Improving thermal comfort in the urban landscape of housing communities in tropical climate: A case study of Bang Chalong Community, Thailand

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Abstract

In developing countries, low-income housings seem to sacrifice quality over quantity. For a tropical country such as Thailand, where the temperature remains consistently high throughout the year, thermal comfort impacts living quality, especially in urban areas. Bang Chalong Community is a cluster of densely arranged mid-rise apartments in Samut Prakan, the peri-urban area of Bangkok, chosen by the NHA (National Housing Authority) to improve its living quality as a pilot project. While current literature investigates and explores solutions to mitigate thermal comfort in buildings, few studies focus on outdoor areas adjacent to buildings. This research aims to assess the outdoor hot-spot of the community, proposes appropriate attributes and design approaches to improve urban landscape elements leading to comfortable conditions, and recommends landscape design strategies for similar future development.

The thermal condition was conducted using the Wet Bulb Globe Temperature (WBGT) data logger on 25 locations. The ambient temperature (TG) was used as the indicator for thermal comfort. It is found that critical attributes affecting the thermal condition are 1) the type of surfaces – hardscape or soft scape, and 2) the amount of surface and time exposed to solar energy – shade or sunlight. The thermal comfort improvement, including potential uses by landscape design, was proposed under four strategies; shading, added green, orientation & ventilation, and functional refinement. They are recommended to create suitable thermal comfort by landscape design for future development of a similar type.

Keywords: low-income housing, urban landscape, thermal comfort, **tropical climate**

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Introduction

Housing is fundamental to people's needs and well-being, physically and mentally. Housing quality is associated with income and affordability (Baqutaya et al., 2016). Thailand's National Housing Authority (NHA), responsible for providing residential for the low-income population, has developed over 740,000 dwelling units over 49 years of its history (Ritthimat, 2022). Typical of low-income housing in developing countries such as Thailand, these residential developments were built by prioritizing cost and quantity over quality and comfort (Bhikhoo et al., 2017; Fuller et al., 1993; Sultan Sidi, 2010). What has been observed is the generalized planning and design as "cookie-cutter" for cluster arrangement, architectural design, minimal consideration toward surrounding context, either land uses or existing landscape, and very little attention to the outdoor living condition.

Although several studies in developing cities focus on housing quality factors covering several aspects, such as design elements, architecture, site planning, construction, maintenance, services, and others (Chohan et al., 2015; Sadrian et al., 2015), there is still a lack of focus on landscape and the outdoor environment. In a tropical country like Thailand, the hot-humid climate experienced throughout the year impacts living conditions, especially the thermal comfort for dwellers (Bhikhoo et al., 2017). Due to the city's expansion from the past to the present, the Urban Heat Island phenomenon happens at the city and district-scale where land use and land cover (LULC) and local climate zone (LCZ) change and the temperature differences between built-up and others are rising (Khamchiangta & Dhakal, 2021). Researchers and people are well aware of the effect at the neighborhood scale. They could be motivated to change their behavior and attitude toward traveling patterns and daily activity to mitigate the problem (Iamtrakul et al., 2014). Current literature investigated the thermal comfort improvement and energy saving for indoors and buildings of various functions (Bhikhoo et al., 2017; Chindapol, 2019; Panraluk & Sreshthaputra, 2020). However, few articles studied outdoor thermal improvement in the urban landscape (Janpathompong & Murakami, 2021; Srivanit & Jareemit, 2020). While most literature that shares similar interests assessed or evaluated various outdoor devices or features that could ease the thermal comfort problem (Jareemit & Srivanit, 2022; Rinchumphu et al., 2021), this study offers design strategies to minimize the impact of thermal conditions.

The NHA has continuously developed various housing types across the country. Bang Chalong Community Housing is a mid-rise, medium-density apartment cluster suitable for urban areas. It consists of 92 residential buildings, a 5-story condominium, in approximately 100 rai (the study area community No. 1 consists of 16 residential buildings in approximately 14 rai) (Figure 1). By nature of this type of development, most of the construction materials are permanent hardscapes such as concrete or asphalt, with minimal green spaces due to the tight arrangement of the master plan. Buildings gathered densely, such as the Bang Chalong community, cause a phenomenon of the Urban Heat Island Effect, which raises the air temperature to higher than usual. This community was chosen as a pilot project by the NHA under their strategic direction, SSC: Smart Sustainable Community 2564 (2021) Initiative, to improve its existing development toward sustainability. The study of opportunities, limitations, and improvement is one of NHA's key policies to elevate the community as a model for sustainable development.

Therefore, this research aims to 1) identify physical attributes that cause the outdoor thermal problems in Bang Chalong community No. 1, 2) indicate areas with high potential for landscape restoration or improvement for functional, aesthetic, and environmentally friendly purposes, and 3) propose mitigation strategies using landscape elements that are effective for creating comfortable conditions and developing green areas for sustainable living as a model for other projects of the NHA.

The contribution of this study focuses on practical aspects of conceptual landscape design and site planning (for the newly planned project) and landscape mitigation techniques (for existing projects). Usually ignored or overlooked by site planners and policymakers, these concepts should be considered to create comfortable living conditions, especially the thermal problem in tropical countries. It emphasizes how to minimize the impact using the current knowledge, according to the NHA's strategic direction, SCC, rather than assessing the thermal condition itself, which is a known fact.

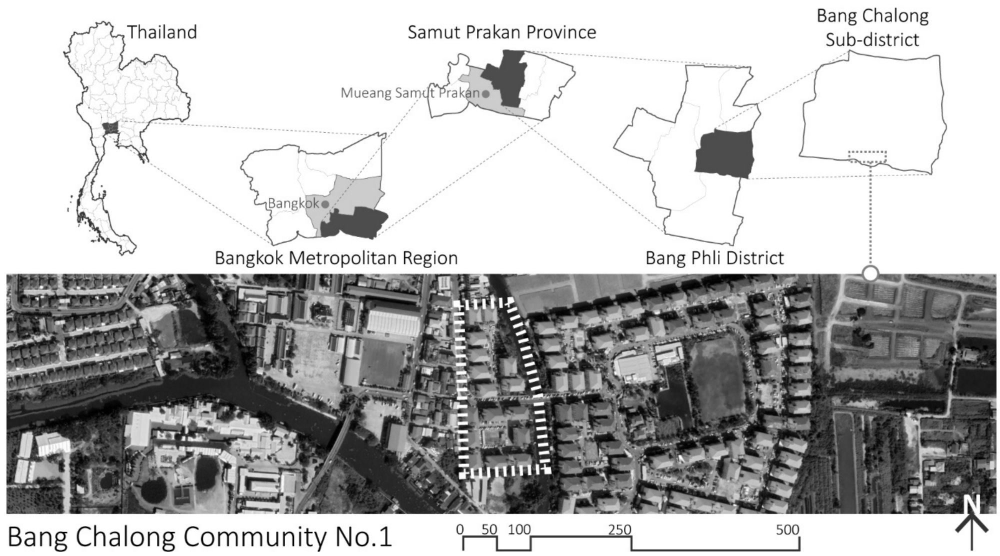


Figure 1 Bang Chalong Community Housing Area Layout (Community No. 1, dashed box)

