NATURAL VENTILATION:
Design for Suburban Houses in Thailand

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Submitted to the Department of Architecture on May 8, 1998
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ABSTRACT

Natural Ventilation is the most effective passive cooling design strategy for architecture in hot and humid climates. In Thailand, natural ventilation has been the most essential element in the vernacular architecture such as the traditional house, but has become unused nowadays because of the urbanized conditions in big cities like Bangkok. This thesis explores the potential of using natural ventilation for modern houses by using a Computational Fluid Dynamics (CFD) program.

The research investigates the characteristics of Thai houses from the past to the present that climate, culture and technology have influenced. The analysis of the climate data concludes that natural ventilation can be used approximately four months a year to create conditions within the zone of thermal comfort.

In a suburban housing project, site planning has a significant impact on the wind pattern and velocity. The simulation results indicate that the wind has better characteristics in the houses with square shapes than those with rectangular shapes. The vegetation around the houses also has some effect on the wind by slightly reducing its speed. Lastly, the prevailing winds from the north and north-northeast have similar wind patterns in a large housing project.

The final stage is to design a prototype by using some climatic characteristics from the traditional Thai house. The air movement is inadequate in a house with regular size windows. Therefore, the study tests three more cases with larger windows. The results demonstrate that the maximum size window provides better thermal comfort. Finally, the study finds that the stack effect is negligible.

The study shows the possibility to use natural ventilation for the houses in this region. The investigation has developed comprehensive design guidelines for architects. Necessary further research is presented in the end to find more solutions for climate-responsive architecture in today’s physical conditions.

Thesis Supervisor: Qinyan Chen
Title: Assistant Professor of Building Technology
To whom it may concern
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1.

FROM PAST TO PRESENT: NATURAL VENTILATION AND THAI HOUSES

Until now, wind has played a great role in architecture in hot and humid areas. Air movement makes humans feel cooler and more comfortable under a slightly hot environment. Thus, natural ventilation serves as the most effective passive design strategy for the tropical regions, where the temperature only slightly exceeds the comfort zone.

Considered the only vernacular architecture in Thailand, the traditional Thai house (Fig.1.1) was designed by taking the full advantage of the prevailing wind. However, more urbanized and dense conditions in today’s big cities like Bangkok discourage the use of natural ventilation even in the most basic residential structure. Therefore, most designers replace this natural system with an air conditioning system to get rid of the heat accumulated in buildings. As a result, not only does this give a high level of energy consumption in the buildings, but it affects the environment directly. An air conditioning system needs additional energy to carry the heat from the buildings to outside, thus warming up the environment.

This research explores the possibility of using natural ventilation for the physical conditions in the present time. The first chapter studies the development of Thai houses from the past to present.
1.1 Traditional Thai House

Since ancient times, Thai people have settled along the rivers and canals (Fig. 1.1). While the land is fertile, such topographical features of most of Thailand are often flooded. Therefore, the topography of the land and the hot and humid climate conditions are the most significant design considerations for any architecture built in this region.

With major concern about the climate and its existing conditions, the traditional Thai house is regularly built with three eminent characteristics which include an elevated floor, long and high roof and large open terrace. The raised floor (Fig. 1.3), which creates the house-on-stilts type of architecture, prevents sudden flooding and dangerous animals, while it allows more wind to flow through the living space. Functionally, the space under the floor is normally used as storage or a place to keep cattle. Located in the shaded area, the space under the floor is used for day-time activities or living space as well.

Due to the heavy rain during long rainy season, the roof in the traditional house (Fig. 1.4) needs fast drainage. Therefore, to avoid leakage of the roof tiles which are made from natural material, the roof has to be high. In consequence, the high space underneath the roof provides a comfortable condition for the living space by letting the hot air rise. The roof also needs to be pitched far over the activities area and verandah to provide shade and protection from the rain for the door and window openings.
Living in the hot and humid area, Thai people normally have their activities in the outdoor space. Thus, the traditional house normally has a large open terrace (Fig. 1.5) which takes about 40% of the total area, or up to 60% if it includes the verandah area (Jongjairak, 1996, p. 30). This open terrace links various sections together and functions as a space for common work or social activities. People usually use this space in the evening when the air is cooled down. Moreover, when the sun angle is low, the house and nearby trees can provide shade to this area, making it a pleasant place to use.

Besides the physical consideration, Thailand's unique culture is another major factor affecting the traditional house. Unlike in western culture, the Thai family is an extended family mostly based on agricultural occupations. Family members have close relationships and live together in a large group to help each other in farming. Therefore, their houses need to be expandable. A newly founded family may start from a simple form of a house (Fig. 1.6) that can be expanded later to be a complex for a larger family.

When the next generations are ready to have their own family, they will build their houses next to, or in most cases, opposite their parents' original house. The terraces of each house will be linked and serve as a common space or sharing facilities for each of the family members (Fig. 1.7). Therefore, the multi-family traditional house have a clustered characteristics.
1.2 Development to the Present Time: the Influence of Western Culture

In the 18th century, Thailand started to have connections with foreign countries and began to import some construction technology. The influence from Chinese masonry skilled labor and western styles of architecture gradually changed the outlook of Thai house (Fig. 1.8) from their traditional wood architecture.

In a more modern world where the information can be transferred faster, the influence from western culture has become more significant to architecture in Thailand, including the Thai house. One of the trends was modern architecture, which started to have an impact on Thai houses in the 1950's (Fig. 1.9). Thai architects adapted the style to the conditions of the environment and climate rather well, concerning the use of prevailing wind, sun shading and rain protection.

Since the 1970's, Thailand's economy has grown very rapidly; so has the construction industry. While large numbers of housing projects are constructed, they serve mainly commercial purposes rather than improving the quality of the living conditions. Most of the designers only treat the houses as products, which are mostly taken directly from western styles (Fig. 1.10). As a result, most of them lack responses to the users' requirements, especially regarding the climatic aspect.
In the late 1990's, some designers have tried to find solutions to the problems concerning climate by introducing insulation materials for building envelopes. However, the designers still lack the thorough understanding since the designs (Fig.1.11) are imported directly from a western design without any adaptation to the climate.

In addition, western culture also has a great impact on the living style of Thai people. For example, people in the cities do not live in a large family any more. Therefore, there is no longer a need for expansion and the large open terrace.

1.3 Comparison of the Conditions in the Past and the Present

Without any mechanical equipment in the past, the Thai people tried to make their houses livable by using the maximum advantage from the nature (Fig.1.12). Firstly, the houses were chosen to be built in cool micro environments. By settling the communities near water sources such as rivers or canals, people could use the evaporative cooling to cool down the air. Although the relative humidity in this region can be high, the evaporative cooling reduces the air temperature. Since the human body is more sensitive to the temperature than the humidity (Fry & Drew 1982), the evaporative cooling gives a better comfort level.

Big trees and the exposed ground also create cooler environments. Normally, shaded areas under big trees have a lower air temperature than the ambient air. As a result, the wind that moves past these spaces into the house increases the comfort level of people, especially during the day time. In general, the ground temperature is quite stable and lower than the air temperature. Therefore, the cool
radiant from the ground makes the space near the ground cooler. The design of the traditional house takes this advantage by selecting the location surrounded with big trees and having the day time living space near the ground.

The building materials of traditional houses were natural ones such as wood and hay. The materials are appropriate for the climate that has low diurnal temperature difference. They are light-weight materials and do not store heat. Therefore, the structure can be cooled down very quickly after the sun sets, thus providing a comfortable condition in the house during the night.

Today’s house (Fig.1.13), on the other hand, ignores any aids from the nature. Densely built conditions in a city create a hot micro climate. This is deteriorated by using the wrong design approach and inappropriate building materials. Most houses do not provide enough shade for the door and window openings, thus allowing direct sun to penetrate into the living space. Moreover, the building envelopes are made of materials with high thermal mass such as concrete and brick. These materials store heat during the day and radiate into the living space during the night. As a result, the indoor conditions of the houses are too hot and not livable in both day time and night time.

Physically, the design for today’s houses has to face the problem regarding flooding. The design ignores the fact that the topographical features of most of Thailand are in low altitude. The floors of most houses are very close to the ground and can be easily flooded.
All of the problems occur because the technology and culture from the west are adopted without any adjustment to the existing conditions, while the lessons from the past are forgotten. As a result, not only does today's Thai house lose its identity, but it also has to face plenty of physical problems that used to be solved successfully in the past. This research therefore takes the consideration of various parameters including physical, social, and cultural factors into the design for a livable house in today's conditions.
THERMAL COMFORT

Human beings need to maintain a body temperature at 37°C (98.6°F), while the bodies continuously generate heat by means of metabolism. Therefore, the bodies need a cooler environment to give heat to in order to keep this constant temperature. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) found that humans can be comfortable in a certain range of temperature and humidity. This range is called “Thermal Comfort Zone”.

This chapter discusses the theory of thermal comfort, the cooling effect from the wind and the comfort level for Thai people.
2.1 Discussion of Thermal Comfort

The ranges of thermal comfort given by ASHRAE (Fig.2.1) for winter lie between 20°C and 23.5°C (68°F to 74°F) at 18°C (64°F) wet bulb and between 20.5°C and 24.5°C (69°F to 76°F) at 2°C (36°F) dew point. The effective temperature lines of 20°C and 23.5°C (68°F and 74°F) present the tilting borders of the winter zone.

