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A Study on Developing Ventilation in Restaurants in Re-purposed Row Houses

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Abstract

The building ventilation of seventy-seven row houses in eight districts in Chiang Mai province of Thailand was surveyed and investigated. A typical row house re-purposed as a restaurant refers to a 3.5 m high space with two stoves in the front of the building and a closed rear area to serve as storage. As a base-case, restaurants had an average capacity of 24 customers in the dining area. Measurements of internal air quality of a selected restaurant were conducted in the summer season of 2015 and 2017, and the results revealed average air temperatures of 36°C and 33°C, relative humidity values of 46% and 33%, and air speed values of 0.28 m s^{-1} and 0.10 m s^{-1}, respectively. The Computerised Fluid Dynamics (CFD) and the Center for the Built Environment (CBE) thermal comfort tool were used to simulate the efficiency of current and proposed ventilation techniques and also analyse thermal comfort conditions for each scenario. Low-cost cooling techniques of air speed and humidity adjustment were chosen to improve thermal conductions. By applying the combined techniques, the overall temperature was reduced by 2°C and the thermal comfort levels were improved from the ‘hot’ to the ‘warm’ zone. Some conditions in the second restaurant are in the expanded ‘adaptive thermal comfort zone’. Although most results appear to exceed the ‘adaptive thermal comfort zone’, conditions could not be further ameliorated since 1.5 m s^{-1} was the maximum air speed that could be employed in the dining area to avoid wind discomfort. Limited investment in ventilation improvement was the main challenge since air-conditioners and multiple fans were not affordable and were also insufficient for the re-adaptation option. Feasibility study of ventilation improvement technique is limited in this study.

Keywords: Ventilation improvement; Natural ventilation; Thermal comfort; Row house; Summer; Hot–humid climates

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Introduction

Many row houses or Chinese shop houses in Southeast Asian countries have been re-purposed as restaurants. Due to limited natural ventilation, many different techniques have been used to improve the thermal conditions in these row houses. In Malaysia, several techniques are used, including construction of a small internal courtyard combined with nocturnal and radiative cooling techniques [1]. Previous research in Indonesia suggests the use of mechanical fans since people in the tropics are accustomed to higher wind speeds from fans than those tolerated in cooler climates [2]. From 1,854 locations worldwide, natural ventilation techniques in Malaysia and Singapore show little potential to improve thermal comfort [3]. Techniques such as natural wind forces and buoyancy show potential if vertical ventilation is available [4]. To understand the limitations to improving thermal conditions in a restaurant in a typical row house, the design and characteristics of such houses are explained below.

1) Restaurants in typical row houses in Thailand

In Thailand, many row houses are re-purposed as small local restaurants. However, these row houses were not originally designed as naturally well-ventilated spaces. When these units are used as low-cost restaurants, they have limited budgets for improvement as regard the customer's thermal comfort. Typically, row houses vary from 12 m to 22 m in depth and are commonly designed as a block of up to ten attached dwellings which can form a single structure up to 40 m long. There is no specific building regulation for kitchens in row houses or for a rowhouse renovation, only Building Code No. 55 [5], which allows each unit to have a maximum depth of 16 m without opening windows and each individual dwelling to have a minimum width of 4 m with a minimum height of 3.5 m required for the ground floor and 2.5 m for each higher floor level. The end houses typically have at least 10% window opening in the wall area. The same building regulation also requires a minimum of 1 m between the rear wall of the structure and the boundary of the property at the back.

Row houses therefore have limited natural ventilation. According to the Building Code, the minimum width and length of row houses are 4 m and 16 m, respectively, with a minimum height of 3.5 m for the first floor and 3.0 m for the others. The houses in the middle, in particular, have the most limited ventilation. They lack side windows, so they are entirely dependent on cross-ventilation which must travel up to 16 m through the building from front to rear. Additionally, when these houses are re-purposed to become restaurants, the 1 m rear courtyard area is frequently re-purposed to become a second kitchen space which is often separated from the dining area by a full-height internal wall. This wall then blocks the only available route for natural ventilation. The restaurants also have restrictions imposed on the types of changes that can be made to the space. The rental contract conditions usually preclude any interference with the structure of the building, and only portable devices are allowed. This reduces the options available for improving thermal conditions.

2) Effect of heat sources in restaurants

There are two possible locations for kitchen areas in these restaurants. This research found that the kitchen area is usually located at the front or the rear, or both sections of the row houses. Multiple stoves and kitchens mean an increase in the number of heat sources. Additionally, a second kitchen in the back courtyard obstructs natural ventilation. Such a combination of kitchens and an internal wall can result in excessive heat build-up in the dining area. Diners also act as heat sources. According to Fanger's thermal comfort equation

[6], an average man has a core temperature of 37°C and skin temperature of 35°C. With a maximum restaurant capacity of 24 customers from the typical seating area available in the base-case, heat buildup from diners can be considerable in the dining area.

There are also certain re-purposing issues such as budget limits and rental contract conditions. These restaurants are low-cost and local-style; therefore, improvement in customers' thermal comfort needs to focus on low-cost cooling techniques without air-conditioning systems. This study focused only on physical environmental factors.