Note: An image adapted from Google Earth Pro, 2020.

Literature review

Microclimate concepts

The urban heat island phenomenon occurs due to increased temperature and heat radiation. The built environment absorbs solar energy and gradually radiates heat to the surroundings. The heat is also caused by construction, human activities, or the radiation properties of the city's infrastructure, such as buildings, roads, and many others. The properties of building materials in the city include the reflection of sunlight exothermic and heat capacity (United States Environmental Protection Agency [US EPA], 2008). There are two types of urban heat island phenomena; 1- Surface urban heated islands: As the surface material absorbs thermal energy, the surface heats up and radiates back to the surrounding area; and 2- Atmospheric urban heated islands: It is the warmer climate of the urban regions compared to the cooler air in the surrounding countryside (US EPA, 2008). Urban heat islands are less effective from morning until the day and have a more substantial effect after the sun goes down due to heat released from buildings and infrastructure within the city. The elevation of Urban heat islands can be divided into two different levels (US EPA, 2008); 1) the Urban Canopy-Layer (UCL) are layers of the atmosphere that start from the layers inhabited by people, from the ground to the deck and treetop level, and 2) the Urban Boundary-Layer (UBL) ranges from the rooftop and the top tree level and generally does not exceed 1 mile (1.6 km) (Figure 2).

Bang Chalong community is a low mid-rise medium density; therefore, its microclimate is governed by the urban canopy-layer (UCL). The community is located on the fringe of Bangkok, where the urban heat island has been increasing its intensity to a maximum of about 6-7 °C in the dry season. Weather conditions with land cover control the urban canopy-layer heat (Arifwidodo & Tanaka, 2015).

The relationship between surface temperature and air temperature

Typically, the surface temperature changes more than the air temperature during the day, and the differences are varied. Developed urban areas generally comprise approximately 75%-100% of hardscape areas where the evaporation rate is high due to less surface moisture.

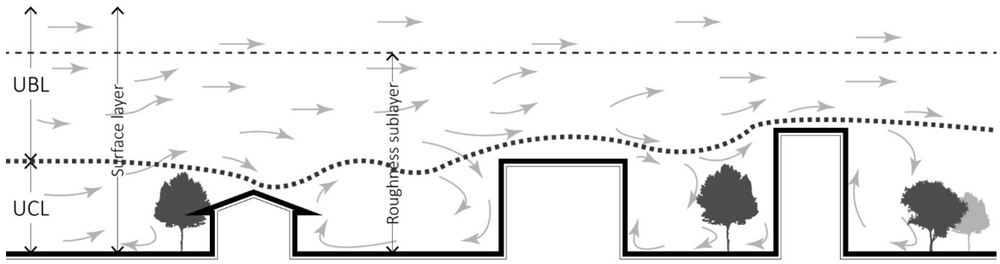


Figure 2
The Structure of the Urban Boundary-layer of the City

Note: The image shows the structure of the Urban Boundary-layer of the city caused by the uneven creation of buildings at the canopy level, allowing for better ventilation for urban areas (UBL = Urban Boundary Layer and UCL = Urban Canopy Layer).

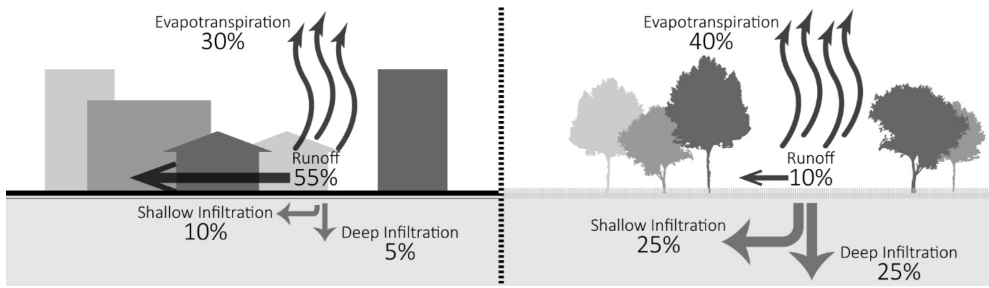


Figure 3
Highly developed urban area (left) and green area (right)

However, the softscape areas remain damp, and the evaporation rate is low, resulting in lower surface and air temperature (US EPA, 2008) (Figure 3).

Urban geometry and orientation

Urban geometry refers to the dimensions and space between buildings, including their spatial configuration within a city. When the sunlight hits the surface of gaps between buildings, solar energy is reflected and absorbed by the building's walls and road surfaces, making the areas warmer. The orientation of building blocks and street directions, related to north-south and east-west, allows or limits ventilation and shade. Researchers explained that urban climate is affected by weather and the built environment in the city (Eliasson, 2000; Landsberg, 1981). The urban areas significantly alter the surrounding meteorological conditions, increase heat dissipation, raise the average temperature, reduce wind speed due to buildings, and lower relative humidity. These effects impact urban areas and their environment (Landsberg, 1981).