For summer, the ranges lie between 22.5°C and 26°C (73°F to 79°F) at 20°C (68°F) wet bulb and between 23.5°C and 27°C (74°F to 81°F) at 2°C (36°F) dew point. The effective temperature lines of 23°C and 26°C (73°F and 79°F) present the tilting borders of the summer zone.

While ASHRAE set a standard of thermal comfort for human all over the world, regardless of the disparity of climates or nations, another group of scientists have a different point of view. They believe that thermal comfort can be adjustable since human can acclimatize or have physiological variations (Lovins 1995, p.5). The results conducted from the field studies, show the discrepancies of the comfort zone from those of the laboratory tests. They prove the theory that different people can have different thermal comfort zones.

John Busch conducted an experiment for office space in Thailand, testing on more than 1100 Bangkok workers. The result (Fig.2.2) shows that, based on 80% satisfied workers, the upper limit of the comfort zone is 28°C (82.4°F) for people in the air conditioning buildings and 31°C (87.8°F) in the naturally ventilated buildings (1992, p.248 & Lovins 1992, p.15).
The result of Busch's research corresponds to other sources. It has been suggested that the comfort zone which was given for the USA from 20 to 25°C (68 to 78.8°F) at the latitudes about 40°N can be shifted by 1°C for every 12° (1°F for every 7°) change in latitude (Cowan 1991, p.333). For example, Bangkok, which is located on the latitude of 14°N will have an increase in the comfort zone of (40-14)/12 = 2.2°C (4°F). As a result, the upper limit of the comfort zone in this case is about 28.2°C (82.8°F).

The most recent research of thermal comfort for transitional spaces in Bangkok, conducted by Jitkhajornwanich, Adrian, Malama, & Steve, shows a harmony in the result. The upper limit of the thermal acceptability in this experiment is as high as 31.5°C (88.7°F). It agrees with 31°C (87.8°F) in Busch's study for the naturally ventilated case (1998, p.11).

2.2 Wind and Thermal Comfort

Besides ambient temperature, relative humidity and mean radiant temperature, air movement is another environmental factor that has an impact on thermal comfort (Lechner 1991, p.28). It increases the rate of the convective and evaporative heat loss from human skin to the environment. Heat and sweat can be taken away from the skin faster under high wind speed, reducing the temperature of the skin (Chen 1996, p.11). As a result, humans will feel cooler than the ambient temperature if the wind flows past the bodies.

Table 2.1 shows the effect of wind velocity. As can be seen, the desirable wind speed for indoor environment should be at least 0.2 m/s (40 fpm). However, the wind velocity should not exceed the upper limit at 1 m/s (200 fpm).

<table>
<thead>
<tr>
<th>Air Speed (m/s)</th>
<th>Equivalent Temperature Reduction (°C)</th>
<th>Effect on Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0</td>
<td>Stagnant air, slightly uncom-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fortable</td>
</tr>
<tr>
<td>0.2</td>
<td>1.1</td>
<td>Barely noticeable but comfort-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>able</td>
</tr>
<tr>
<td>0.4</td>
<td>1.9</td>
<td>Noticeable and comfort-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>able</td>
</tr>
<tr>
<td>0.8</td>
<td>2.8</td>
<td>Very noticeable but acceptable</td>
</tr>
<tr>
<td>1</td>
<td>3.3</td>
<td>Upper limit for air conditioned space, good air velocity for natural ventilation</td>
</tr>
</tbody>
</table>

Table 2.1 Air velocity and effect on thermal comfort (Lechner 1991, p.196)
because the wind might start to pick up loose paper and light objects around 0.8 m/s (160 fpm, Reynolds 1992, p.40).

### 2.3 Comfort Zone for Thailand

As discussed earlier, thermal comfort for the Thai people can be as high as 31°C (87.8°F) in the naturally ventilated buildings. However, based on the fact that most people nowadays are used to the air conditioned space, from their work places, cars, to houses, their thermal comfort zone should be similar to that of the air conditioned group in Bucsh's research. Thus, the upper limit of temperature should range from around 28°C (82.4°F) when the air is stagnant, to 31.3°C (88.3°F) under the air movement of 1 m/s. This can be demonstrated in details in the ASHRAE psychometric chart (Fig.2.3).

---

**Fig.2.3 Thermal comfort zone on the ASHRAE psychometric chart**
Since buildings in Thailand need cooling in the hot weather throughout the year, the ASHRAE summer comfort zone is used as the reference zone. The upper limit is under 26°C (78.8°F) effective temperature and the 20°C (68°F) wet bulb temperature lines. In Thailand, this limit can be shifted to be under 28°C (82.4°F) effective temperature and the 22°C (71.6°F) wet bulb temperature lines. This zone is described as the area under the line of v=0 in the chart.

For cooling effect from the wind, it has been suggested that the comfort zone can be shifted along the relative humidity line (Ashley 1984, p.8). Therefore, the upper limit under the wind velocity of 0.2, 0.4 and 1 m/s is under 29.1, 29.9 and 31.3°C (84.4, 85.8 and 88.3°F) effective temperature and 23, 23.5 and 24.5°C (73.4, 74.3 and 76.1°F) wet bulb temperature respectively. These lines can also be plotted in the bioclimatic chart (Fig.2.4).

Fig.2.4 Thermal comfort zone on the bioclimatic chart
CLIMATE OF THAILAND

Located in tropical area between the latitudes of 6°N and 20°N, Thailand experiences small seasonal changes throughout the year. Although not distinct, three different seasons can be recognized. The hot months, starting from March to June, are characterized by high sun angle, warm temperature, and moderate southerly wind. The rainy season, from July to October, has lower temperature but higher humidity. The remaining months of November to February are winter where the sun is in the lowest position and the temperature is not very high.

This chapter analyzes the effect of all environmental factors from the raw data. Most data are acquired from the meteorological department in Bangkok. The effort is to find whether there is a possibility to use natural ventilation and know when to use it.
3.1 Air Temperature and Relative Humidity

For most parts of the country, the air temperature and relative humidity are higher than the comfort zone throughout the year. The air temperature ranges from 21°C to 35°C (70 to 95°F), while the relative humidity ranges from 45 to 95%. Located in the center of the country on 14°N latitude, Bangkok metropolitan area can be the reference spot for the climate study. The 10-year raw weather data acquired from the meteorological department in Bangkok are analyzed and plotted in the bioclimatic chart with the comfort zone and the cooling effect of the wind. Each spot on the chart presents the hourly average value on 10-day basis.

In summer (Fig.3.1), both temperature and relative humidity fall beyond the range of the cooling by natural ventilation. As can be seen, the lowest temperature in the early morning is about 25.5°C (78°F) but the relative humidity is almost 90%, while the afternoon air can be as hot as 34.5°C (94°F).

The temperature is lower in the rainy season (Fig.3.2) but the humidity is very high. In the early morning, the temperature can be as low as 24.5°C (76°F) but the relative humidity exceeds 90%. Although the highest afternoon temperature is as low as 32.5°C (90.5°F), the relative humidity is almost 60%. There is only a small part of the season that the spots fall into the zone that can use the cooling effect from the wind. That period is the last ten days of October before the winter begins.
The highest possibility to use natural ventilation is in winter (Fig. 3.3). Most of the spots fall into the zone that can use the cooling effect from the wind. The air in the morning and evening in November and December is already within the comfort zone. For the rest of the season, the air is in the range that can use the cooling effect from the wind. However, there are some afternoon hours in January and February that the temperature exceeds the upper limit of 31.3°C (88.3°F) which is too high to use the cooling effect from the wind.

Fig. 3.3 Temperature and relative humidity in winter
3.2 Prevailing Wind

Wind Direction

Like other hot and humid climates, Thailand experiences only gentle wind from two predominant directions. For most part of the year, the prevailing winds are from the south and southwest directions which are influenced by the Southeast Asian monsoons from the Gulf of Thailand. However, the only period of the year that has a possibility to use the wind for cooling is in winter where the predominant winds are from the north and northeast directions. It is these cold and dry winds from the southern part of China that brings some comfort level to the people in Thailand.

Again, the 10-year raw data from the meteorological department in Bangkok are analyzed. The information of the wind were collected hourly by measuring its direction and velocity. The wind directions were recorded in round numbers from 0° to 360°, with intervals of 10 degrees. As a result, they can be interpreted as 36 directions. In this thesis, the wind data are equally divided into 12 directions with the intervals of 30 degrees.

By counting the frequency of the wind from each direction, the one with the highest frequency shows the direction of the predominant wind for each month. Starting from the end of October, the prevailing wind changes its direction from the south to the northeast by north (NNE) and the north (N). Most of the winds in November (Fig.3.4) and December (Fig.3.5) are from these directions. The wind direction starts to change in January (Fig.3.6) from NNE to the southwest by south (SSW) and the south (S). At this time, the temperature begins to increase but still in the zone that can use natural ventilation.
The direction turns into SSW and S completely in February (Fig. 3.7). The wind from the Gulf of Thailand starts to bring hot and moist air to the land. The temperature is in the high end of the zone that can use natural ventilation. At the end of this month, the season changes into summer.

**Wind Velocity**

Wind speed in the winter months (Fig. 3.8) is slightly lower than that in other seasons. However, the average hourly wind velocity of 0.4 to 3.2 m/s is adequate for the cooling purpose. As can be seen, high velocity occurs during the day when people need breeze in the hot weather, while low velocity occurs during the night when people do not need breeze because the air is already cooled down.
3.3 Solar Radiation

Located near the equator, most parts of Thailand experience a high level of solar radiation all year round. The sun paths (Fig.3.9) are high in the sky for most part of the year, giving a high possibility of the solar radiation to penetrate through the atmosphere.