3) SET and adaptive thermal comfort model

The theories used in this research are based on the adaptive thermal comfort models, referring de Dear in ASHRAE 55 -2013 [7]. The model is suited to natural ventilation in a hot-humid climate where people are acclimatized to a hot outdoor environment. Ventilation can expand the comfort threshold range by approximately 1.2°C, according to ASHRAE's adaptive thermal comfort model [7]. Using the PMV-PPD and adaptive thermal comfort models, it has been found that the thermal comfort range for Thai people is 25-28°C in air-conditioned spaces [8-9] and 26-31°C in naturally ventilated spaces [8, 10-12]. In subtropical climates, adaptive thermal comfort studies were conducted in public semi-outdoor spaces during the warm and humid season in Taiwan, Japan, China and Singapore. The overall comfort band in naturally ventilated buildings for Southeast Asia has been established as 26-34°C [13]. Taiwanese researchers concluded that the comfort band of participants in transitional spaces was 26.3-27.1°C [14]. It should be noted that the comfort temperature in the subtropics is 2°C higher than the ASHRAE standard [7], which is consistent with the studies in Thailand mentioned above.

In the warm-humid climate zone of China, the comfort temperature range has been identified as 2-29.5°C, and the upper temperature limit can extend to 31-33°C when the wind speed is 1.2-2.1 m s^{-1} [15]. A lower specific comfort temperature using calculations from the adaptive thermal comfort model has been affirmed in cooler climates. For example, the comfort temperature in the semi-outdoors is 26°C in Japan [16], while it is 24°C in Sydney [17].

Methods

Seventy-seven restaurants in re-purposed row houses were surveyed in eight districts in Chiang Mai (18.7953° N, 98.9620° E) in March and May 2015. This survey investigated five selected physical features related to ventilation improvement: width of the restaurant area; ceiling height of the restaurant area; zoning of the kitchen areas; number and types of stoves; and ventilation systems in use. Seventy owners were available for interview. Several techniques which might improve the restaurant conditions were suggested during the interview. Each participant was informed of the cost and efficiency of each proposed technique. Then, they were asked to nominate their top three preferred techniques and the reason for these choices. The top five proposed options were as follows: an extra fan (28 USD, possible 1-6°C reduction); a water-misting fan (140 USD, possible 5-15°C reduction); an air-conditioner (560 USD, possible 5-10°C reduction); an overhang at the front area (150 USD, possible 1-5°C reduction); and an exhaust system (300 USD, possible 0-8°C reduction). As noted, both efficiency and the prices were reported by the suppliers. Therefore, the top three techniques were chosen to proceed with the study.

Of the 77 restaurants, a typical case was chosen as the base case as mentioned earlier for further investigation of thermal conditions and possible changes after simulated interventions. This restaurant was selected since it shared all common features. From the 77 restaurants, these features are the most frequently found and represent the base-case features: a middle row house of 4 m in width, 3.5 m ceiling height, 12 m in depth and 0.1 m width of concrete block infill wall between structural columns, with no side window. The only natural ventilation passed from the front (South-facing) to the rear of the unit. The base-case restaurant had five fans in total: two 0.4 m diameter wall-mounted, oscillating, directional fans installed at 2 m above floor level every 4 m on each side and one centrally placed ceiling fan.

The instrument used to measure the indoor climate parameters at the case-study site was a Kimo AQ300 (OneTemp, Co. Ltd, accuracy ±5%), measuring at two levels: 1.1 m (head height when seated) and 0.6 m (abdomen when seated) (Figure 1). The following parameters were calculated for thermal comfort analysis: operative temperature, neutral temperature, accepted temperature for adaptive thermal comfort, adaptive thermal comfort temperature and its expanded accepted temperature. This is classified as a Class I measurement, following ASHRAE [7]. The measurement was conducted in May 2015 which is the most humid period of summer in Thailand. Four physical environmental parameters were measured: air temperature, mean radiant temperature, air speed and relative humidity. The measurements were conducted during full operation to record peak conditions at the restaurant.

These four parameters were first assessed in the case study restaurant. The three most popular cooling techniques nominated by the participants were then applied to a simulated model of the case study restaurant. Ventilation was simulated using Phoenics, a computerised fluid dynamics (CFD) program (X-Y-Z meshing: 104-51-52 cell with 3,000 total number of iterations and global convergence criterion 0.1%). The simulation took human temperature into account as an additional heat source. As the observed change in the indoor climate with the nominated cooling techniques was insufficient for analysis with alternative thermal perception tools, the results were analysed using the program CBE thermal comfort tool based on ASHRAE 55-2013 [7, 18]. The saturated effective temperature (SET) was calculated using the CBE thermal comfort tool. The adaptive thermal comfort [7] was calculated and analyzed.

Finally, the conditions in the selected base-case restaurant was measured in summer 2016 (1st-restaurant) and 2017 (2nd-restaurant). Noted that the 1st- and 2nd-restaurant are the same restaurant with the 1st-year and the 2nd-year measurements. Both restaurants installed a water-misting fan to improve thermal comfort. The physical environment in the restaurants was measured before and after intervention. The thermal perception of 20 customers was assessed using a questionnaire interview form during operational hours. To identify changes, the measurements between, before and after intervention were analysed.

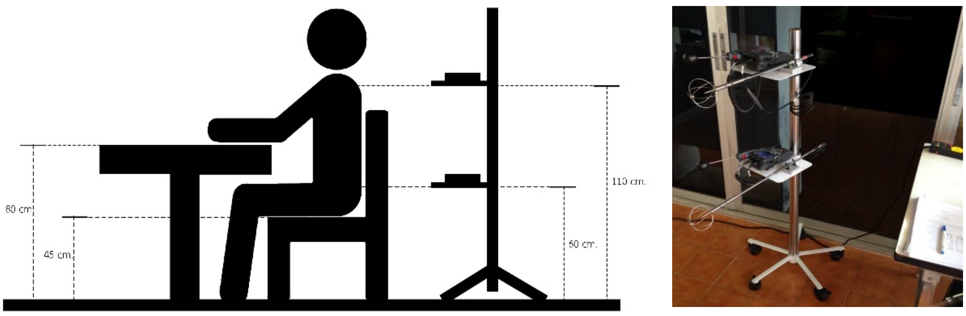

Figure 1 The instrument installed with the Kimo AQ300 at two heights (0.6 m and 1.1 m).

