start of the day, 11 o'clock, and 15 o'clock. Comparing the comfort responses between cities, there were many responses of "slightly comfortable" and "comfortable", especially in Singapore and Hong Kong, whereas in Hanoi there were fewer such answers.

## 4. Air leakage survey

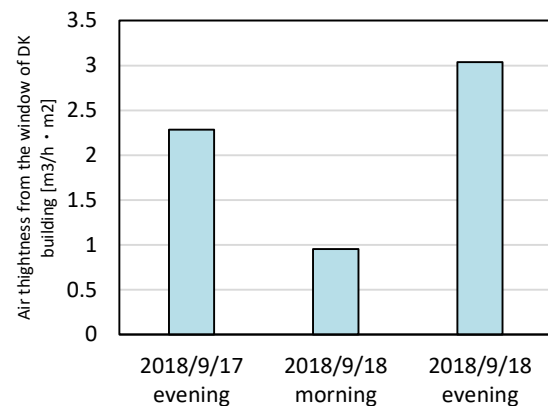
### 4.1. Air leakage survey

The number of leaks from the entire office calculated from the actual measurement results in each case is shown in Figure 19. It was relatively high in Hanoi and Taipei. On the other hands, it was low in Singapore and Hong Kong. In Bangkok, only the leakage of DK was higher, but this could have been influenced more by leakage to the next room than by poor outer skin performance. The results of the leak condition from the outer skin of the DK building will be described later.





**Figure 19.** Air leakage amount per hour



**Figure 20.** Difference of air tightness between morning and evening at DK Building

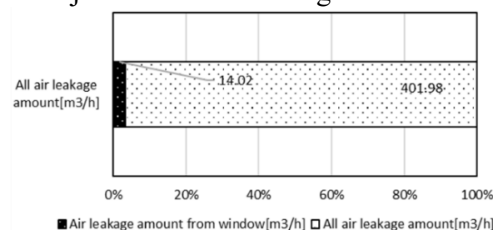
From the results of air leakage amount and the comfort answers by questionnaire, it is contrary to the tendency of the comfort answers of the questionnaire, suggesting the possibility of comfortable answers decreasing when the leakage frequency is high.

In addition, in the DK building, we measured the leakage performance of the outer skin by the CO<sub>2</sub> decay method. CO<sub>2</sub> was injected three times, beginning at: 18:48 on 9/17, 08:59 on 9/18, and 18:02 on 9/18. In each case, the CO<sub>2</sub> inlet was opened for 5 minutes, and the inlet was closed again at about 10,000 ppm. After the injection of CO<sub>2</sub>, the same attenuation occurred for all three trials and decreased to the same CO<sub>2</sub> concentration as before the injection in 4 hours. Since the values of the four CO<sub>2</sub> densitometers were almost the same at any time point, it is assumed that the CO<sub>2</sub> concentration distribution in the tent was uniform. The differential pressure inside and outside the office on 9/18 and 9/19 was 0~10 Pa.

As for the leakage volume of the outer skin of the DK building, Figure 20. shows that the relative amount of leakage at night is a few times larger than that during the day. The cause for this is considered to be the presence or absence of mechanical ventilation. By operating mechanical ventilation during the day, the room is kept at negative pressure, making it difficult for air to flow outdoors. The default value of the natural ventilation schedule of the Energyplus simulation at ASHRAE comnet is set to be larger at night in consideration of this influence.

Furthermore, we compare the amount of leakage, and the number of leaks to the window surface, with the sash airtight rating of the JIS standard. JIS A 4706-2000 (sash) sets the grades for the airtight performance of the sash. The leaks are tested according to JIS A 1516-1998 (Test method of air leakage of fittings) [4] where it is stipulated that the aeration volume does not exceed the air leakage grade line. The air leakage grade is higher in the order of A-1, A-2, A-3, A-4 [5]. The value is obtained by dividing the leakage volume by the window area and then comparing the aeration volume with the JIS airtight performance class. The air leakage was found to be on the order of grade A-3 because the indoor and outdoor pressure at the time of measurement was about 10 Pa.

When comparing the leakage amount with the entire office space and the window surface, the amount of leakage from the window surface is as small as 3% of the whole, as shown in Figure 21, so that most of the leaked air flows to the adjacent room or ceiling.



**Figure 21.** Breakdown of air leakage



#### 4.2. Influence of airtight performance on indoor environment by multiple regression analysis

We clarified which elements are deeply involved in the indoor environmental satisfaction. Multiple regression analysis was performed on the comfort-rate questionnaire responses using Excel with dry bulb temperature, absolute humidity, CO<sub>2</sub> concentration, leakage amount, clo value, and wind speed as independent variables, and standard partial regression coefficients were derived. The degree of influence on the indoor environmental satisfaction of each element was calculated.