The daily irradiation on the horizontal plane (Fig.3.10) is at the highest level in the hottest month of April at about 7.3 kilowatt hours per square meter (kWh/sq.m) and continues to be at the level of 7 kWh/sq.m for the rest of summer and rainy seasons. The daily irradiation starts to drop to the lowest level at around 5.3 kWh/sq.m in December. Because the sky in Bangkok is mostly cloudy, the diffuse radiation is usually significant. In the wet season, the diffuse component can contribute up to 60% of the total intensity (Thai Gypsum Products 1995, p.24).

3.4 Combined Environmental Factors

As mentioned earlier, ambient temperature, relative humidity, air movement and mean radiant temperature are the environmental factors on thermal comfort. This section discusses the combined effect of all factors on the design of a house.

Heat Gain

Like other building types, the house generates heat simultaneously from human, lighting and appliances. The house also gains heat from the exterior in the forms of solar radiation via building envelopes. Therefore, the indoor environment is usually warmer than outside. In natural ventilation mode, most of the heat generated is carried to outside by the wind.
For a house, heat gain (Table 3.1) can be estimated to be approximately 5.3 kilowatts (kW) for the sensible part and 0.55 kW for the latent part. In this case, heat gain from exterior is considered from the roof, walls and windows. It can be presented in the heat transfer equation as:

\[ Q = U \times A \times \Delta T \]

where
- \( Q \) = Rate of heat flow
- \( U \) = Thermal transmittance of material (U-value)
- \( A \) = Surface area
- \( \Delta T \) = Indoor-outdoor temperature difference

Cooling load temperature differential (CLTD) value for single-family detached residences is used to calculate heat gain through the roof and walls. The CLTD is the temperature difference between indoor and outdoor which takes into account for the heat flux from radiation, conduction and convection. Thus, it represents the \( \Delta T \) in the heat transfer equation. For low daily range climate with the design temperature of 29°C (84.2°F), the CLTD is 23°C (41.4°F) for the roof and 4°C (7.2°F) for the north walls (ASHRAE 1993, p.25.2). All walls are considered north walls because they are supposed to be well shaded.

It has been suggested that roof in Thailand should be insulated at least by 3" microfiber (Thai Gypsum Products 1995, p.89). This will give the total resistance (R-value) for the roof system about 2.30 sq.m°C/W (R-13.5). Therefore, the U-value for this roof is 0.44 W/ sq.m°C. In general, walls have approximately the same R-value as the roof. Therefore, the walls are assumed to have the same R-value as the roof in this preliminary calculation.

<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Description</th>
<th>Heat (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>Q = U A CLTD ( = 0.44 \times 80 \times 23 )</td>
<td>810</td>
</tr>
<tr>
<td>Walls</td>
<td>Q = U A CLTD ( = 0.44 \times 168 \times 4 )</td>
<td>295</td>
</tr>
<tr>
<td>windows</td>
<td>Q = GLF A ( = 25 \times 48 )</td>
<td>1,200</td>
</tr>
<tr>
<td>People</td>
<td>5 occupants x 70 W</td>
<td>350</td>
</tr>
<tr>
<td>Lighting</td>
<td>10 Lamps x 100 W</td>
<td>1000</td>
</tr>
<tr>
<td>Appliances</td>
<td>Stove</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Refrigerator</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Computer</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>TV</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Stereo</td>
<td>200</td>
</tr>
<tr>
<td>Total Sensible Heat Gain</td>
<td>5,300</td>
<td></td>
</tr>
<tr>
<td>People</td>
<td>5 occupants x 30 W</td>
<td>150</td>
</tr>
<tr>
<td>Appliances</td>
<td>Stove = 40% of sensible heat gain</td>
<td>400</td>
</tr>
<tr>
<td>Total Latent Heat Gain</td>
<td>550</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1 Internal heat gain calculation
Window glass load factors (GLF) method for single-family detached residences is used to estimate the heat gain through fenestrations. The GLF value is used instead of the terms $U$ and $\Delta T$ in the heat transfer equation. In Thailand, all windows are supposed to be well shaded, thus the values for north windows are selected. The GLF value is 63°C (113.4°F) for the heat absorbing double glass at the latitude of 40°N (ASHRAE 1993, p.25.3). However, it is suggested that there should be a reduction of 30% for the latitude of 32°N. In this case, GLF value is estimated to be 40% of the value given or 25°C (45°F) since the latitude of Bangkok is 14°N.

**Cooling Load**

Due to the first law of the thermodynamics, the total heat generated in the house is equal to the heat taken to outside. Nevertheless, not all of the heat gain will be taken away immediately due to the time lag of building materials. Cooling load represents the amount of heat that is carried away by a cooling system. In this case, it is estimated to be approximately 75% of the heat gain or 4 kW for the sensible part. This number is assumed to be more or less the same during the day or night because the external heat gain which occurs during the day has about the same amount as the heat gain from lighting and appliances which are mostly generated at night.

In the natural ventilation mode, the cooling load is the heat taken to outside (or heat loss) by the wind (convection) and via building’s envelope (conduction). However, compared to the loss by convection, heat loss by conduction is negligible because the house is supposed to be well insulated to prevent heat gain in the hot season. The equation of the energy loss by natural ventilation can be expressed as:
\[ Q_s = \rho \times V \times C_p \times \Delta T \]

where
- \( Q_s \) = Sensible cooling load
- \( = 4 \text{ kW in this case} \)
- \( \rho \) = Density of the air
- \( = 1.16 \text{ kg/m}^3 \)
- \( V \) = Volumetric flow of the air
- \( = \text{Inlet area (A) \times Wind speed (v)} \)
- \( C_p \) = Specific heat of the air
- \( = 1.01 \text{ kJ/kg}^\circ \text{C} \)
- \( \Delta T \) = Temperature difference of outdoor and indoor

Therefore, in this case
\[ \Delta T = \frac{3.41}{V} \]
\[ = \frac{3.41}{A \times v} \]

From the equation, the increase of indoor air temperature is an inverse function of the inlet area and the wind velocity. Table 3.2 shows the relationship among these three parameters. The typical house in Thailand has the average floor area of about 160 square meters (1,750 sq.ft.). Thus, the inlet area presented in the table ranges from 5% to 15% of the total floor area. This area has direct influence on the increase of indoor air temperature from 0.14°C (0.25°F) under the wind speed of 1 m/s to 2.13°C (3.83°F) under the wind speed of 0.2 m/s. In other words, the higher the wind speed and the larger the openings are, the lower the increase of indoor air temperature will be.

In most cases, it is desirable to have as large inlet area and as high wind velocity as possible, except for some morning hours where the air is humid but cool. In those situations, heat needs to be kept inside a little longer to reduce the relative humidity. Therefore, the inlet area should be smaller and/or the wind speed should be lower.

<table>
<thead>
<tr>
<th>Inlet Area (m²)</th>
<th>Temperature increase (ΔT,°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( v=1 )</td>
</tr>
<tr>
<td>8</td>
<td>0.43</td>
</tr>
<tr>
<td>16</td>
<td>0.20</td>
</tr>
<tr>
<td>24</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table 3.2 The effect of the wind velocity on indoor air temperature
Selecting Design Strategies

To find when to use natural ventilation, at what wind speed and how large the inlet area should be, six critical points from the weather data (Fig. 3.11) are selected to analyze. Point 1 and 2 are the period that has the highest relative humidity which exceeds the level of thermal comfort. Point 3 and 4 are at the upper ends of the relative humidity at 80%. Point 5 and 6 are close to the intersections of the wet bulb lines and the temperature lines. Each point of these three pairs is distinguished from one another by the wind speed needed. Ones are the conditions under the need for the wind velocity of 1 m/s (under v=1 line), while the others are under the need for the wind velocity of 0.4 m/s (v=0.4 line).

All six points are plotted in the psychometric chart (Fig. 3.12) to find the temperature and relative humidity of the indoor air, which are different from those of the ambient air because of the heat gain. The outdoor air conditions will be shifted along the slope that is the ratio of the sensible heat (4 kW) and the total heat (4.4 kW). This ratio is equal to 0.9 in this case.

Then, the indoor conditions can be found by using this slope and the values of the temperature increase (ΔT) from table 3.2 which are affected by the wind speed and the inlet area. The objective is to select the wind speed and the inlet area that will shift the indoor conditions into the zone.

The values selected need to correspond to the zone that can use the effect from the wind. For example, point 3 which has the temperature of 25.5°C (78°F) and the relative humidity of 80% needs at least 0.4 m/s wind speed to keep the indoor air under the v=0.4 line. It cannot use 0.2 m/s wind speed because the indoor air condition will be above the v=0.2 line.
Table 3.3 The conditions of indoor air and possibility to use natural ventilation

*Each month is divided into 3 periods: 1 is given for day 1 to 10 of the month, 2 for 11 to 20 and 3 for 21 to 31.

*min. means minimum requirement to achieve the comfort level

The conclusion from the study of the reference points (Table 3.3) shows the possibility to use natural ventilation for different period of time. It is found that natural ventilation can be used for most part of winter. Under a mild wind speed of 0.4 m/s and small size of inlet (point 3 and 6), a large portion of the season can be within the comfort level. A higher wind speed of 1 m/s will cover almost all part of winter including some hot afternoon hours.