Many studies have pointed out that thermal comfort has become essential for livable urban spaces. Therefore, in hot and humid countries where outdoor spaces are used all year round, It is necessary to establish an appropriate comfort level (Koerniawan & Gao, 2015). According to Koerniawan and Gao (2015), home comfort can be improved through natural reflections of urban design. However, the improvement is difficult to achieve in the case of open spaces between many buildings at the superblock level. By measuring the heat absorption and reflection of the surface (Albedo), construction surfaces made of hard materials such as concrete, asphalt, or other conventional materials absorb and radiate more heat back to the surroundings than natural areas. Therefore, shady spots are essential for urban spaces such as open-air plazas, pedestrians, and other public places to create comfortable conditions facilitated by improving the microclimate (Akbari et al., 2001; Akbari et al., 2009).
In general, thermal comfort improvement can be achieved using landscape and green features, influencing the temperature in

the urban canopy-layer (Koerniawan & Gao, 2015). Densely vegetated large tree areas reduce mental stress caused by overheating. Planting trees at various heights generates more airflow and creates comfortable conditions (Koerniawan & Gao, 2015). In the tropical zone, air temperature between 23.3 °C – 29.4 °C is the comfortable range (Olgyay, 1962). Nevertheless, thermal comfort depends on air temperature, relative humidity, airspeed, radiant temperature, activity level affecting metabolic rate, and clothing insulation (Srivanit & Auttarat, 2015). For a tropic city, consistent or occasional wind can produce a comfortable condition at temperatures below 34°C. If there is no wind but 70% humidity, the comfortable air temperature varies between 28.5 °C - 32.8 °C, and the radiant temperature between 28.71 °C - 32.57 °C (Ahmed, 2003). However, from numerous studies, it is not yet possible to provide a precise and standardized limit of the humidity range because the environment of each region is different. The thermal comfort survey is an assessment of a person's sense of individuality and character (subjective) (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], 1997).

Ahmed's research (2003) concluded that one of the critical factors in creating comfortable conditions in urban areas is shade. Shading is of utmost necessity and beneficial, especially between 12.00-15.00. For complete coverage, it is best to shade from 10:30 to 15:30. The top priority is arranging and designing urban blocks where shade can be maximized. From observation, users are always gathered in a shaded area. Therefore, the landscape elements in public places (street furniture) under shade, such as chairs, pavilions, covered walkways, or large trees that provide continuous shading, are considered a high priority in urban outdoor areas of the tropical zone.

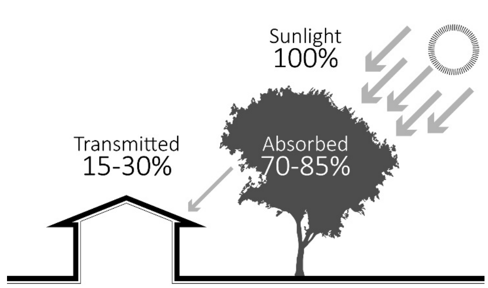


Figure 4
A large tree absorbs heat and transmits only a small amount to ground level

Thammapornpilas (2015) proposed a solution to the heat island phenomenon in urban areas as the followings. 1) Adding plants and trees in urban areas (Figure 4) – at night, in areas with dense trees, the temperature drops sharply; during the day, it provides shade to the area; the shade caused by buildings or trees is no different. However, trees do not reflect the heat radiation in the area; trees help control the wind direction in urban areas. 2) Increasing the ability to reflect heat away from the area – appropriate construction materials help reflect heat away from the building but cannot fully help fix the problem. 3) Changes in the physical characteristics of urban areas – to control the opening and closing of the soil surface; to control the volume of the building mass and urban geometry; to control the orientation, size, and direction of the road.

Many indices assess thermal comfort, such as SET*, PET, UTCI, etc. According to Rinchumphu et al. (2021), the PET is suitable for outdoor thermal comfort assessment. In Malaysia, which has a hot and humid nature similar to Thailand, acceptable thermal comfort is below 34°C PET (Makaremi et al., 2012). The PET depends on six variables: air temperature or dry bulb temperature (TA), relative humidity (RH), airspeed (V), black globe radiant temperature (TG), activity level affecting the rate of energy metabolism, and the degree of clothing insulation (Srivanit & Auttarat, 2015). However, the activity level and the degree of clothing insulation are beyond the scope and duration of this study. In addition, due to limited resources, only the WGBT data logger was available for equipment. As a result, the airspeed or airflow was not measured. In fact, from the survey by the research team, there was a very low airspeed (V) and could not be felt.

Therefore, the values from the field survey used in this study were the TA, TG, and RH% measured by the WGBT data loggers. All the collected data are consistent with a study in Kuala Lumpur, Malaysia, by Abu Bakar and Gadi (2016). It suggests that a comfortable thermal comfort should be at a minimum of 27.5°C and a maximum of 33.7°C of TA and RH% in the range of minimum 50.7% to maximum 85% under wind speed of not less than 0.1 m/s for tropical outdoor areas. Based on the above studies, the research team evaluated the thermal comfort using the TA of 34°C as the highest acceptable temperature with 50-85% of RH% and coupled with the TG at the exact value of 34°C. This evaluation value is consistent with research by Ahmed (2003) stated that the TA should be below 34 °C with constant or occasional wind speeds for acceptable thermal comfort. The TG is always higher than the TA, as observed from the site survey.

Methodology

Research framework

1. Study the current physical characteristics of Bang Chalong Community Housing No. 1 to identify opportunities and constraints of the current usage and environmental needs, divided into 1) natural factors such as the size of the area, the direction of sunlight, water resources, green areas, and 2) man-made factors such as buildings, traffic routes, and land use.

2. Study the residents' outdoor space and landscape needs through surveys and observations.

3. Analyze the effectiveness of landscape elements within the project area, the impact of current land use, the thermal comfort, and opportunities and limitations from 1 and 2

4. Propose design ideas to improve the thermal comfort using landscape elements that meet the functional needs and provide effectiveness for the conservation and development of green areas that allow good living conditions.

Data collection, survey, and analysis

The initial survey found that the physical environment outside the buildings is still cluttered and disordered. Although the general use of outdoor spaces is to serve daily needs, some utilizations increase beyond the planned capacity or even unplanned. For example, parking spaces are insufficient; sidewalks have been used for street vendors that have recently increased, and several others. In addition, the Covid-19 epidemic has caused residents to lose their jobs and spend more time in the community, resulting in the use of outside spaces for various activities. However, the area can still be improved in responding to changing needs, which is one way to adjust to a better community environment.