The questionnaire about comfort was done three times per day: at the start of work, 11 a.m., and 3 p.m., but at the beginning of work the indoor environment and the degree of environmental adaptation of humans and metabolic rate are different according to the multiple regression model. As a result, we used only the 11 a.m. and 15 p.m. answers. The comfort rate to be explained in the questionnaire answers is the proportion of answers that said "comfortable" or "slightly comfortable" among the responses at the either of those times:

$$\bullet \quad \text{ComfortRate} = \frac{\text{NumberOfOfficersWhoAnswredComfortable} + \text{NumberOfOfficersWhoAnswredSlightlyComfortable}}{\text{NumberOfOfficersWhoAnswredToTheQuestionnaire}}$$

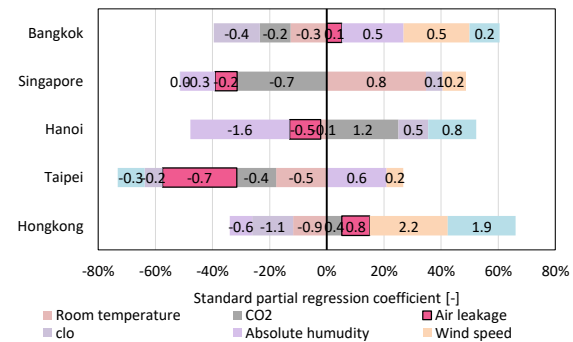
In addition, in order to show the validity of the model calculated by the multiple regression analysis, after analyzing the residuals and checking for the presence of multiple collinearity, we show the corrected decision coefficients.

**Table 2.** Standard partial regression coefficients

Objective variable	Explanatory variable							Coefficient of determination
The rate of satisfaction	Room temperature [°C]	CO <sub>2</sub> [ppm]	Air leakage [l/h]	clo [-]	Absolute humidity [g/g]	Wind speed [m/s]	MRT	
Hongkong	-0.928	0.418	0.769	-1.141	-0.616	2.160	1.883	0.8431
Taipei	-0.487	-0.379	-0.713	-0.175	0.575	0.162	-0.258	0.7859
Hanoi	-0.098	1.157	-0.503	0.484	-1.604		0.773	0.5991
Singapore	0.765	-0.692	-0.169	0.129	-0.269	0.179	-0.0003	0.7880
Bangkok	-0.284	-0.240	0.119	-0.362	0.484	0.518	0.235	0.6702

**Table 3.** Correlation coefficients

Objective variable	Explanatory variable						
The rate of satisfaction	Room temperature [°C]	CO <sub>2</sub> [ppm]	Air leakage [l/h]	clo [-]	Absolute humidity [g/g]	Wind speed [m/s]	MRT [°C]
Hongkong	-0.562	0.297	-0.458	0.216	-0.592	0.768	-0.652
Taipei	-0.627	-0.368	-0.650	0.080	-0.081	0.044	0.268
Hanoi	0.001	-0.012	-0.039	-0.113	-0.599		-0.405
Singapore	0.348	-0.404	0.044	-0.188	-0.006	0.329	0.180
Bangkok	-0.237	-0.298	0.105	-0.729	-0.102	0.592	-0.041



**Figure 22.** Standard partial regression coefficients

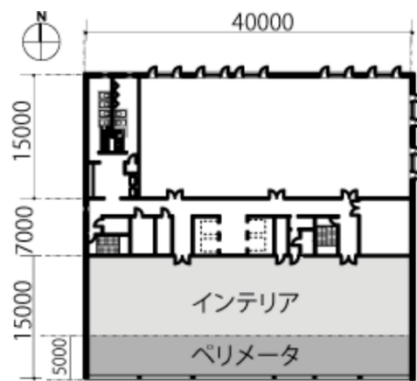
In any of the multiple regression models, the coefficient of determination is 0.6 or more, and the accuracy can be said to be higher (Table 2.). For all of the multiple regression models, it is assumed that there is almost no multi-collinearity influence since the VIF value was suppressed to 10 or less. In Hanoi and Taipei, where the number of leaks was relatively high, the decrease in absolute humidity contributed more to the improvement of the comfort rate. Although the number of leaks is inferior to other indoor environment main factors, as it decreases, the comfort rate improves. Particularly in Taipei, the involvement of the number of leaks had a large correlation. In Bangkok and Hong Kong, a slightly positive correlation was calculated for the number of leaks. It can be expected that the indoor comfort will decrease because of an increase in the number of leaks, but there are conflicting results, where the amount of leaked air in Bangkok was a smaller factor than in other cities. Based on the analysis results of each of the cities above, the number of leaks does not directly affect the improvement of the comfort of the indoor environment, but it is suggestive that when the number of leaks is large, it exerts an adverse effect on comfort. Moreover, we also calculated the correlation coefficient obtained by performing the single regression analysis of each independent variable (Table3.). For Hanoi, we found that there is a stronger correlation for absolute humidity, clo value, and MRT than for other factors. For Taipei, it was found that there is a stronger negative correlation with indoor dry bulb temperature and number of leaks compared with other factors. A major negative correlation with the number of air leaks occurs for Taipei. The same tendency is also recognized in the multiple regression. It can be said that improvement of the airtight performance is not involved at all but contributes to comfort in the indoor environment. For Bangkok, the correlation between the clo