The exception is that natural ventilation cannot be used for some period of time including the humid morning of the last 2/3 of February (point 2) and some hot afternoon hours. At point 2, the moist air with the relative humidity of 89% can be shifted to be a dryer air by using the low wind speed of 0.2 m/s to keep the heat inside, but the final condition will become above the v=0.2 line.

Using table 3.2, the upper limit for the ambient air that can be brought into the house is calculated to be 31.16°C (88°F) under the effect of both highest wind speed of 1 m/s and largest inlet area of 15% of the floor area.
Fig. 3.13 The design priority for natural ventilation

All of the environmental factors are now combined to be the design strategies for natural ventilation. This is given by means of design priority (Fig. 3.13) that can be divided into 5 groups:

1: too hot, not possible for ventilation
2: need maximum ventilation, highest priority
3: in the comfort range, need ventilation
4: too humid, not possible for ventilation
5: cool but humid, need minimal ventilation
The air conditions of these 5 groups are plotted on the time table (Fig.3.14). Each area is combined with the data of the prevailing wind. As can be seen, the conditions in group 2 that needs maximum ventilation fall into most of the day time. Therefore, the time that has lowest wind speed in group 2 will be selected as the design condition. In this case, it is in the evening of January and February with the average wind velocity of 1.4 m/s from SSW and S directions.

Fig.3.14 Time table for the need of natural ventilation.
4.

SITE PLANNING

The surroundings have a significant impact on the wind pattern and velocity in an indoor environment. For example, houses in a big city like Bangkok that are surrounded with large buildings can easily be in the wind shadow. Houses in the suburban area, on the other hand, have more opportunity to take advantage of the prevailing wind because the neighboring environments are less dense. Moreover, most residential areas are located in the suburbs rather than the urban part of the city. Therefore, houses in the suburbs can be perceived as typical houses for Thailand in the present time. These houses are known as houses in large housing projects.

This chapter discusses the impact of the site planning of a housing project on the wind behavior. Various parameters are taken into account, ranging from general design consideration such as buildings’ orientation to complicated factors such as the effect of the surrounding vegetation. A CFD program named PHOENICS, version 2.2.1 is used to simulate the effect of these parameters on the wind characteristics in the complicated cases. The results will provide design guidelines for the site planning for good natural ventilation.
4.1 General Design Consideration

Alignment of the houses

Most of the master plans in today’s typical housing projects (Fig.4.1) do not encourage the use of the wind. Houses are mostly aligned within grid systems of the roads for several reasons. The grid systems are easy to plan and give no useless fractions of the land. They are appropriate for the projects with small land size which do not allow various alternatives. However, this type of alignment strongly discourages the use of natural ventilation. The houses at the windward side block the wind towards the houses in the following rows by creating large wind shadow areas at the back of the first row. The space between houses in the same rows are usually narrow to have minimum area that confronts the roads. This saves some cost for the road construction but forbids the wind to flow to the houses in the next rows. As a result, it is unlikely to use natural ventilation in most housing projects which are designed with this kind of alignment.

It has been suggested that building be staggered (Fig.4.2) in hot and humid regions to encourage natural ventilation (Lechner 1991, p.234, & Moore 1993, p.180). Buildings in the front row do not directly block the wind towards the next rows. However, the linear alignment will create a wind shadow which is a result from the low-pressure areas at the back of each house (Moore 1993, p.180).

The best arrangement is the staggered that have an angle to the prevailing wind (Fig.4.3). This reduces the wind shadow area at the back of each house, thus giving maximum airflow to the house at the back (Moore 1993, p.180). It is considered the most suitable alignment for the design of natural ventilation.
Orientation

Two major concerns for building's orientation are the solar heat gain and the prevailing wind. Victor Olgyay studied the optimum proportion of buildings concerning solar energy. He found that the best configuration for hot and humid climates has a ratio of 1:1.7 with the long sides facing north and south (1963). Area of the openings should be maximum on these long facades and minimum on east and west to reduce heat gain. This ratio is also appropriate for natural ventilation as the prevailing wind is mostly from NNE and SSW.

Land Size

The building codes in Thailand regulate the single houses in housing projects to have the minimum land size of 200 sq.m. (2,200 sq.ft.). This small size of land makes the design with good orientation for wind and solar energy almost impossible. In suburban areas of Bangkok, the average land size of 240 to 250 sq.m. (2,700 sq.ft.) is slightly larger than that given in the building codes. It provides more potential to use the wind. Therefore, the minimum dimensions for the land should be around 15 by 16 meters (165 by 176 feet). At the same time, the width of the land must not be larger than its depth; otherwise, the road will be unnecessary too long.

All three general considerations can be concluded in a proposed master plan (Fig.4.4). Houses are staggered with an oblique angle to the prevailing wind from NNE and SSW. However, the decision about building shape cannot be made at this moment because houses with the optimum shape of 1:1.7 can block the wind to the next rows while the square shape will do less. They will be tested in the CFD model in the next section.

Fig.4.4 A proposed master plan with staggered alignment
4.2 Input for CFD Simulation

The thesis uses a CFD program, named PHOENICS, version 2.2.1 to study the wind behavior in more complicated cases. The program uses the discretization methods to solve a system of differential equations. It uses the control-volume method to solve for 7 variables in 7 differential equations.

The variables are pressure (P), wind velocity in X, Y and Z directions (U, V and W), temperature (T), kinetic energy (K) and dissipation of turbulence energy (E). They can be solved by the differential equations of:

1. Continuity equation (to solve for P)
2. Momentum equation in X direction (for U)
3. Momentum equation in Y direction (for V)
4. Momentum equation in Z direction (for W)
5. Energy equation (for T)
6. K-equation (for K)
7. E-equation (for E)

Therefore, various parameters need to be set up properly. These include dimensions of the simulation field, geometry of the buildings, boundary conditions and calculation numbers.

Dimensions of the Simulation Field

A CFD program consumes long computational time for each simulation. While accurate results are appreciated, they should be achieved within a reasonable simulation time. This can be accomplished by selecting the appropriate numbers of grid size and amount of cells. To have an accurate result, the grid size should be small enough to catch all the eddies which sometimes can be as small as 1 mm. The computer capability of a PC with 64 mB memory, on the contrary, can handle a simulation that contains up to 30,000 cells for
the whole field, or approximately 30 cells on each axis. Should the adjustment not be made, it is impossible to simulate a large case of the outdoor airflow.

This thesis allows the grid size to be as large as 1 meter with a turbulence model. The turbulence model allows the use of common grid system but the accuracy is slightly relaxed. The calculations use 50% more cells in the site planning cases to accomodate more accuracy results. The field dimensions of the site are 32 meters (107 ft.) wide, 100 meters (333 ft.) long and 20 meters (67 ft.) high. Irregular grid systems are used to help increase the dimensions of the field. Larger cells are put in the places where the calculation results are not significant such as places without buildings, whereas finer grids are placed in more meaningful positions. This allows a more reasonable computational time, while keeping the accuracy of the simulation to one level.

Additional variables need to be set up for the calculation including the variables that the program solves for. In the site planning cases, the program solves for all variables mentioned above except T. The properties of the air such as the viscosity and density need to be input as the media for the simulation field.

**Building Geometry**

Buildings and trees can be treated as blockages in the coordinates of the CFD model. To study the wind pattern on a particular house in a housing project, it is essential to have several rows of houses on the windward side since they can change the behavior of the wind. In these cases, 4 rows are modeled. They are treated as solid blockages that do not allow the wind to flow through. Although in the actual situation, some
of the windows in those houses can be opened, they are uncontrollable parameters. They can be considered as the worst case scenario where all opening are closed.

The target house on the fifth row is modeled by using some elements from the past including the elevated floor and long roof. A venting tower is proposed to study the stack effect. This 2-storeyed house has openings on both floors to study the wind velocity at the inlets. The configuration of the house itself will be discussed in more details in chapter 6.

**Boundary Conditions**

One of the most important input for a CFD program is the correct specification for the conditions of the boundaries. In these outdoor airflow cases, a set of houses are modeled instead of the whole housing project. By using the periodic boundary conditions (Fig.4.5), two boundaries have identical conditions. The flow state in the left is the same as that in the right. The values on one side will be taken from another's. In other words, the width of the whole field becomes infinite. Therefore, the prevailing wind can be input on only one boundary though it comes from an oblique angle.

The opposite boundary of the incoming wind and the sky are defined as fixed temperature. The ground is defined as a non-slip boundary. It means that at the surface of the ground, the velocity of the wind is zero.
The friction of the terrain creates a velocity gradient of the wind (Fig. 4.6). Therefore, the wind profile is needed to make the cases realistic. As discussed in chapter 3, the design wind speed for calculation is 1.4 m/s from the SSW direction while most of the winter wind comes from NNE. Despite having different angles, the prevailing winds from two directions can be simulated as one case since they come from the exact opposite positions.

This wind speed of 1.4 m/s is considered to be measured at 10 meters above the ground level. The reference velocity and wind velocity on the site can be expressed as:

\[ U_H = U_{ref} \times (H/H_{ref})^a \]

where
- \( U_H \) = Wind velocity (m/s)
- \( U_{ref} \) = Reference wind velocity (m/s)
- \( H \) = Height (m)
- \( H_{ref} \) = Reference height (m)
- \( a \) = Velocity profile exponent
  - = 1/4.5 for suburbs

The reference wind velocity can be calculated to be 3.15 m/s for the suburbs of Bangkok. From the equation, the velocity gradient can be presented according to each cell in the CFD model (Table 4.1).