1) This research uses site reconnaissance, surveys, and the project plan. Physical characteristics, including the location of buildings, flats, shops, abandoned areas, roads, utilities, sports, and social activities areas, and the nature of the current use of space, were recorded by on-site exploration with the community leaders.

2) Obtain the project area layout plan (Auto CAD) to create a base map for surveying.

3) Thermal comfort measurement tool; WBGT Data Logger AD-5695DL Heatstroke index monitors with data logging function ISO7243/JIS Z 8504 standard (Figure 5).

Figure 5
WBGT Data Logger AD-5695DL and the setting

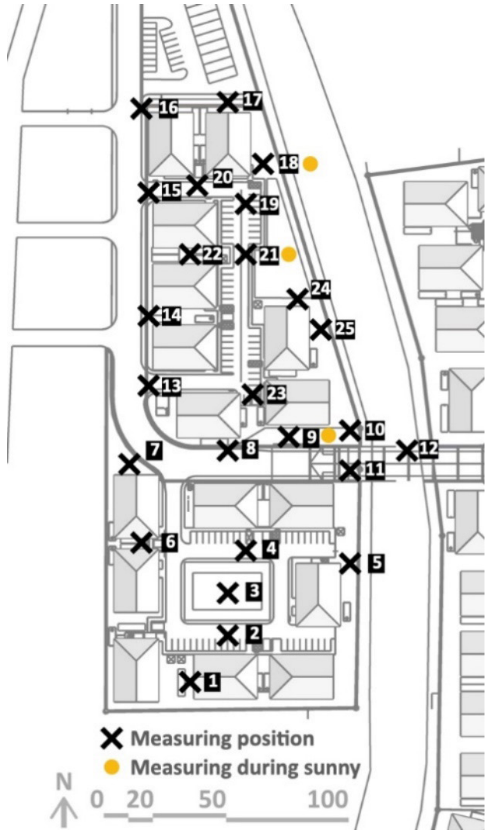


Figure 6 The map indicates the 25 thermal comfort measurement positions using the WBGT Data Logger

4) Develop a plan to determine the measuring positions, considering the primary traffic of footpaths and roads, spaces between buildings, waterfront areas, under-utilized areas, and other physical features (Figure 6). The measurement will be checked at 3-time intervals; morning 9:00-10:00, midday 12:00-13:00, and afternoon 14:00-16:00, to compare the current states of thermal comfort during the day. A GPS tracker application for cell phones pinpointed the exact locations to measure.

5) Create a 3D digital model with Sketch Up Pro to analyze the sunlight and shading pattern in different seasons of the locations (Figure 7).

6) Data of the highest and lowest temperature, from each day and each position, was extracted and mapped on the site plan to indicate their distribution (Figure 10).

7) The amount of built environment affecting the thermal comfort of these positions was quantified by expert assessment from site observation under four attributes: softscape (green area), hardscape (built structure), shading, and solar exposed area. The amount of surface areas of each position was estimated in percentage of 100%, 75%, 50%, 25%, and 0% with the score of 4, 3, 2, 1, and 0 representing, 4 points = most suitable, 3 points = suitable, 2 points = moderate, 1 point = less suitable, and 0 point = unsuitable respectively.

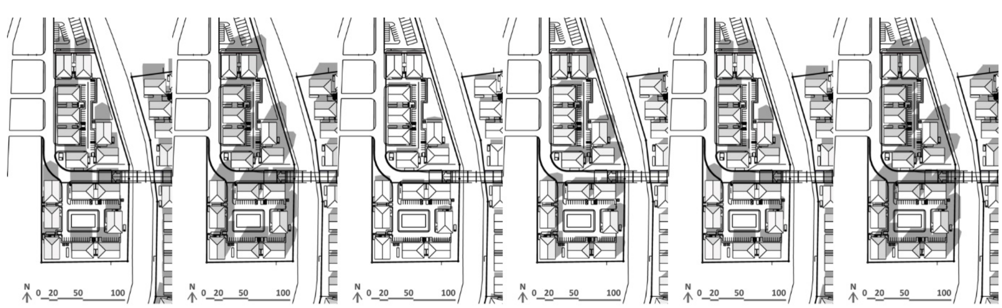


Figure 7 The Shade Pattern from the Buildings in February, May, and October

Note: An analysis by the 3D model to show the shade pattern from the buildings in February, May, and October at 12.00 and 14.00 (preliminary simulated version before the actual site survey).

Microclimate measurement

Temperature measurement locations were identified where differences in physical composition are presented, for example, hardscape, softscape, gaps betweenbuildings, and open spaces. These positions were chosen based on the base plan, 3D model, and site reconnaissance. Spacing between these locations is consistent in measuring the differences at the microscopic level affected by various environmental elements. A total of 25 positions were established across Community No. 1. The instrument, the WGBT data logger, is set up by a tripod, and all data are measured within 2 minutes on each position, then proceed to the next until all 25 positions are measured. Total measuring time was limited to 2 hours maximum for each working period; morning, noon-afternoon, and afternoon-evening. All measuring positions are recorded with the GPS Tracker application; therefore, the data were collected at the same points every day throughout the survey period (November 2020 – March 2021).

Analysis and results

Initial analysis of the site plan

The project site plan (ACAD) was used as the base for 3D digital modeling to study the community's sun exposure and shading pattern in critical seasons and times. The results show that the entry road, which lies in the north-south direction, receives full sunlight from 10:00 to 14:00. All areas and pavement materials are constructed of concrete and concrete blocks that absorb and retain heat. This large area absorbs solar energy and becomes the radiating source that significantly impacts the thermal comfort of the surrounding buildings. In addition, local winds from southwest to northeast also carry the heat into the northeastern buildings, increasing their temperature (Figures 6 &7).

As for the group of buildings on the south side, the concrete multipurpose sports court at the south building cluster is surrounded by residential buildings and concrete driveways with parking spaces (Figure 8 – right). They become the heat source affecting all surroundings, similarly to the northeastern buildings. Although the south and west buildings partially offer shade for the streets and parking, they provide a limited effect only after 14.00. When approximately 10:00 to 13:00, roads and parking still receive full sunlight in winter. The concrete multipurpose sports court receives full sunlight from 10:00 to 14:00 (Figures 6 & 7).