Results

The reported possible choices are limited by affordability. The top three affordable techniques chosen by the owners were as follows: one or more additional fan (78%), an overhang (38%) and a water-misting fan (30%) (each owner could select three from seven available options). Cost and efficiency are the main selection criteria. Some owners reported that they would prefer installing an air-conditioner if they could afford the cost in the future. The survey was conducted in summer in Chiang Mai. The restaurant faced North and had installed an overhang and a water-misting fan. The first restaurant was measured in May 2015. The average indoor conditions were recorded in the middle of the dining area at 36.7±1.0°C temperature, 37.4±1.2°C mean radiant temperature (MRT), 0.28±0.59 m s^{-1} natural air speed and 46±6.4% relative humidity (Table 1). Outdoor conditions were recorded at 36.04 ±0.83°C temperature, 37.7±0.7°C MRT with 48.10± 5.80% relative humidity. The second restaurant was surveyed in April 2017, using the same protocol as the first restaurant. The average conditions were 33.5±0.8°C temperature, 33.7± 1.0°C MRT, 0.1±0.73 m s^{-1} natural air speed and 32.8±7.6% relative humidity. The indoor conditions were approximately 0.3°C temperature and 1 m s^{-1} air speed more than the outdoor conditions.

As the measured data from the 1st-restaurant paralleled the 10-year average condition from the Thailand Meteorological Department (TMD) in the hot-summer of Chiang Mai (average 36°C with 50% relative humidity), this research used the TMD data for simulation representing the base-case restaurant. The average conditions recorded inside the restaurant were approximately 1°C higher with air flow velocity 0.2 m s^{-1} higher than the outdoor conditions due to two stoves and 24 customers (Figure 2-3). Hot-summer means a summer with more than one-third of the number of days classed as very hot (>34°C) [19]. The conditions in the 1st-restaurant could represent a better example of the hot peak situation than it was in the 2nd-restaurant, therefore its figures are shown in Figure 2-3).

Velocity

0.45	0.68	1.26	0.77
0.49	0.23	0.50	1.17
0.45	0.26	0.34	1.31
0.46	0.56	0.48	1.24
0.13	0.28	0.53	0.82
0.13	0.31	0.44	0.40
0.16	0.26	0.39	0.30
0.28	0.37	0.34	0.19
0.36	0.38	0.31	0.14
0.41	0.38	0.26	0.07
0.43	0.29	0.20	0.08
0.47	0.11	0.11	0.09

Temperature

36.03	36.04	36.07	36.11
36.02	36.03	36.04	36.09
36.02	36.02	36.03	36.08
36.02	36.02	36.03	36.08
36.00	36.01	36.04	36.11
36.00	36.04	36.11	36.16
36.01	36.08	36.14	36.23
36.01	36.12	36.13	36.18
36.01	36.17	36.14	36.27
36.01	36.25	36.17	36.29
36.00	36.32	36.29	36.43
36.00	36.05	36.37	36.52

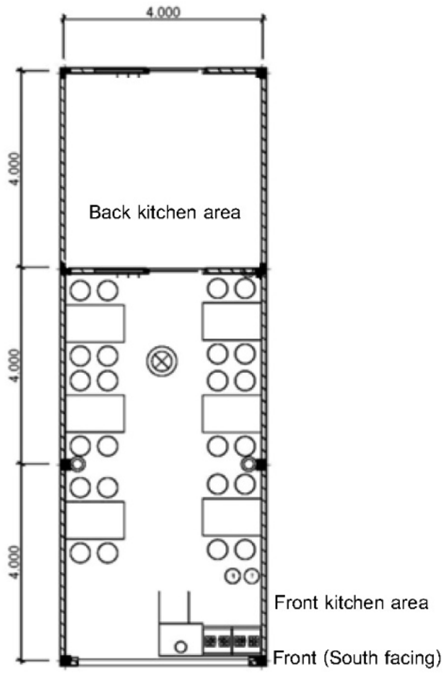

Figure 2 Simulation results of the restaurant during full operation, presenting air velocity (m s^{-1}) and temperature (°C).