value and MRT is strongly negative. For Singapore, no significant correlation was found between any elements. Among the seven analyzed elements, the greatest negative correlation was CO<sub>2</sub> concentration. In Singapore's case, the airtight performance was generally high, the proportion of comfort was high, and it was stable as an office environment. We found that the negative correlation is large in Taipei where the relative amount of leakage is large. There are positive correlations in cities where the number of leaks is low, such as Bangkok and Hong Kong, but this is because almost no comfort factor is affected. Furthermore, the correlation between the number of leaks and the comfort rate was determined for each city and considered. In Hanoi and Taipei, where the number of leaks is high, reduction in the number of leaks tends to improve the comfort rate. The involvement of the number of leaks showed large correlation coefficients, particularly in Taipei. In Bangkok and Singapore there was a minute positive correlation. An increase in the number of leaks can be expected to lead to a decrease in comfort, but the conflicting result is that the number of leaks was less than in other cities. Based on the above results, the number of leaks does not directly affect the improvement of comfort, but there is a possibility that the comfort rate could be adversely affected if the number of leaks is large.

## 5. Energy saving effect by improving airtight performance

### 5.1. The simulation model

In this study, a heat load calculation is carried out using "hload-L". For this calculation, the target building was the web standard model (1000 m<sup>2</sup>, office) that was published under the Ministry of Industry's energy conservation standards in US. In the calculation, the opening was set as one room with a lateral continuous window on the south side, a perimeter within 5 m of the window surface in the room, and the interior of the room was set as the interior.



**Figure 23.** Plan diagram of simulation model

**Table 4.** Conditions of simulation

Discription	Actual	A3 level	A4 level
No of floors		16	
Floor to ceiling height [m]		2.6	
Office area		600	
Ratio of window		0.65	
Glass SHGC		0.37	
Structure		RC	
Floor/Wall/Ceiling reflect		0.4/0.7/0.5	
Building of neighborhood		N/A	
Viewing factor of sky		0.5	
Albedo		0	
Lighting gain [W/m <sup>2</sup> ]		3.5	
Equipment gain [W/m <sup>2</sup> ]		11.2	
Blind color		White	
Set illuminance [lx]		700	
Air leakage one time per hour	0.186665294	0.02	0.005

### 5.2. Simulation conditions

For all cities, but especially for Hanoi, where a large amount of leakage was observed, the energy-saving effect of improving the airtight performance was examined. In order to conduct a more realistic study, a model reflecting the values calculated from the Hanoi survey was prepared. The heat load simulation was conducted using "hload-L" for those buildings whose airtight performance was changed to the current level, the sash A-3 grade level, and the A-4 grade level. Table 4 shows the input conditions of the model and input values of the airtight performance. Weather data from IWEC (International Weather for Energy Calculations) was used as the weather conditions of Hanoi.

In Hanoi and Tokyo, airtight performance was changed to calculate the heat-load reduction effect. For weather data, we used the data of TOKYO Hyakuri and VNM Hanoi from the IWEC epw data set.

Long-wavelength radiation data is necessary for hload-L, but since data on long-wavelength radiation does not exist in the epw data, the value was calculated from equation (4-1).

$$\bullet \quad I = \varepsilon \sigma T^4 \quad (4-1)$$

( $\varepsilon$ : Injection rate, set to 0.97 here  $\sigma$ : Stefan Boltzmann's constant,  $5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$   
 $T$ : Absolute temperature)

### 5.3. Weather conditions / Analysis on the divergence between measured data and epw data in Hanoi

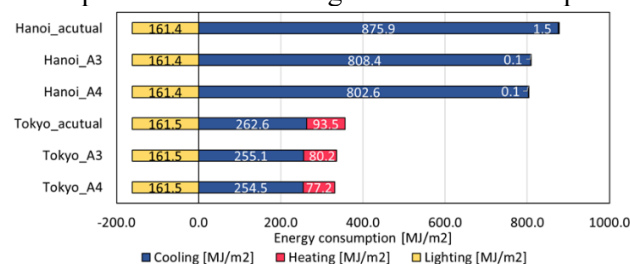
In order to perform a more accurate calculation, we analyzed whether epw weather data used for the simulation deviates from actual weather data. For that purpose, we compared the cumulative frequency distribution of measured data with epw data and evaluated the divergence.