In the vertical direction, irregular grid system is used from cell number 14 to 16. That zone is the region for the sky where the calculation is not as important as that for the building area. The positions for each of these cells can be calculated as:

<table>
<thead>
<tr>
<th>Cell no. in CFD model</th>
<th>Height (m)</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>0.84</td>
</tr>
<tr>
<td>2</td>
<td>2.00</td>
<td>0.98</td>
</tr>
<tr>
<td>3</td>
<td>3.00</td>
<td>1.07</td>
</tr>
<tr>
<td>4</td>
<td>4.00</td>
<td>1.14</td>
</tr>
<tr>
<td>5</td>
<td>5.00</td>
<td>1.20</td>
</tr>
<tr>
<td>6</td>
<td>6.00</td>
<td>1.25</td>
</tr>
<tr>
<td>7</td>
<td>7.00</td>
<td>1.29</td>
</tr>
<tr>
<td>8</td>
<td>8.00</td>
<td>1.33</td>
</tr>
<tr>
<td>9</td>
<td>9.00</td>
<td>1.37</td>
</tr>
<tr>
<td>10</td>
<td>10.00</td>
<td>1.40</td>
</tr>
<tr>
<td>11</td>
<td>11.00</td>
<td>1.43</td>
</tr>
<tr>
<td>12</td>
<td>12.00</td>
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<tr>
<td>13</td>
<td>13.00</td>
<td>1.48</td>
</tr>
<tr>
<td>14</td>
<td>14.35</td>
<td>1.51</td>
</tr>
<tr>
<td>15</td>
<td>16.81</td>
<td>1.57</td>
</tr>
<tr>
<td>16</td>
<td>20.00</td>
<td>1.63</td>
</tr>
</tbody>
</table>

Table 4.1 Wind profiles in the CFD model
\[ x_i = \left(\frac{i}{n}\right)^e \times L \]

where \( x_i \) = Coordinate of cell in X direction  
\( i \) = Number of the cell  
\( n \) = Total number of cells in the area  
\( L \) = Length of the area (m)

These local velocities are put as the inlet boundary. Since the predominant wind of NNE or SSW is from 30 degree angle of N or S, each velocity can be divided into two directions of the velocity in the X and Y axis. They are represented as the factors of the actual velocity as U-factor and V-factor which are equal to \( \sin 30^\circ \) and \( \cos 30^\circ \), respectively.

**Iteration and Relaxation**

A good result can be achieved by the input of reasonable numbers of calculation including iteration and relaxation because CFD solves non-linear differential equations. For the cases without heat sources like the site planning simulations, the iteration should be at least 500. The relaxation numbers can be given in terms of false time steps (FALSDT) which can be estimated by the ratio of the minimum size of cell (1 m) and the highest velocity in the whole field (1.63 m/s). They should be about 0.6 in this case or can be rounded up to 1.

**4.3 Building Shape**

This section discusses the effect of building shape to find the best configuration for houses in a housing project. The models of houses with square shape and rectangular shape are tested under the same wind condition.
Case 1- Square Shape

Each house has 2 stories with the area of approximately 80 square meters (900 sq.ft.) a floor. Therefore, the dimension of each floor is approximately 9 by 9 meters (30 by 30 ft.). The floor height is 3 meters (10 ft.) while the roof and attic space is about 5 meters high (17 ft.). The house is raised 2 meters (7 ft.) above the ground, giving the total height of the house to be about 13 meters (43 ft.). Rows of pine trees with 10 meter height (33 ft.) are put between houses on the east and west sides to provide shade to the house.

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Fig. 4.7 Plan view of the airflow on the target house at the first floor level

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Fig. 4.8 Plan view of the airflow at the first floor level
The result (Fig.4.7 to Fig.4.10) shows that the wind velocity is much lower at the houses in the latter rows than those in the first rows. However, the wind starts to be stable after the third row as the wind stops flowing up to the sky (Fig.4.9). Therefore, the target house in the fifth row in this case can be considered to have a typical wind behavior for every house in the housing project.

The wind at the inlet position on the first floor has an average velocity about 0.3 to 0.4 m/s. The velocity is slightly lower at the inlet level on the second floor but much higher on the ground level.
Case 2 - Rectangular Shape

The recommended ratio of 1:1.7 can be given by the floor dimension of 7 by 12 meters (23 by 40 ft.). Therefore, the houses in this case have approximately the same floor area as those in case 1. However, the height is slightly shorter because the houses are narrower and have a lower roof. As a result, the total height of each house is about 12 meters (40 ft.).

Located on the same piece of land as those in case 1, each house has more space at the front and the back but has less space on the sides. Therefore, trees can hardly be planted right between houses and are put on the vacant land at the back and front of each house instead.

The result (Fig. 4.11 to Fig. 4.14) demonstrates a large reduction of wind velocity at the inlet of the house in the fifth row. Again, this house can

Fig. 4.11 Plan view of the airflow on the target house at the first floor level

Fig. 4.12 Plan view of the airflow at the first floor level
Fig. 4.13 Longitudinal section view of the airflow on the site

be selected as the target house since the wind starts to be stable after the third row (Fig. 4.13). As can be seen, the wind at the inlet of the first floor has an average velocity of only 0.1 to 0.2 m/s which is not adequate to shift the conditions to be within the comfort zone.

The results from both cases show that the wind velocity is higher in the houses with square shapes (case 1) than those with rectangular shapes (case 2). The velocity in the latter case is much reduced mainly because the houses at the first row totally block the wind towards the next rows. Therefore, houses with square shapes are better for the design with natural ventilation for a housing project.

Fig. 4.14 Section view of the airflow on the target house
4.4 Vegetation

This section discusses the effect of vegetation on the wind velocity. Model of the square shape houses with different positions of trees and the model without trees are tested under the same wind condition to compare the result.

Case 3- Houses with Trees at the Back and Front.

From case 1, the trees are shifted from the space between houses to the front and the back of the yard. This allows the wind to flow freely between the houses. However, the result (Fig.4.15 and 4.16) shows no large discrepancies of the effect between 2 cases. The wind at the inlet on the first floor has an average velocity of 0.3 to 0.4 m/s which is equal to that of case 1.

Fig.4.15 Plan view of the airflow on the target house at the first floor level

Fig.4.16 Plan view of the airflow at the first floor level
Case 4- Houses without Trees

Since the different positions of trees in case 3 do not contribute to the change in the wind velocity, an extreme case without trees are tested to study whether the trees have effect on the wind. The result (Fig.4.17 and Fig.4.18) shows that the effect of the trees is minimal. The wind at the inlet on the first floor has an average velocity around 0.4 m/s which is slightly higher than those of case 1 and 3.

The results give the conclusion that the effect of the trees is not very important on the site planning for the houses as long as they do not block the wind directly. An interesting notice is that although trees are modeled as blockages in these studies which do not allow any wind to flow through, the overall effect is still not significant.

Fig.4.17 Plan view of the airflow at the first floor level

Fig.4.18 Plan view of the airflow on the target house at the first floor level
4.5 Wind Direction

Case 5- Wind from N and S

In some period of winter, the prevailing winds come from N and S. The wind at the inlet boundary is given perpendicular to the facade of the houses in the model to represent this N or S winds. The result (Fig.4.19 and 4.20) shows a similar wind pattern to the cases with wind from NNE or SSW. However, in this case, the magnitude is lower. The wind at the first floor inlet has an average velocity of 0.3 m/s.

The study of this case supports the concept of Moore (Fig.4.3) that buildings should be arranged with an oblique angle to the wind. However, for most of winter, the prevailing winds come from SSW and NNE which already have oblique angles to the houses aligned as proposed.

Fig.4.19 Plan view of the airflow on the target house at the first floor level

Fig.4.20 Plan view of the airflow at the first floor level
5.

THE PROTOTYPE

While the study of site planning gives a rough configuration of houses that is suitable for the design of natural ventilation, the investigation of the house in more details provide a more in depth information. This chapter discusses various parameters in architectural design which range from general consideration such as users' requirements to complicated factors such as effect of the window size. All these parameters are demonstrated by applying to the actual design of a prototype.

The prototype is designed by using some elements from the traditional Thai house that respond to the climate such as the elevated floor and the long pitched roof. The wind behavior in the house is tested with a CFD program name PHOENICS, version 2.2.2, using the results from chapter 4. The simulation is separated into three categories including wind driven airflow, buoyancy effect and the combination of the two. The wind driven part tests the effect of window size, while the buoyancy part simulates the conditions without the wind. Finally, the combined studies decide whether both effects can support each other or not.
5.1 General Design Consideration

Solar Control

Located in a warm climate, architecture in Thailand has the primary design objective in preventing solar gain. Since the lowest temperature of Thailand can be slightly under the thermal comfort zone, heating is not required all year round. Therefore, buildings need protection from solar radiation, especially the openings where the sun can penetrate through easily.

To provide solar protection, it is necessary to know the path of the sun across the sky. The sun path diagram of the latitude of 14°N (Fig.5.1) represents the positions of the sun and its angles in the sky of Thailand. The values on the outer parameters specify the azimuth angles of the sun from the south. The positions of the sun above the horizon can be found by overlaying the combination chart (Fig.5.2) on top of the sun path diagram. The profile angles read from the chart that has already adjusted to the window plane are the angles above the horizon.