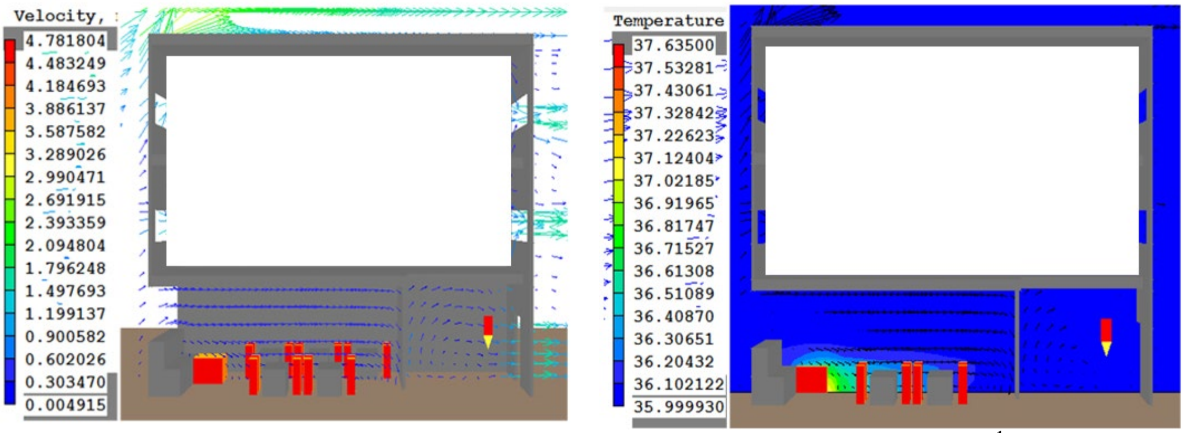

Figure 3 Simulated temperature (°C) and airflow velocity (m s^{-1}) results in the first row house/restaurant combination.

Note: red boxes are heat sources and the right red with yellow arrow is the probe position.

Table 1 Physical environment parameters in case study restaurant

Conditions	Temperature (°C)	Mean radiant temperature MRT (°C)	Air speed (m s^{-1})	Relative humidity (%)
First restaurant				
Indoor	36.67±1.0	37.43±1.2	0.28±0.59	46.03±6.4
Outdoor	36.04±0.8	37.73±0.7	0.55±0.86	48.10±5.80
Second restaurant				
Indoor	33.5±0.8	33.7±1.0	0.10±0.73	32.80±7.6
Outdoor	36.04±0.8	37.73±0.7	0.55±0.86	48.10±5.80

Regarding ventilation, even though the door installed on the internal wall to the rear kitchen was open during the survey, the separated kitchen at the back obstructed ventilation significantly. Average airflow was observed to drop from 0.55 m s^{-1} at the front area to 0.29 m s^{-1} in the middle area in the simulation.

Discussion

In the existing restaurant, thermal comfort was not achievable with the low-cost proposed options as the conditions were not in the comfort zone with 35.8°C SET. Several techniques were then simulated. Elimination of the heat source in the space is the primary concern. First, the stoves were moved to the outside in front of the building where the heat was removed from the dining area. Second, one of the top three selected techniques- an overhang- was installed in the front façade to reduce external heat gain from the sun. However, these two solutions together could reduce simulated average temperature by only 0.1°C. This research proposed other two affordable techniques to improve thermal conditions: increased ventilation and increased ventilation with adjusted humidity. Increased ventilation alone was expected to be more effective since humidity improvement might lead to uncomfortable for diners. However, increased ventilation alone was not sufficient to reach the adaptive thermal comfort zone.

1) Increased ventilation

The most popular choice among restaurant owners was to install at least one extra fan. However, ventilation may not be improved in this case since the rear opening is blocked by the rear kitchen. Nevertheless, adding an extra fan is the most practical measure for these restaurants. The cross-ventilation using two additional standing fans was set at the sitting height (0.8 m). The fans ventilate from the dining area to the front in order to avoid carrying heat from the heat sources to the dining space. Also, the air speed from the fans was limited at 1.5 m s^{-1} so as to not disturb the customers [20].

Theoretically, the ASHRAE adaptive thermal comfort model advocates that thermal comfort of people will adapt in response to outdoor temperatures. Also, the ASHRAE's adaptive thermal comfort band can expand by increasing the air speed in naturally ventilated environments [7]. Eq. 1-2 [7] shows the upper and the lower 80% acceptability range of theoretically neutral comfort temperature (shown as the grey area in Figure 4). The upper limit of the adaptive thermal comfort ranges from 31.0°C to 34.8°C, with 32.7°C as the average. When wind speed is considered, thermal comfort ranges expand in three levels: 1.2°C, 1.8°C and 2.2°C from wind speeds of 0.6 m s^{-1}, 0.9 m s^{-1} and 1.2 m s^{-1}, respectively. As mentioned earlier, the maximum wind speed of 1.5 m s^{-1} leads to the expansion of the upper limit of the thermal comfort range to 34.9°C on average. This approach can decrease the average indoor temperature by only 1°C.

However, the conditions were still not within the expanded thermal comfort zone of acceptability (see the red dots in Figure 4). The mean comfort temperature in this research was calculated as 36.9°C from Eq. 3. This is 2.0°C above the upper thermal comfort band of acceptability. Eq. 3 describes the calculated comfort temperature for customers in the restaurant, with $p = 0.00$, $R^2 = 0.11$.

This research points to a comfort temperature ($T_{comfort}$) for hot–humid climates that is approximately 6°C higher $T_{comfort}$ than that suggested by Eq. 4 [21] and 15°C higher than that suggested by Eq. 5 for Southeast Asia [13]. There are three possible reasons for these differences: time of survey, building type and method. The different summer temperatures might lead to a difference in peak hottest lunch times, so that time may be an important factor [21] Although the Thai survey was conducted in summer [21], it measured $T_{comfort}$ in semi-outdoor spaces and surveyed elderly customers; this might have skewed respondent feedback. The Nguyen et al. [13] research analysed 11 field survey databases in Singapore, Thailand, Indonesia, the Philippines and China, and concluded that the $T_{comfort}$ of the Thai study covered both naturally ventilated and air-conditioned buildings, and considered summer, winter and monsoon seasons. Therefore, the $T_{comfort}$ obtained in the Southeast Asia study was lower than that for Thai summer in general. Regarding limited comparable reference cases, these influential factors might lead to limitation of the research.