Microclimate

According to the average 30-year data by the Meteorological Department, weather in Thailand, the highest temperature was 34.5°C in April, the lowest temperature was 22.0°C in December, and the highest volume of rainfall was 334.3 mm in September. In Bang Chalong, the year-round average high temperature is 32.75°C, the average daytime high and low are 35°C and 30°C, and the average nighttime high and low temperature is 26°C and 18°C (Figure 9).

Site temperature references

Three site surveys were conducted in November 2020, February 2021, and March 2021. Monthly and daily temperatures were referenced in Bang Chalong Subdistrict, Bang Phli District, Samut Prakan Province by the Meteorological Department. In November, the mean daily maximum and minimum were 31.5°C and 24.77°C. The highest and lowest temperature was 35°C and 21°C. In February, the mean daily maximum and minimum were 33.07°C and 23.71°C. The highest and lowest temperature was 36°C and 21°C. In March, the mean daily maximum and minimum temperatures were 34.16°C and 26.74°C. The highest and lowest temperature was 36°C and 24°C. The daily temperature during the dates of the site survey was as follows; the first on November 20, 2020, all day average temperature was 35.5°C during the day and 26.1°C at night; the second on March 27th, 2021, the all-day average temperature was 36°C during the day and 24°C at night; the third on April 6th, 2021, all day temperature. It is 35°C during the day and 26°C at night.

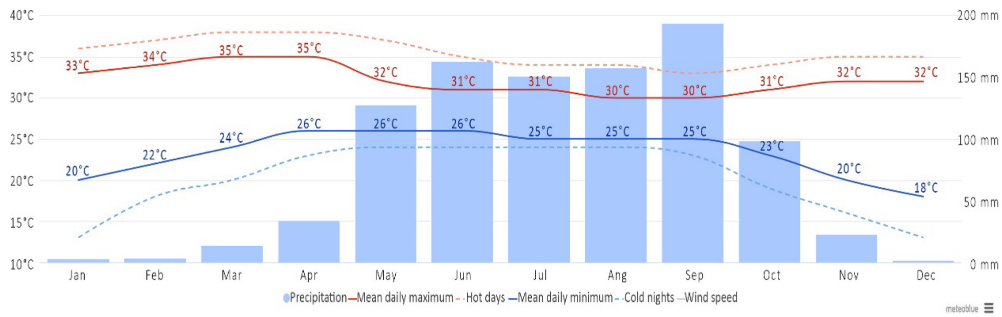
Results from the site survey

Three survey periods during the day were selected based on the most solar exposed timing and residents' usual activities in the morning, approximately 10.00-12.00, noon from 14.00-15.00, and afternoon from 15.30-16.30. From all 25 positions, the lowest and highest temperatures indicated during three time periods, including air temperature (TA) and radiant temperature (TG), were shown in Table 1. These results fell within the same range of data from the Meteorological Department, where the highest average temperature was 35°C on November 20, 2020, 36°C on February 27, 2021, and 35 °C on March 6, 2021.

Figure 8 Street & sidewalk at the Bang Nam Chuet bridge (left), sidewalks and landscape at Bang Nam Chuet bridge's foot (middle), The concrete multipurpose sports court at the south cluster is surrounded by residential buildings, concrete driveways, and parking spaces with a minimal number of trees (right)

Note: Left images: google street view; retrieved March 2021, middle and right images: authors.

Figure 9 Weather chart of Bang Chalong; average temperature and precipitation



Note: From Simulated historical climate & weather data for Ban Khlong Bang Chalong, by Meteoblue, https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/ban-khlong-bang-chalong_thailand_7099827

Table 1 The daily site survey results of the highest and lowest temperatures compared to the temperature data of Bag Chalong from the Meteorological Department on the three site surveys, November 20, 2020, during 10.00-11.00, February 27, 2021, during 11.19-12.18, 13.21-14.14, and 15.29-16.29, and March 6, 2021, during 10.28-11.28, 14.08-15.04, and 15.28-16.26

Date		Daily Forecast by TMD* (°C)															
November 20, 2020			10:00-11:00														
			Time	WBGT	TA (°C)	TG (°C)	RH (%)										
	Highest	35	11:15	30.1	32.9	37.4	66.5										
	Lowest	26	11:35	29.1	32.1	33.1	71.0										
February 27, 2021			11:19-12:18					13:21-14:14					15:29-16:29				
			Time	WBGT	TA (°C)	TG (°C)	RH (%)	Time	WBGT	TA (°C)	TG (°C)	RH (%)	Time	WBGT	TA (°C)	TG (°C)	RH (%)
	Highest	36	12:11	30.3	33.8	42.0	57.0	14:01	30.8	35.0	45.6	49.0	15:52	28.6	37.0	46.7	27.3
	Lowest	24	11:46	29.8	30.3	43.8	61.7	13:35	27.5	31.5	36.5	56.2	15:29	25.4	33.0	35.0	36.5
March 6, 2021			10:28-11:28					14:08-15:04					15:28:16:26				
			Time	WBGT	TA (°C)	TG (°C)	RH (%)	Time	WBGT	TA (°C)	TG (°C)	RH (%)	Time	WBGT	TA (°C)	TG (°C)	RH (%)
	Highest	35	10:42	31.8	34.6	44.2	60.7	14:42	31.4	36.4	46.3	46.2	15:49	30.5	35.2	44.3	47.8
	Lowest	26	11:02	27.2	30.7	32.8	64.0	14:08	31.2	33.2	45.3	61.4	16:25	28.2	31.6	37.3	59.4

*Thai Meteorological Department

Note: The survey results on November 20, 2020, were conducted only in the morning, 10.00-11.00. The afternoon operation was not possible due to the restriction of the Covid-19 protocol posted on the community and transportation restrictions. From Bang Phli, Samut Pra kan, Thailand Weather Calendar, by Weather Underground, 2020, 2021a, 2021b. (https://www.wunderground.com/calendar/th/bang-phli/VTBS/date/2020-11, https://www.wunderground.com/calendar/th/bang-phli/VTBS/date/2021-2, https://www.wunderground.com/calendar/th/bang-phli/VTBS/date/2021-3). Copyright 2014, 2022 by TWC Product and Technology LLC.