The angles of the sun read from the sun chart can be used for the design of shading device. Critical angles (Table 5.1) are selected from the lowest angles of the sun where they are hardest to protect. As can be seen, the profile angles on the east and west are very low, thus making it hard for the sun protection. Therefore, it is recommended that openings should be placed on the south and north.

<table>
<thead>
<tr>
<th>Facade</th>
<th>Date</th>
<th>Time</th>
<th>Profile</th>
<th>Azimuth</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>21/12</td>
<td>8 a.m.</td>
<td>35</td>
<td>68 E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 p.m.</td>
<td>35</td>
<td>58 W</td>
</tr>
<tr>
<td>N</td>
<td>21/6</td>
<td>8 a.m.</td>
<td>63</td>
<td>71 E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 p.m.</td>
<td>63</td>
<td>71 W</td>
</tr>
<tr>
<td>E</td>
<td>21/6</td>
<td>8 a.m.</td>
<td>35</td>
<td>109 E</td>
</tr>
<tr>
<td></td>
<td>21/12</td>
<td>8 a.m.</td>
<td>25</td>
<td>58 E</td>
</tr>
<tr>
<td>W</td>
<td>21/6</td>
<td>8 a.m.</td>
<td>35</td>
<td>109 W</td>
</tr>
<tr>
<td></td>
<td>21/6</td>
<td>4 p.m.</td>
<td>35</td>
<td>58 W</td>
</tr>
</tbody>
</table>

Table 5.1 Critical angles for shading design
**Users’ Requirements**

According to Habraken, Boekholt, Thijssen, & Dinjens, functional spaces in a modern house can be divided into three categories (Table 5.2). They are general purpose space, special purpose space and service space. General space is the area where all the members of the family can share. This space allows a combination of several activities including playing, sitting, eating and watching the television. Special purpose space is the area designated for particular activities such as bedroom, kitchen and studying room. Service space is characterized by its short period of occupancy for specific activities such as restrooms (1981, p.57). The table shows different kinds of spaces with the areas and the needs for natural ventilation.

Because each space serves different activities from another, it has unique characteristics. General purpose space serves various activities that can be changed from time to time. Thus, it should be a flexible and opened space that allows a variation of planning according to the needs of users. Most of the functions in this kind of space are for day time where the air is warmer. Therefore, the need for natural ventilation is very high.

Special purpose space can be designed as a more closed space since it serves individuals rather than the whole family. Most of the functions in this type of space are used during the night time where the air is cooler. Thus, the need for ventilation is not as high as the first group. One exception is the kitchen where it can be categorized as either the general purpose space or the special purpose space depending on the use of the family. In any cases, it needs high ventilation since the cooking in Thailand generates a lot of smoke and smell.

<table>
<thead>
<tr>
<th>Space</th>
<th>Area (m²)</th>
<th>Ventilation priority*</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Purpose Space</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>Family</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Dining</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Pantry</td>
<td>7.5</td>
<td>3</td>
</tr>
<tr>
<td>Terrace</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Special Purpose Space</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Bedroom1</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Bedroom2</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Bedroom3</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Balconies</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Studying</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Spiritual Altar</td>
<td>7.5</td>
<td>2</td>
</tr>
<tr>
<td>Service Space</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Restroom1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Restroom2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Washing Area</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Multi-purpose Area</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>Car Park</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>216</td>
<td></td>
</tr>
<tr>
<td>Circulation 15%</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>248</td>
<td></td>
</tr>
</tbody>
</table>

* Ventilation priority ranges from 0 for out door space, 1 as the highest priority to 3 as the lowest priority.

Table 5.2 Users’ requirement for ventilation
Service space has the lowest priority in the need for ventilation since it is occupied for a short period of time. In the modern Thai culture, most households have maids in their houses. Normally, the maids have their own living spaces as well as the spaces for housekeeping jobs such as cloth-ironing and cloth-washing. These areas can be assigned as the multi-purpose space which also include storage.

Thai people have some spiritual requirements for their houses. They need a spiritual altar to keep the images of the Buddha. This space is normally located at the highest point of the house and should be in a private and quiet place that is hidden from the circulation. In addition, Thai people believe that west is the inauspicious direction. Therefore, important elements of the house such as the entrance should not turn to west.

Building Systems

a.) Traditional System

Houses in the past (Fig.5.3) was designed to use natural systems. Wood was used for their structure, building envelope and interior systems. Other natural materials such as hay or clay tiles were used for the roofs. Natural ventilation was the only HVAC systems available in the past.

Advantages
- Short period of construction
- High workability without sophisticated machine
- Encourage natural ventilation

Disadvantages
- Construction materials are scarce
- Highly skilled labor required
- Use more energy if air conditioned
- High maintenance
b.) Conventional Systems

Building materials in today's houses (Fig. 5.4) are mostly composed of concrete and brick. Cast-in-place concrete is used for columns and beams, while prefabricated concrete is used for floors. Walls are masonry plastered with concrete. Roofs are mostly concrete tiles. Openings are glass with aluminum frames. Mechanical systems are artificial, including air conditioning units and artificial light.

**Advantages**
- Low cost
- Intensive labor with low expense
- High rigidity of structure
- Competitive bidding
- Low maintenance
- Fairly long life-cycle

**Disadvantages**
- Long period of construction time
- Great amount of concrete form work
- Skill carpenters and masons required
- High thermal mass and low resistance materials give energy for cooling very high

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c.) Latest Systems

In the latest development (Fig. 5.5), all building materials are imported. They are light-weight materials such as steel structure and gypsum board wall panels. Mechanical systems are mostly artificial including air conditioning system and artificial lighting system.

**Advantages**
- Short period of construction
- High thermal resistance
- Low maintenance

**Disadvantages**
- Costly
- Special skilled labor required
- Hard to repair by users because it is new technology in the region
- Attitude towards structural rigidity is still doubtful

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Fig. 5.4 Systems of the conventional house

Fig. 5.5 Systems of the latest development (Rush 1986)
5.2 The Design

A prototype for a typical house in Thailand is designed based on all of the factors discussed from the beginning. It demonstrates how to integrate all these factors into a built form.

Planning

Due to the topography of Thailand that can be easily flooded, houses should be raised from the ground. The living space should start from the first floor, leaving the ground level for the service space. According to the users' requirement, the living area of about 160 sq.m. should be divided into 2 floors because of the limitation of the land size. The attic space might be used for the spiritual altar. This will create a two and a half floor house on stilts.

The house with a square shape creates several zones and margins (Fig.5.6) defined by Habraken et al. An alpha zone is the indoor area for private use that is connected to an exterior wall. A beta zone is the indoor area for private use that is not connected to an exterior wall. A gamma zone is the area for public use. A delta zone is the outdoor area for private use. A margin is an area between two zones which is named after them (1981, p.108). It shows combined characteristics of both zones or can be a connecting space between the two.

For good natural ventilation, the space with high priority from table 5.2 should be put in the alpha zone that is adjacent to two exterior walls. The space with lower priority can be added later in the alpha zone connected to one exterior wall or in the beta zone. From the site planning study, the wind on the first floor has a higher velocity than that on the second floor. Thus, the high priority space should be on the first floor.
Fig. 5.7 Ground floor plan

The size of most spaces is about 9 sq.m. (100 sq.ft.) or about 3 by 3 meters (10 by 10 ft.). Some spaces need about 4.5 sq.m. (50 sq.ft.) or about 1.80 by 2.40 meters (6 by 8 ft.). These two sizes generate a modular system of 60 by 60 cm. (2 by 2 ft.) which is shown as grid lines in all figures. All of the building components will be designed based on this grid system.

The ground floor (Fig. 5.7) is used for the service space. Its function is similar to that in the past in terms of its usage as a storage, but in a more modern way. It stores cars instead of agricultural tools. The space also serves as a living space for the maid as well as her working area. The first floor (Fig. 5.8) is mostly used for the general purpose spaces. Each space needs connections among themselves. Therefore, the open plan should be used for the first floor. The second floor (Fig. 5.9), on the other hand, is used for the special purpose spaces. They need privacy, thus, individual rooms are appropriate for the planning. The attic space (Fig. 5.10) is for the spiritual altar as it is the highest place of the house.
Building System Design

The design of each building system should select from the advantage of the systems discussed in section 5.1. The structure should be taken from the conventional systems since it has a high performance with low cost. Building envelopes, in contrast, should be taken from the latest systems where the materials have high performances. Although the materials are costly at the moment, they tend to be less expensive if they can be produced within the country. The mechanical systems should be studied from the traditional systems. Natural light should be introduced to the house as much as possible with good controls of glare and heat gain. For the HVAC systems, natural ventilation should be used as an option of the air-conditioning system.

Airflow Design

While the open plan allows the wind to flow with minimum restriction, the stack effect helps draw air out by replacing hot air with cooler air from the low level. Buildings in the Middle East (Fig.5.11) use this strategy effectively. The venting tower at the top of the roof interrupts the wind current and creates a low pressure area (Evans, 1989, p.74). While the inside hot air itself rises, the low pressure at the top draws higher pressure air from the windows below.