For Hanoi, we used data measured by the laboratory installed on the building rooftop during the period from January 1, 2014 to October 31, 2015. From the data frequency distribution of the dry bulb temperature in Hanoi, we find that the measured value and the epw data have almost the same distribution, so we can say that there is almost no data divergence. For the absolute humidity, it can be seen from the frequency distribution in the above figure that there is no particularly large deviation between the measured value and epw data. However, absolute humidity tends to be slightly smaller in the actual measured values. Regarding the amount of solar radiation, it can be seen from the history that the measured value is smaller in every season. Alternatively, the frequency distribution shows that there is no particularly large deviation in the trend.

Based on the analysis of the deviations between the epw data and the measured data above, we consider that the weather data used for the simulation for Hanoi is consistent with the actual situation.

### 5.4. Simulation results

Figure 24. shows the primary energy consumption calculated by the simulation. The airtight performance of sashes is almost unchanged for A-3 and A-4 grades, but compared with Hanoi's current airtight performance model, it is about 8% in Hanoi and 6% in Tokyo. In terms of the reduction rate, Hanoi is slightly dominant, but in absolute terms, Hanoi's energy reduction is about 1.5 times that of Tokyo. It was found that the energy conservation effect of the improvement measures of airtight performance in the Tropical Asian area is higher than done in Japan.



**Figure 24.** Result of the simulation

## 6. Conclusion

This research aimed to elucidate the actual condition of airtight performance in the hot areas of Asia and to verify the energy-saving effects of improving airtight performance. The research clarified the tendencies of the thermal environment in the office hot spot in the Tropical Asian area, determined the amount of leakage from the entire office, measured the amount of leakage from the windows in the DK building in Thailand, and confirmed the energy-saving effect of improving airtight performance.

In Hanoi's offices we found that the PMV value is in the "slightly warm" environment of 0 to 1, especially in the CE building "warm" environment. In cities other than Hanoi, especially in Singapore, we found a "slightly cool" environment with PMV values between -1 and 0.

The air leakage amount per hour in Hanoi and Taipei was relatively high, but in Singapore and Hong Kong, it was low.

The value obtained by dividing the leakage volume by the window area was compared with the JIS air leakage rating as the aeration volume, which was found to be approximately A-3 grade. In addition, when comparing the leakage amount with the entire office space and the window surface, the amount of leakage from the window surface is as small as 3% of the total, so it is conceivable that that most of the leakage is air exiting into the adjacent room or the ceiling.

In Hanoi and Taipei, where the number of leaks was relatively high, the decrease in absolute humidity contributed more to the improvement of the comfort rate. Although the number of leaks is inferior to other indoor environment factors, as it decreased it tended to improve the comfort rate. Particularly in Taipei, the involvement of the number of leaks was large in the simulation.

In Bangkok and Hong Kong, a slightly positive correlation was calculated for the number of leaks. It can be expected that indoor comfort will decrease due to an increase in the number of leaks. The reason why the conflicting result is that there are many instances where the amount of leaked air in Bangkok was smaller than in other cities. Based on the analysis results of each city, the number of leaks does not directly affect the improvement of indoor environment comfort, but it was found that when the number of leaks is large, it exerts an adverse effect on comfort.

Although it is effective in reducing the latent heat load in winter, even in areas such as Tokyo where winter also occurs, it was found that airtight performance improvement in the hot spring areas of Asia, such as Hanoi, was sufficiently effective.

Because airtight performance tends to be low in Asian countries such as Hanoi, Taiwan, and others, it is considered that the increase in energy saving due to the improvement of airtight performance is great, compared to the present airtight performance in Tokyo. Moreover, if it is possible to promote technological transfer in order to improve airtight performance in Asian countries that are now growing, it is possible to lead to significant energy reduction.

This paper only describes the knowledge gained from a limited number of cases, only one in Thailand for experiments of airtightness, and only Vietnam and Japan for simulation. Therefore, going forward it will be necessary to accumulate data from other countries by conducting experiments and actual measurements based on the findings obtained from the actual measurement, experiment, and simulation in this study.

## 7. Acknowledgement

This research was supported by a Tokyo Metropolitan Government Platform collaborative research grant (representative: Assoc. Prof. Masayuki Ichinose). All of the kind support for the case study is gratefully acknowledged.

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