The Thai study covered both naturally ventilated and air-conditioned buildings, and considered summer, winter and monsoon seasons. Therefore, the $T_{comfort}$ obtained in the Southeast Asia study was lower than that for Thai summers in general. Regarding limited comparable reference cases, these factors might limit the value of the study.

$$\text{Upper 80\% acceptability limit} = 0.31\ T_{out} + 22.5 \quad \text{(Eq. 1)}$$

$$\text{Lower 80\% acceptability limit} = 0.31\ T_{out} + 14.3 \quad \text{(Eq. 2)}$$

where T_{out} = outdoor temperature.

$$T_{comfort} = 0.1046\ T_{out} + 33.06 \quad \text{(Eq. 3)}$$

$$T_{comfort} = 0.2757\ T_{nv\text{-}in} + 26.67 \quad \text{(Eq. 4)}$$

$$T_{comfort} = 0.341\ T_{out} + 18.83 \quad \text{(Eq. 5)}$$

where $T_{comfort}$ = comfort temperature and $T_{nv\text{-}in}$ = naturally ventilated indoor temperature.

However, the 36.5°C mean comfort temperature reported in Chindapol et al. [21] is similar to the 36.9°C mean comfort temperature in this study. These two surveys are comparable since both the surveys were conducted in summer in Chiang Mai, Thailand.

2) Increased ventilation with adjusted humidity

The water-misting fan is representative of low-cost cooling through increased ventilation combined with increased water vapour. The simulation applies two water-misting fans and a small fountain. Although the use of a mist fan was successful in outdoor environments in low humidity conditions such as in Tokyo [22], the 46% relative humidity measured in the survey was found to be adequate to improve thermal comfort. Based on the psychrometric chart for Thailand, it is evident that latent heat from water vaporisation can reduce perceived temperature by increasing the apparent humidity level to be equivalent to 80% relative humidity [23]. Although this approach has most often been used in hot–dry climates rather than hot–humid climates, the prevailing low humidity in Chiang Mai during the survey period would allow the evaporative cooling technique to work effectively.

Using the direct evaporative cooling method, sensible heat is transferred to latent heat through evaporation of water. The prevailing low humidity which in Chiang Mai during the survey period would allow the evaporative cooling technique to work effectively [24]. There are many evaporative products available, such as the evaporative pad as used in Brazil [25] and the cooling pad, as used in farming shelters in hot–humid Thailand [26]. The Thai study claims that the outlet temperature can be reduced by as much as 13°C from the 41°C inlet temperature. However, the air volume used in the study was 9.2 kg s^{-1} to maintain the 80% relative humidity during the summer. Another study in a livestock farm used a 'CeLPad'; the 35°C dry bulb temperature can differ from wet bulb temperature by as much as 12°C in conditions of 30% relative humidity and evaporation effectiveness of 88% [27]. Both the studies conducted in Thailand show that the volume and the speed of the air significantly influence evaporation efficiency. This technique is the most suitable method for outdoor environments since high humidity levels may cause indoor air quality issues. However, the cooling pad technique was judged unaffordable for the restaurant's owner due to limited budget.

In this research study, it was observed that the affordable evaporative cooling from mist fans was less efficient than equivalent affordable commercial evaporative cooling products. The evaporative fan model MIK-07EC (MasterKool International, Co., Ltd) can provide just 0.6 kg h^{-1} volume of evaporated water, limited by the 1.5 m s^{-1} maximum air speed. Even though the product claims a 15°C temperature difference between input and output, the simulation shows that only a 1°C reduction in average indoor temperature, while a 15% increase in relative humidity can be expected from this technique.

In relation to the adaptive thermal comfort in the first restaurant, although the mean $T_{comfort}$ using this technique was calculated from Eq. 6.1 as 35.9°C, at least 1.0°C above the upper thermal comfort band of acceptability (the grey area in Figure 4) without using adjusted humidity. Some conditions were observed to be within the comfort band (the blue dots in Figure 4). Eq. 6.2 shows the calculated $T_{comfort}$ for customers using both increased ventilation and adjusted humidity, with $p = 0.00$ and $R^2 = 0.12$, meaning that the results are highly significant statistically.