Results from Table 1, in combination with the site observation, found that the positions with the highest TA are exposed to solar energy almost all day, especially in the afternoon (Figure 10). There were some shading areas from trees or buildings, and those areas have a very low percentage of green or no green space. Most pavement and wall materials are concrete or hard materials such as concrete blocks, tiles, and similar products. These results show that they are good thermal conductors, low surface heat reflection (Albedo), and slow release of thermal energy. The radiated heat caused those areas and their surroundings to reach high temperatures most of the time.

On the other hand, the areas with the lowest TA are the shaded areas from the buildings or large trees during the survey. Some of which are outdoor areas or areas around buildings. In addition to having shadows of buildings or tree coverage, these areas consist of green patches with large trees, grass, or shrubs that residents have planted in containers. They also have a low proportion of concrete or good thermal conducting materials. These combinations make these areas comfortable to sit and cool at various times of the day. Furthermore, higher humidity positions next to the water (the canal) have low temperatures.

Evaluation

From the total of 25 measuring positions, 11 positions were selected for evaluation, no. 1, 7, 9, 12, 14, 15, 19, 21, 22, 23, and 24 (Figure 6 & 11), based on the highest and lowest temperature measured during the three days of the site survey (Figure 10 & 11). They were evaluated for their built environment attributes affecting the thermal comfort by expert assessment from site observation under four attributes: softscape (green area), hardscape (built structure), shading, and solar exposed area (Table 2 & 3). The amount of surface areas from these 4 attributes in each position was estimated in percentage of 100%, 75%, 50%, 25%, and 0% with the score of 4, 3, 2, 1, and 0 representing, 4 points = most suitable, 3 points = suitable, 2 points = moderate, 1 point = less suitable, and 0 point = unsuitable respectively. Eight of eleven positions, 7, 9, 14, 15, 19, 21, 22, and 23 (Figure 11), were chosen for design mitigation. Positions No. 9 and 21 were also chosen to implement the design idea of functional uses needed by the community (Figure 11). An additional design area to improve thermal comfort and not listed in all positions is the multipurpose sports court in the south cluster of the community (Figures 8 - right).

Discussion and recommendation

Discussion

Air temperature (TA) data, comparing the highest and lowest temperatures for each visiting period (Table 1), showed that the highest TA was around 37°C in the afternoon. It is higher than the highest temperature, which ranged about 35°C -36°C, from the weather data in Bang Chalong Subdistrict by the Meteorological Department. This phenomenon clearly shows that the original design of the physical environment and the planning of this housing project do not support low air temperature. It can be seen that most built materials are good thermal conductors absorbing and storing heat. It was constructed with hardscape throughout. The project's green area is minimal due to its higher density. Each of them is too small. The lack of shade from both the building and the small number of large trees could not provide enough shading areas appropriate to the size of the project. All these factors affect the project causing the urban heat island phenomenon. Therefore, the general temperature is higher than average in almost all areas throughout the day.

In addition, the radiant temperature (TG) (Table 1) indicates that the radiation generated by the surrounding environment, such as vehicles, concrete floors, and concrete walls, will release or retain and gradually radiate the heat back to the area. These phenomena severely and negatively affect thermal comfort, as seen from the temperature comparison table between the TA and TG (Table 1). They show that the maximum TG reached as high as 46.9 °C. Therefore, the TG is a crucial consideration in addition to TA because the TG is one of the main parameters affecting thermal comfort. In some areas, even with a lower TA, there was a high TG due to accumulated heat, making it less comfortable.

It can be concluded that the comfortable condition consists of several factors promoted by all physical components of the environment. Prolonged exposure to sunlight, surrounded by the built environment with a high proportion of hardscape, cause high temperatures in the range of 34°C -37°C. Compared to the lower temperature areas, it is found that those areas are surrounded by green or covered by shades. Creating or providing shade is vital in facilitating a comfortable environment, especially in areas with regular uses with the hardscape and walls of buildings on the south and west sides. The humidity from the waterfront also plays a vital role in reducing

Figure 10 The map indicates the distribution of the highest-lowest temperature positions from the three days and three-time period

Date	Period		Positions	Time	TA	TG	Percentage %				Score 1-4				Total
							Green	Hardscape	Solar exposed	Shady					
Nov 11, 2020	Morning	Hottest	*21*	11.15	33	37	0	100	100	0	0	0	0	0	0
		Coolest	*1*	10.2	31	33	25	75	0	100	1	1	4	4	10
Feb 27, 2021	Morning	Hottest	*23*	12.11	34	42	25	75	75	25	1	1	1	1	4
		Coolest	*12*	11.46	30	44	0	100	100	0	0	0	0	0	0
	Afternoon	Hottest	*19*	14.01	35	46	25	75	75	25	1	1	1	1	4
		Coolest	*7*	13.35	32	37	0	100	0	100	0	0	4	4	8
	Evening	Hottest	*12*	15.52	37	47	0	100	100	0	0	0	0	0	0
		Coolest	*1*	15.29	33	35	25	75	0	100	1	1	4	4	10
Mar 6, 2021	Morning	Hottest	*7*	10.42	35	44	0	100	50	50	0	0	2	2	4
		Coolest	*15*	11.02	31	33	25	75	0	100	1	1	4	4	10
	Afternoon	Hottest	*14*	14.42	36	46	0	100	100	0	0	0	0	0	0
		Coolest	*1*	14.08	33	45	25	75	25	75	1	1	3	3	8
		Coolest	*24*	15.02	33	43	75	25	25	75	3	3	3	3	12
	Evening	Hottest	*9*	15.49	35	44	100	50	100	0	4	2	0	0	6
		Hottest	*22*	16.15	35	40	25	75	50	50	1	1	2	2	6
		Coolest	*24*	16.25	32	37	100	25	25	100	4	3	3	4	14

Table 2 Evaluation of physical environment at the 11 highest and lowest temperature positions
Note: The hottest and coolest temperature selection is based on air temperature (TA).