The prototype is designed by adopting this technique to improve the indoor airflow by having a venting tower in the middle of the house (Fig.5.12). The lower pressure created by the tower and the buoyancy effect might help pull air from the windows in the lower area. The design needs to be tested with the CFD program to prove that the effect works as expected.
Sun Shading Design

The critical angles from table 5.1 dictate the sun shading devices. The profiles angles on the east and west are very low. Thus, it is recommended that vertical devices be used (Fig.5.13). North and south windows are easier to shade (Fig.5.14). A reasonable length of horizontal shading devices should provide enough shade for both facades. However, on the south side, the profile angles can be very low. Thus, the opening might need a combination of vertical and horizontal shading devices or trees to have enough shade.

Simple models of the house looking from different angles of the sun (Fig.5.15) demonstrate the efficiency of the shading devices. They show that the 1 meter horizontal overhang on the south side is not adequate. They also confirm that the vertical devices on east and west facades should be able to rotate due to the different positions of the sun.

Fig.5.13 Shading design on east and west

Fig.5.14 Shading design on south and north

Fig.5.15 Sun's eye view study
5.3 Input for CFD Simulation

The simulation for the prototype is calculated by a newer version of PHOENICS (2.2.2). This version is different from the previous one in terms of input and output. It has better user interface and has default values for some input. As a result, the input process is more convenient. However, all of the parameters are still the same including dimensions of the simulation field, geometry of the buildings, boundary conditions and calculation numbers.

Dimensions of the Simulation Field

After the simulation of site planning, the results can be used as the local wind speeds for the indoor simulation. In this case, the field of simulation (Fig.5.16) narrows down to be one house and its surroundings. The dimensions of the field are 16 meters (53 ft.) wide, 22 meters (73 ft.) and 20 meters (67 ft.) high. The total amount of cells are approximately 36,000 cells (32 by 34 by 33). In this version, the grids are automatically adjusted to the nearest geometry without any manual setting like the previous version.

The domain settings include some other variable such as the type of model (K-E model in this case) and properties of the air. However, the input is more convenient. For example, by selecting the air, using ideal gas law, will allow the computer to select other properties of the air automatically.

Building Geometry

Building components are input as blockages or plates. Blockages are given for the elements with thickness such as floors and roofs. Plates are assigned for elements whose thickness is not significant such as walls and windows.
Both blockages and plates are treated as solid which do not allow the wind to flow through. Windows and doors in Thailand need a protection from insects by having aluminum screens attached to them. They can reduce the wind speed up to 30%. Thus, they are modeled with the porosity of 0.7 which allow 70% of air to flow through.

In the stack effect cases, CFD solves for another variable of temperature by solving the energy equation. Heat sources inside the space are modeled as hot plates. The heat is given by either fixed temperature or fixed heat flux for each plate.

**Boundary Conditions**

All boundaries in the calculation domain can be set similarly to those in the site planning cases. They can be set as inlet where the wind comes from, outlet where the wind flows out, or plate for the ground. However, the identical boundaries cannot be input in the virtual reality mode of this version. They need the command mode like the previous version to execute this command.

The outlet boundaries are specified for the sky and the opposite boundary of the incoming wind. The identical boundaries are located in the middle of the space between two houses in the same row. The inlet boundary is right at the back walls of the houses in the previous row.

Local wind velocity and direction at the inlet position can be read from the result in the site planning simulation. The wind speed ranges from high speed at the level near the ground (Fig. 5.17) to a low speed at the building level (Fig. 5.18) and high again above the roof level (Fig. 5.19 to 5.22).
Wind data from every point of the inlet are measured to find the average values (Table 5.3). Each average velocity and degree from the normal plane represents the average values of every cell on the same height. They can be grouped to be an easier input for the inlet boundary in the simulation.

Table 5.3 The average wind velocity and direction of the inlet.

<table>
<thead>
<tr>
<th>Cell no. on Z-direction</th>
<th>Average Velocity (m/s)</th>
<th>Average Degree from Vertical Plane (X direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>0.9</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0.45</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>0.55</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>0.6</td>
<td>11</td>
</tr>
<tr>
<td>14</td>
<td>0.7</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>0.9</td>
<td>16</td>
</tr>
<tr>
<td>16</td>
<td>1.3</td>
<td>22</td>
</tr>
</tbody>
</table>
The input can be divided into six groups (Table 5.4) depending on the wind characteristics. Each group has an average wind velocity and direction which represents the average value of every point in the group. The simulations of the house use different amount of cells from the cases of site planning. Thus, the input values need to be adjusted to appropriate cell numbers in the inlet plane. In addition, some inlet areas do not spread from one end to another because they are blocked by the houses in the previous row.

### Calculation Numbers

Iterations can be varied from one case to another. In a case without heat sources such as the wind driven airflow, 500 iterations are adequate to get a good result. More iterations are needed in a case with heat sources such as the combined wind driven and buoyancy airflow. Such case may need as many as 5,000 iterations. The stack effect airflow may need up to 10,000 iterations for a good result. The relaxation can also be varied but it still can use the ratio discussed in the last chapter and test with the preliminary run. An adjustment could be made if the result is not likely to converge.

<table>
<thead>
<tr>
<th>Cell no. on Z-direction from Sita Planning Cases</th>
<th>Average Velocity (m/s)</th>
<th>Average Degree from Normal Plane</th>
<th>Cases of house and Its Surroundings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>1.05</td>
<td>16</td>
<td>1-32</td>
</tr>
<tr>
<td>3-10</td>
<td>0.38</td>
<td>0</td>
<td>8-24</td>
</tr>
<tr>
<td>11-12</td>
<td>0.50</td>
<td>0</td>
<td>4-28</td>
</tr>
<tr>
<td>13-14</td>
<td>0.65</td>
<td>13</td>
<td>1-32</td>
</tr>
<tr>
<td>15</td>
<td>0.90</td>
<td>16</td>
<td>1-32</td>
</tr>
<tr>
<td>16</td>
<td>1.30</td>
<td>22</td>
<td>1-32</td>
</tr>
</tbody>
</table>

Table 5.4 Wind input data for the inlet boundary
5.4 Base Case

The prototype is firstly designed using regular window size. It has the area of openings around 30% of the floor area or 48 sq.m. (530 sq.ft.). The north and south facades each has about 10% opening area or 16 sq.m. (225 sq.ft.). The rest of the openings are on east and west facades. All openings are opened.

Considering only wind driven airflow, the result (Fig.5.23 to 5.25) demonstrates that the wind velocity is not adequate to shift the conditions into the comfort zone. The wind exits almost immediately at the first rows of windows. Thus, the space beyond those windows experiences a very low wind speed, mostly lower than 0.1 m/s. Moreover, the high wind speed at the ground level flows through the staircase without helping draw wind to the living space. It needs some improvement to have a higher wind velocity for the cooling purpose.

Fig.5.23 Airflow in the section of the base case
Fig. 5.24 Airflow in the first floor plan of the base case

Fig. 5.25 Airflow in the second floor plan of the base case
5.5 Effect of Window Size

Case 1 - Improvement of Base Case

Three major changes from the base case have been made. First, the door on the ground floor is closed to draw high-speed wind from the ground level up to the living space. Next, all first row windows are closed to stop the flowing out of the wind. Then, every interior door is enlarged to allow more wind from the rooms at the front to the rooms at the back.

The result (5.26 to 5.28) shows an improvement of the wind speed in the living space. However, the wind velocity in some spaces is still not adequate to shift the conditions into the comfort zone, especially on the second floor where the velocity is still very low. It needs more improvement, for example, the change of window size.

Fig. 5.26 Airflow in the section of case 1
Fig. 5.27 Airflow in the first floor plan of case 1

Fig. 5.28 Airflow in the second floor plan of case 1
Case 2- Small Inlet, Large Outlet

Case 3- Large Inlet, Small Outlet

Case 4- Large Inlet, Large Outlet

The size of the inlet and/or outlet is doubled from 10% of the floor area in the base case or 16 sq.m. (225 sq.ft.) to 20% or 32 sq.m. (450 sq.ft.). Three combinations of small inlet with large outlet (case 2), large inlet with small outlet (case 3), and large inlet with large outlet (case 4) are tested using wind driven airflow.

In case 2 (Fig.5.25), small inlet causes high velocity up to 0.4 m/s in the space right next to the first floor inlet because of the Venturi effect. The velocity in case 3 (Fig.5.26) is lower (0.3 m/s) at the space near the inlet but higher at the space near the outlet due to the Venturi effect. The velocity of case 4 (Fig.5.27) is the most uniformed and highest at 0.3 to 0.4 m/s.

Fig.5.29 Fig.5.25 Airflow in the first floor plan of case 2
Fig. 5.30 Airflow in the first floor plan of case 3

Fig. 5.31 Airflow in the first floor plan of case 4
In general, wind velocity on the second floor is lower than the first floor. The air in the long room on the west side is almost stagnant in both case 2 (Fig.5.32) and case 3 (Fig.5.33). This long room is modeled differently from the original drawing to study the effect of the wind on different spaces. In case 4 (Fig.5.34), the velocity in the long room is much higher with the average about 0.2 to 0.3 m/s. But it still experiences some stagnation at the corners.

Comparing the small room on the north-east, case 2 provides the highest wind speed due to the Venturi effect. In case 3, the air in the small room at the same position is almost stagnant. However, case 3 provides a higher velocity in the small room on the south-east than that of case 2 because of the Venturi effect near the outlet.

Fig.5.32 Airflow in the second floor plan of case 2
Fig. 5.33 Airflow in the second floor plan of case 3

Fig. 5.34 Airflow in the second floor plan of case 4
5.6 Effect of Heat Sources

Hot air rises because it has lower density than cool air. This phenomena is called buoyancy effect. The openings at the top of the house can let the hot air rise and have the cool air replace at the lower level. This section studies the effect of the heat generated inside the house on the airflow.