$$T_{comfort} = 0.1046T_{out} + 33.065 \quad \text{(Eq. 6.1)}$$

$$T_{comfort\ (evap)} = 0.1303T_{out} + 31.052 \quad \text{(Eq. 6.2)}$$

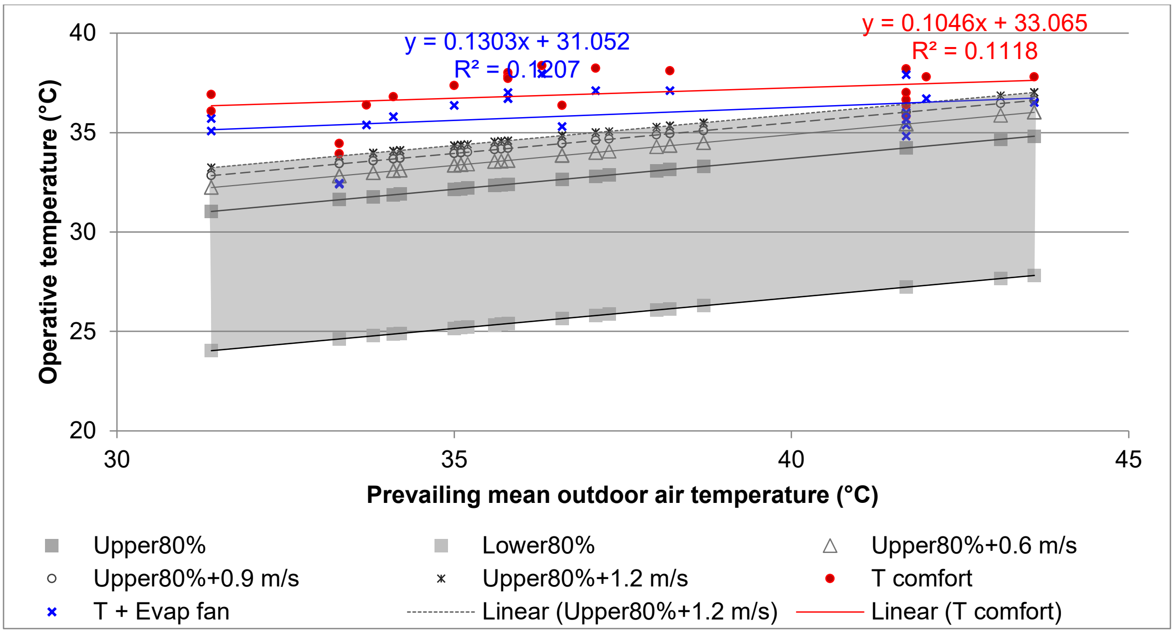

Figure 4 Comfortable temperature in the acceptable operative temperature ranges for naturally conditioned spaces (from the first restaurant).

The conditions in the second restaurant are within the comfort band of acceptability (the grey area shown in Figure 5) since conditions were less extreme than those in the first restaurant. The mean $T_{comfort}$ from the effect of ventilation and adjusted humidity was calculated as 33.5°C, and it is in the comfort band of acceptability (see the blue dots in Figure 5). Eq. 7 shows the calculated $T_{comfort}$ for customers using the humidity adjustment technique in the second restaurant, with p = 0.00 and R^2 = 0.04. It should be noted that some conditions with increased humidity are above the comfort band of acceptability since ventilation and humidity levels fluctuated during the actual measurements.

By using the CBE thermal comfort tool [18], the SET in the first restaurant was reduced to 33°C and the thermal comfort status became 'warm', compared with the pre-intervention condition in the restaurant, classed as 'hot' with SET reaching 35°C (see Figure 6). The second restaurant was measured under less extreme conditions; the SET was observed to decrease to 26.9°C from 32.5°C. Even though the average relative humidity in the second restaurant increased by only 2%, the thermal comfort sensation was found to have significantly improved from 'hot' to 'slightly warm' (Figure 7). (Note: 32.5°C with high RH in Figure 7 denotes as hot while 33.4°C with low RH denotes as warm sensation).

Improvement in comfort in middle row houses by using extra fans and water-misting fans can be interpreted as follows. First, the high MRT does not influence the indoor environment. Second, the use of evaporative fans does not greatly increase the humidity (which increased only from 46% to 60%) since the air speed was limited to 1.5 m s^{-1}.

$$T_{comfort(evap)} = 0.2538T_{out} + 25.03 \quad \text{(Eq. 7)}$$

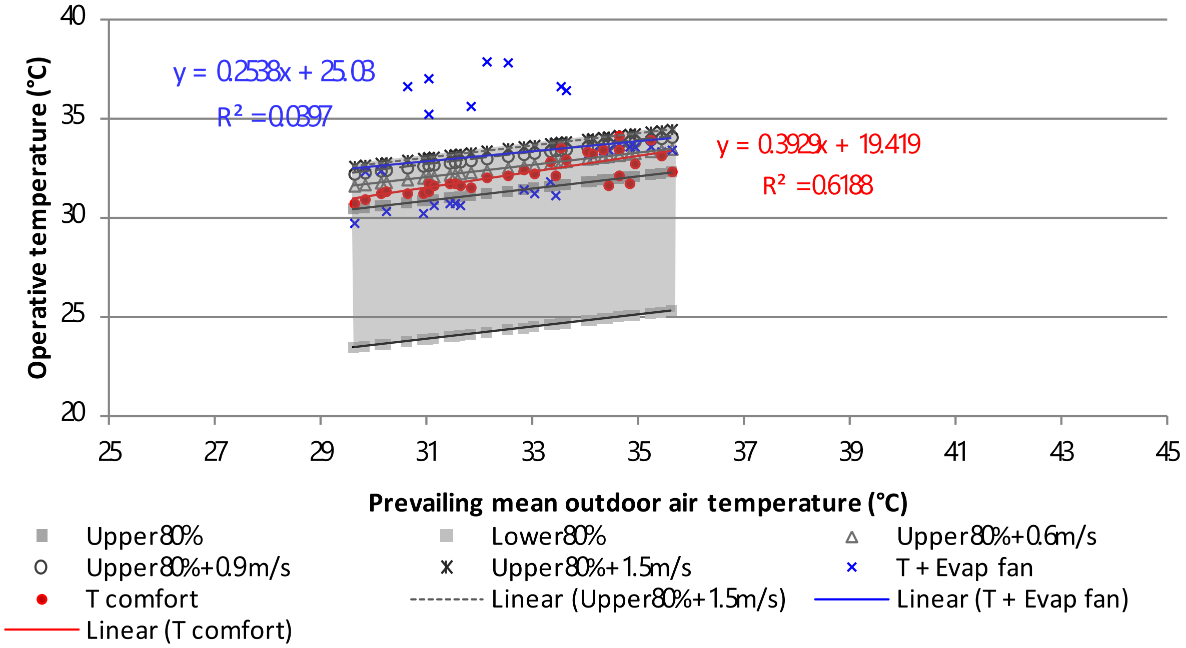

Figure 5 Comfortable temperature in the acceptable operative temperature ranges for naturally conditioned spaces (from the second restaurant).