Date	Period		Positions	Observed description
Nov 11, 2020	Morning	Hottest	21	A sunny area with a metal wall of trash bins, at north is concrete floor and no green space.
		Coolest	1	Hardscape with a small green patch at back, shady area by the surrounding buildings
Feb 27, 2021	Morning	Hottest	23	Solar exposed with some shaded areas, majority concrete with some container garden
		Coolest	12	Solar exposed on all concrete pavement with no green, but next to the canal
	Afternoon	Hottest	19	Open-air area, occasional shady, concrete pavement, small green patches
		Coolest	7	Street-side area, occasional shady, concreate walls, no green
	Evening	Hottest	12	Open-air, no shade, all concrete, no green but next to water
		Coolest	1	Hardscape with a small green patch at back, shady area by the surrounding buildings
Mar 6, 2021	Morning	Hottest	7	Street-side, fully exposed to sunlight, concrete walls on the side, no green
		Coolest	15	Occasional sun light exposed, large shading trees, concrete pavement with little green
	Afternoon	Hottest	14	Afternoon sun light, no shading, concrete pavement & walls, no green
		Coolest	1	Hardscape with a small green patch at back, shady area by the surrounding buildings
		Coolest	24	Large amount of green, occasional sun light, shading from concrete walls of buildings
	Evening	Hottest	9	Fully sun light all day, concrete block pavement but not permiable, litle shade by green
		Hottest	22	Fully sunlight all day, concrete walls on both sides, few trees
		Coolest	24	Large amount of green, occasional sunlight, shading from concrete walls of buildings

Table 3 Observed description of the physical environment at the 11 highest and lowest temperature positions

Figure 11 Pictures of the 11 evaluated positions

Note: Images 1,7,12,14,15 from Google Street View; retrieved March 2021. Images 9,19,21,22,23,24 by authors.

temperature. This conclusion is consistent with the findings from Jareemit & Srivanit (2022) that a dense tree canopy generates a better cooling effect than artificial shading. However, combining both and other techniques can be applied in various situations. Rinchumphu et al. (2021) also indicate that adding large canopy trees in the southwest is the best option compared to other techniques, such as water features or shrubs (to reduce hardscape). Planting trees in various sizes and shapes influences shading, airspeed, and solar radiation, ensuring a lower PET and raising the outdoor thermal comfort of the area (Rinchumphu et al., 2021).

The academic contribution of this research lies in the conceptual design baseline (for newly planned projects) and mitigation technics (for existing projects) that should be considered when planning and designing for comfortable living conditions, especially the thermal problem in tropical countries, which site planners and policy makers usually overlook. They are: 1) key attributes affecting the thermal comfort are the number of surface materials (hardscape vs. soft scape) and surfaces exposed to solar energy (shade vs. sunlight); and 2) Four key strategies to mitigate the impact are shading, the surface that reflects heat and absorbs moisture, through ventilation, and increasing green area.

Recommendation

Improving thermal comfort in Bang Chalong Community No. 1 can be categorized into four strategies: shading strategy, green area strategy, orientation & ventilation strategy, and functional strategy. These strategies can be integrated into similar projects' design and planning guidelines and considered for future projects. The followings are design proposals that improve the thermal comfort of the built environment.

Shading strategy

Creating and adding shade can effectively provide a comfortable environment. It can be seen from the low-temperature analysis results in the project. The results are consistent with studies by Akbari et al. (2001, 2009), who argued that shady areas are essential and can improve the microclimate. Thermal comfort can be created by using shade.

Shading strategy 1 (Figure 12): Position no. 15 (Pedestrian area), along the project's entrance, was proposed to increase the number of large trees for shading the roads and sidewalks, reducing solar exposure and heat radiation from the hardscape. Recommended plant species are spread canopy and low maintenance, such as Angsana (Pterocarpus indicus) and Siamese neem tree (Azadirachta indica).

Shading strategy 2 (Figure 13): Position no. 14 (front of the building and street parking), because the existing area has narrow sidewalks due to additional parts of the buildings with minimal setback distance; therefore, large canopy trees were added by creating green panels on parking spaces, separated by intervals of 3 parking slots. Each panel consists of two large trees planted in shrub beds to add shade on sidewalks, car parks, and roads. Trees are recommended to be broad canopy shape, and their branches are not brittle or easily broken.

Green area strategy

Modifications to surface materials that retain moisture and are porous can reduce air and radiant temperatures, such as green spaces or water-permeable and moisture-absorbed pavements that increase humidity resulting in lower surface temperatures. In addition, increased water permeation also reduces the burden on the drainage system

Green area strategy 1 (Figure 14), the multipurpose sports court at the south building cluster, the concept is to turn the surrounding areas of this concrete field into a suitable space for recreation. Changing concrete sidewalks along the perimeter and edges of the field into grass blocks helps decrease the thermal conductivity of the area. On the west side of the field, additional shading structure with extended eaves, high ceilings, and light-colored asphalt shingle as the roof material will help reduce surface temperature, radiant temperature, and heat dissipation. The structure itself is recommended to have stacked-roof layers to create through ventilation. All sides of the field should be planted with large, broad canopy trees for shading, recommended species such as Trumpet tree (Dolichandrone serrulata), Cananga tree (Cananga odorata), and Burma padauk (Pterocarpus macrocarpus).

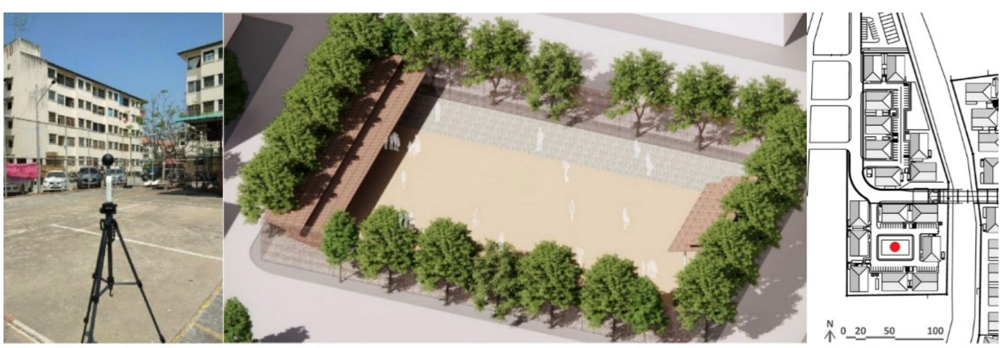
Green area strategy 2 (Figure 15): Position no. 23 (typical parking areas), surfaces of all parking areas could be changed from the original solid concrete into grass block to increase green spaces and reduce their thermal conductor property. Increasing water permeation promotes higher humidity and releases the drainage system's loading. Adding green panels with large trees creates shading for sidewalks and road surfaces for various purposes besides parking.