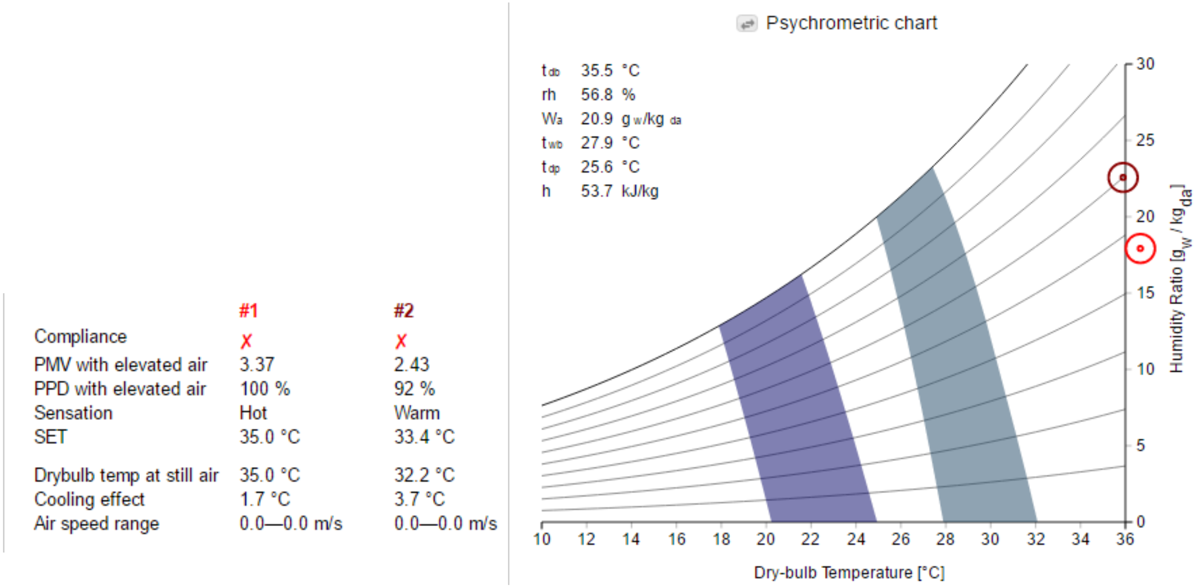

Figure 6 Comparison of conditions in the first restaurant: initial measurement (purple) and increased ventilation with the adjusted humidity techniques (grey).

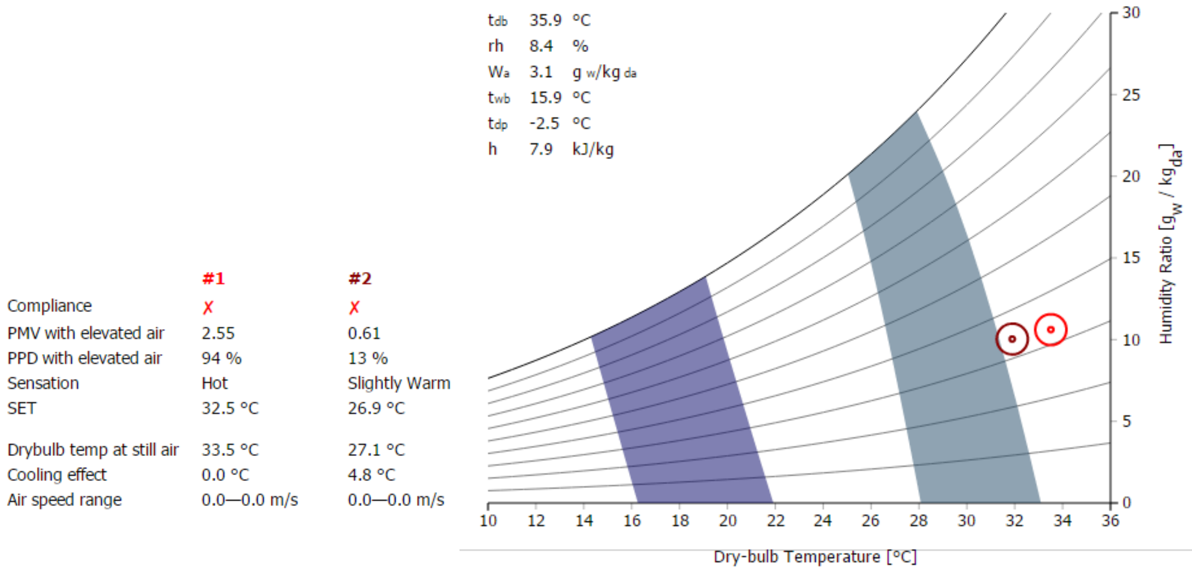

Figure 7 Comparison of conditions in the second restaurant: initial measurement (purple) and increased ventilation with the adjusted humidity techniques (grey).

3) Comparison of conditions before and after intervention

After intervention, the thermal comfort indicators measured in the two restaurants show that the combined techniques could improve comfort conditions. Upon using the increased ventilation technique in the first restaurant, the 37.43°C $T_{comfort}$ and the 35.80°C SET improved to 36.90°C and 33.40°C, respectively. Both the $T_{comfort}$ and the SET registered decreased in the range of 0.5-2.4°C compared to conditions before intervention. Using increased ventilation with the adjusted humidity technique could improve the case study condition to 35.90°C $T_{comfort}$ and 33.4°C SET. These results are equivalent to a 1.5°C $T_{comfort}$ reduction and a 2.4°C SET reduction. Even though the average temperature did not improve significantly, the comfort status was improved, from 'hot' to 'warm' and from 'too warm' to comfortably warm', according to the thermal comfort vote results (Table 2).

In the second restaurant, the thermal comfort indicators also showed improvements in comfort conditions. The increased ventilation technique could improve the physical environment by 0.1°C and 0.8 m s^{-1}. Thermal comfort conditions also improved: $T_{comfort}$ improved from 32.87°C to 32.05°C and SET improved from 28.2°C to 27.4°C. The increased ventilation with the adjusted humidity improved conditions to 34.74°C $T_{comfort}$ and 26.1°C SET, equivalent to the 1.87°C elevated $T_{comfort}$ and the 1.3°C SET improvement. Although the air temperature had a 0.11°C change with the first technique and a 1.5°C change in the second technique, the thermal perception was significantly better in that it changed from 'hot' to 'neutral' and from 'too warm' to 'comfortable', according to the thermal comfort vote results.

Table 2 Comfort conditions before and after intervention

Condition	Temperature (°C)	Comfort temperature (°C)	SET (°C)	Sensation	Thermal sensation vote	Thermal comfort vote
First restaurant						
Before intervention	36.67	37.43	35.8	Hot	Hot	Too warm
Increased ventilation	35.90	36.90	33.4	Warm	Hot	Too warm
Increased ventilation with adjusted humidity	34.80	35.90*	33.4	Warm	Hot	Comfortably warm
Second restaurant						
Before intervention	33.51	32.87	28.2	Slightly warm	Hot	Too warm
Increased ventilation	33.40	32.05	27.4	Slightly warm	Slightly warm	Comfortably warm
Increased ventilation with adjusted humidity	31.90	34.74*	26.9	Slightly warm	Neutral	Comfortable

* Comfort temperature is a temperature that people can feel comfortable with. It can be elevated at high temperature with other cooling techniques without decreasing temperature.

4) Implication of increased ventilation with adjusted humidity

Increased ventilation with adjusted humidity technique can improve thermal comfort condition in restaurants when air temperature and humidity levels are not excessive. Even though both cases showed improvements in comfort conditions according to the thermal comfort vote results, the SET in first restaurant did not improve sufficiently when the adjusted humidity technique was applied. Theoretically, an increase in humidity is effective when air temperature is less than 25°C and relative humidity is less than 50% [28]. For example, indirect evaporation techniques used to improve thermal comfort conditions were applied in soil-concrete construction in a desert [29]. Thermal comfort conditions could be improved by 1-2°C SET using this technique. The conditions in the second case is a good example since the results of both the thermal sensation vote and the thermal comfort vote showed improved responses, from 'hot' to 'neutral' and from 'too warm' to 'comfortable', respectively. The relative humidity in the second restaurant was 35%, considered as a 'dry' condition. This allows evaporative cooling to work effectively.

However, this study could not define the range of conditions under which increased ventilation combined with the adjusted humidity technique would work effectively since the measurement and the analysis conducted were based on comparison between two cases. Also, humidity negatively affects the comfort condition when skin wetness appears [30]. Nevertheless, the question remains as to what extent the increase in humidity will help improve thermal comfort for local people who are accustomed to a hot–humid climate. Future research should test the performance of these techniques to define the range of effective comfort conditions.

Conclusion

Restaurants in re-purposed row houses have only a few options to improve their thermal conditions since improvement is limited by restrictions in rental contract and limited budget. Of the five techniques available, the top three affordable techniques selected to improve conditions in the simulation include an extra fan, a water-misting fan and an overhang. The main concern of restaurant owners in regard to these choices was the investment cost and the efficiency of the techniques. The 36°C average temperature and 46% average relative humidity recorded during the survey was taken as the baseline condition for simulated models and analysis. The increase in air speed provides a 1°C reduction in the average temperature, while improvement in air speed combined with the evaporative fans results in an average temperature reduction of 2°C, equivalent to a 2°C expansion in the adaptive thermal comfort band. Even though the physical environment did not significantly improve and the thermal comfort condition was still not achievable in this study due to limited budget for investment, the thermal comfort vote was improved, improving from 'too warm' to 'comfortably warm' and becoming 'comfortable' in the first and the second restaurant, respectively. The 35.9°C average comfort temperature calculated by the adaptive thermal comfort equation is the result of all the techniques combined. The combination provided only 1°C average temperature above the upper limit of the adaptive thermal comfort band of acceptability. To improve thermal comfort for restaurant customers, this research recommended that owners should combine all three techniques. While on very humid days, the adjusted humidity by a mist fan might be ineffective, otherwise, all techniques could help improve customer comfort with low investment. The study had several limitations, including the limited periods permitted by owners to conduct measurements. Consequently, the first measurement was conducted in May 2015, while the second measurement was conducted in April 2017. Secondly, the investment feasibility analysis of ventilation improvement techniques was outside the scope of the study. The owners were told only about the cost of each technique and asked about their preferred options. Subsequent research should focus on both investment and the efficiency of cooling techniques.

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