Current Condition Proposed Design Key Plan

Figure 12 Shading strategy 1: Position No. 15, project's entry road and sidewalk

Current Condition Proposed Design Key Plan

Figure 13 Shading strategy 2: Position no. 14, entry street's parking in front of buildings



Current Condition Proposed Design Key Plan

Figure 14 Green area strategy 1 - The multipurpose sports court at the south building cluster

Current Condition Proposed Design Key Plan

Figure 15
Green area strategy 2 - Typical parking areas

Green area strategy 3 (Figure 16): Position no. 19 (parking at wastewater treatment area), in this area, it is the similar changes to the green areas strategy no. 2 by changing pavement material to grass block and adding green panels with large trees. Recommended plant species are Umbrella tree (Schefflera actinophylla), Spanish cherry (Mimusops elengi), Lamut sida (Madhuca esculenta), Mangosteen (Garcinia mangostana). These species have fewer leaves falling off, which would cause spoilage in the wastewater system.

Orientation and ventilation strategy

Greater airflow can create comfortable conditions in microclimate (Gunawardena et al., 2017). A Green area or water surface would bring a cooling effect to the site. Placing buildings across the wind direction (cross ventilation) also creates good ventilation.

Orientation & ventilation strategy 1 (Figure 17): Position no. 22 (the space between buildings); because it is the space between the buildings, there are breezes and shadows of the structures throughout the day in the east area. However, there are tall canopy trees planted tightly, blocking the wind. Therefore it is suggested to remove some old, unhealthy trees allowing through ventilation. It is also suitable to create a community farming and activity area on the all-day solar exposed side of the west. Additional openings or windows on the building walls to increase ventilation are recommended. In the more shady areas, the east, public facilities (street furniture) such as tables or benches are advised. These elements encourage recreational and socializing activities, for example, gathering to work in vegetable gardens.

Orientation & ventilation strategy 2 (Figure 18): Position no. 7 (in the market's food stall structure), it is suggested to extend the shade canopy by increasing the length of the eaves, raising the roof ceiling, and installing a stacked-roof layer to allow through ventilation. The pavement could be changed from concrete to grass block, reducing heat absorption. The structural design should be similar if the storefront is extended toward the north entry.

Functional strategy

The areas around all buildings that are small or scattered throughout the project can be used to increase their economic value, for recreational spaces, and strengthen the social relations of the residents either near each building or the whole community.

Functional strategy 1 (Figure 19): Position no. 21 (the area between the vegetable garden adjacent to the building and the wastewater treatment area), the vegetable garden acts as a central activity for residents in normal circumstances. Therefore, it is recommended as a demonstrating plot for planting experiments, cultivating polt for consumption within the community, or trade with visitors. Spaces next to the buildings with shadows can be used for recreation. Additional pavilions and supporting facilities (street furniture) allow for equipment storage and social gathering. The existing trees help filter strong sunlight for the vegetable garden.

Functional strategy 2 (Figure 20): Position no. 9 (the vegetable garden at the Bang Nam Chuet bridge's foot) is currently a vegetable plot in the community with limited space. Therefore, relying on the shade from the building to help reduce the temperature, it can serve as a recreational area. Additional structures increase agricultural areas by vertical framing and provide equipment storage.

Suggestions to create suitable thermal comfort by landscape architectural concept for future projects

The finding from this research not only mitigates the thermal problem in the Bang Chalong Community but also applies to a similar development in tropical climate countries. The following should be considered when planning new projects or improving existing ones. 1) Limitation of heat storage in construction materials by two means: 1.1) minimize hardscape, using it as needed, and maximize softscape as much as possible; 1.2) provide shade for all outdoor spaces, primarily upon the hardscape. 2) Facilitation for better thermal comfort spaces by four key strategies: maximize shading area, use materials that reflect heat and absorb moisture, allow through-ventilation, and increase green area.

In master planning of a cluster housing, buildings should be positioned considering the use of shade from other buildings for maximum benefit, according to the specific needs of each location, such as setting up areas for daily outdoor activities to the north and east for afternoon shade, and spacing between buildings for good ventilation. Planting or positioning large trees for shade casting on the building's walls is strongly suggested, especially in the afternoon. In the case of multiple buildings placed close to each other, they should be placed at an appropriate distance and oriented in ways that allow ventilation to cover the entire façade's height.

Figure 16 Green area strategy 3 - Parking around the wastewater treatment area

Figure 17 Orientation & ventilation strategy 1 - the space between buildings

Figure 18 Orientation & ventilation strategy 2: the market's food stall structure along the main street

Figure 19 Functional strategy 1: the area between the vegetable garden adjacent to the building and the wastewater treatment area

Figure 20 Functional strategy 2: the vegetable garden at the Bang Nam Chuet bridge's foot

The ground floor is also proposed to be opened air for ventilation or to direct the wind (by region). The open ground floor can also be classified as a community recreation area. Planning for green areas should be spatially efficient. The suitable size green should not be too small to become a wasteland. Long and narrow public spaces, such as the longitudinal side of buildings or sidewalks, should be wide enough for a large tree. The tree-pit size should be at least 2.00 X 2.00 m or more to allow sufficient plant growth.

In terms of pavement, using porous materials, light color, and a high percentage of albedo with low heat absorption is recommended. Using concrete pavement or hardscape that is not permeable should be limited. For landscape structures such as sidewalks or covered walkways, small gazebos, or trellis panels, consideration should be given to design and material selection, following the same standards as tropical & energy-efficient architectures. The potential highly solar-exposed open spaces, especially hardscape, should be shaded as much as possible, except for certain activities, such as sports fields which require standard dimensions. However, using "the emergent layer" species (the tallest trees in the rainforest; more than 40 meters) to shade, if properly positioned, can provide a comfortable condition. Shading from surrounding tall buildings may also be effective too.

In addition to the above considerations, good community-based management is of the utmost importance in creating a sustainable environment, especially landscape architecture with living elements.

Limitation

Regarding COVID19, it was problematic to complete measurements in every season, follow up the fieldwork as planned, and extend the research period as needed. The available period for the site survey is between November 2020 – March 2021 due to travel restrictions and limited access to the community. Due to the limited resources and funds, allocating the budget for procuring all necessary measuring equipment was not possible.

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