Calculation of Heat Sources

The discussion of the heat generated in the house is given in section 3.4, but the input for the CFD model uses local heat sources at the actual positions. The sources include people, lighting, appliance and the heat gain from solar radiation. The total amount of the first three and the heat gain via windows and walls accumulates to be 3.3 kW. They are specified in the model as fixed heat flux from hot plates.

The heat from the roof due to solar radiation can be achieved from a computer program named Opaque, developed by the University of California at Los Angeles (UCLA). Opaque calculates the temperature distribution inside building envelopes using the ASHRAE's method. It considers the sun angles and outdoor temperature that can be input by user. Then it creates the sol-air temperature for each surface, taking into account the color of the surface. In a hot climate, the roof should have light color which has the absorptivity of about 0.2. The maximum sol-air temperature is used as the fixed temperature on each outside roof surface in the CFD model. Based on indoor temperature of 30°C, the program gives the maximum sol-air temperatures at 33.9, 38.3, 35.6 an 37.2°C for the roofs that have tilted angle of 25° on the north, south, east and west, respectively. These are based on the roof construction of Table 5.5.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (cm.)</th>
<th>R value (m²·°C/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Air</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Shingle</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Plywood</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Air Space</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Fiberglass</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td>Gypsum board</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Inside Air</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.30</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.5 Thermal resistance of the roof
Case 5- Stack Effect

This case studies the effect of the buoyancy effect inside the house. In case that the outside air is stagnant, the heat generated in the house can create some air movement.

The result (Fig.5.35 to 5.41) shows that the effect can generate the maximum air speed of 0.25 m/s when the heat source is as large as 1 kW such as the stove in the kitchen (Fig.5.39). However, most wind has a very low speed since the height difference of the openings is small. In the venting tower, the velocity inside can be as high as 0.1 m/s, while most living space (Fig.5.40, 5.41) experiences stagnation.

In most space, the hot air rises and is replaced by the cooler air from outside at the lower level. Therefore, the high temperature stays at the high level (Fig.5.36), while the temperature at the low level is almost equal to the outside air.

Fig.5.35 Airflow in the section of case 5
Fig. 5.36 Temperature gradient in the section of case 5

Fig. 5.37 Pressure distribution in the section of case 5
Fig. 5.38 Airflow in the section of the rooms on the east in case 5

Fig. 5.39 Airflow in the section of the rooms on the west in case 5
Fig. 5.40 Airflow in the first floor plan of case 5

Fig. 5.41 Airflow in the second floor plan of case 5
Case 6- Combined Wind Driven Airflow and Buoyancy Effect

This case studies the wind driven airflow from case 4 combined with the buoyancy effect from case 5. The result (Fig.5.43, 5.46, 5.49 and 5.52) represents the actual airflow in the house.

Case 7- Wind Scoop

The case adopts the concept of wind scoop from houses in the Middle East (Fig.5.42). The wind scoop raised above the roof can draw the air from the top to the living space by creating a high pressure area at the front openings. The method is introduced in this case (Fig.5.44, 5.47, 5.50 and 5.53), because the wind has a high speed at the roof top level.

Case 8- No Stack Ventilation

All windows at the venting tower are close in this case to test whether the stack ventilation is appropriate in this climate or not (Fig.5.45, 5.48, 5.51 and 5.54)

Fig.5.42 The concept of wind scoop used in the Middle East (Evans 1989, p.73)

Fig.5.43 Airflow in the section of case 6

Fig.5.44 Airflow in the section of case 7

Fig.5.45 Airflow in the section of case 8
The results from these three cases demonstrate no big difference among them. The main reason is that the airflow caused by the difference of temperature is easily overcome by the prevailing wind (Evans 1989, p.73). Moreover, the air movement caused by the heat has to counter the wind driven airflow in the leeward side of the venting tower. As can be seen, the low pressure area in case 8 (Fig.5.48) is larger than those of case 6 (Fig.5.46) and case 7 (Fig.5.47). As a result, the case without the stack ventilation (Fig.5.51 and 5.54) can have a slightly higher wind velocity in the interior space than the other cases (Fig.5.52, 5.53, 5.55 and 5.56).
Fig. 5.49 Airflow in the first floor plan of case 6

Fig. 5.50 Airflow in the first floor plan of case 7

Fig. 5.51 Airflow in the first floor plan of case 8

Fig. 5.52 Airflow in the second floor plan of case 6

Fig. 5.53 Airflow in the second floor plan of case 7

Fig. 5.54 Airflow in the second floor plan of case 8
CONCLUSION

The investigation presented in this thesis can provide design techniques for the natural ventilation of a typical house in Thailand. The thesis develops a list of comprehensive design guidelines for architects. It includes the guidelines for site planning, building design and time to use natural ventilation. In addition, research is still needed to study natural ventilation for other types of buildings.
6.1 Design Guidelines

Site Planning

1. Houses in a housing project should have a staggered alignment (Fig.6.1). The staggered alignment with an oblique angle to the prevailing wind provides higher wind velocity because it reduces the recirculation at the back of each house.

2. Houses in a housing project should have square shape with openings on the south and north (Fig.6.2). Square shape allows higher wind velocity at the inlet than rectangular shape because houses in the front row do not block the wind to the next rows. The openings should be on the south and north which are the directions of the prevailing wind. They are also easier to shade against the sun than those on the east and west.

3. Plants should not directly block the wind (Fig.6.3). Although the study shows that vegetation does not have a significant impact on the wind velocity at the inlet, it should not be located at the position where it can directly block the wind.

Building Design

1. Houses should be raised from the floor (Fig.6.4). Besides the purpose of flooding protection, the elevated floor allows more wind to flow through the houses. From the environmental point of view, it has less impact on the ecology systems. By being partly unpaved, this kind of design can have less ground coverage area.
2. **Guide the wind from the ground (Fig.6.5).**

The elevated houses have a high wind speed near the ground. It can enhance the indoor wind velocity by having an opening at the windward side on the ground level. The opening at the leeward side on the ground level should be closed to scoop the wind up to the living space.

![Fig.6.5 The use of wind from the ground](image)

3. **Make the plan as open as possible (Fig.6.6).** Open plan allows the highest wind velocity in the interior space. If single rooms are required, some parts of the partitions should be moveable or allow the wind to flow through. Louvered doors are recommended for the interior space.

![Fig.6.6 Closed plan v.s. open plan](image)

4. **Have large openings on the north and south and avoid east and west (Fig.6.7).**

Houses with large inlet and outlet areas have the highest average indoor velocity. Openings should be minimal on east and west, especially near the inlet position. Otherwise, most wind will exit at the first rows of windows, giving the space at the back a lower wind speed.

![Fig.6.7 Openings on east and west](image)

5. **Long rooms should be on the east while small rooms should be on the west (Fig.6.8).** At the inlet level, the air from the previous row of houses tends to move around the house, while the prevailing wind is from an oblique angle, mostly NNE. Thus, the airflow in the house is the resultant of both flows. If the long rooms are located on the west side, the wind from the previous row that tends to move away to the west is enhanced by the prevailing wind. As a result, the space near the east wall experiences a stagnation like the long rooms on the second floor of most cases.

![Fig.6.8 Long room on west v.s. long room on east](image)
On the other hand, long rooms on the east like those on the first floor have different wind patterns. The wind from the previous row that tends to move away to the east is combined with the prevailing wind. The resultant of both flows gives a straight flow through the living space with less stagnant area.

Small rooms can use interior partitions to guide the wind. Therefore, they can avoid the stagnant area occurred in long rooms and can be located on the west.

6. **Locate the space with heat source on the south** (Fig.6.9). The space that generates a lot of heat such as kitchen should be located near the outlet. Because the prevailing wind is mostly from NNE, this space should be located on the south.

7. **Select the size of inlet and outlet from the function of the space** (Fig.6.10). Equal window opening areas can give a different indoor wind velocity. The house with small inlet and large outlet has a higher wind velocity at the inlet than the house with large inlet and small outlet. But the latter case allows a higher wind speed for the space near the outlet. It also gives a more uniform wind speed and has less area of stagnation. Moreover, it has less solar heat gain since large openings are on the north facade where the radiation is lighter.

Therefore, the selection of the opening size depends greatly on the function and furniture layout of the space. However, in general, the space with large inlet and small outlet is better because it allows a higher volumetric flow rate.
Considering the airflow on the first floor from case 3 in the simulation of the house, the flow rate is the product of the inlet area (32 sq.m.) and the average velocity (0.3 m/s). It is equal to 9.6 cu.m. Although the velocity is higher in case 2 (0.4 m/s), the inlet area is much smaller (16 sq.m.). Thus, the flow rate of case 2 in the simulation is equal to 6.4 cu.m. As a result, the cooling effect of the space with large inlet and small outlet is higher. In other words, Venturi effect produced by smaller windows is rapidly dissipated. The effect cannot fall deep into the interior space.

Operating Time to Use Natural Ventilation

1. Period: November to first 10 days of February except hot afternoon. Since the highest velocity inside the house can be only 0.4 m/s, the period of time that can use natural ventilation is the area under v=0.4 line in the bioclimatic (Fig.6.11) or psychometric chart. This area includes most of the time in winter except the last 2/3 of February and some hot hours in the afternoon where the temperature exceeds 29.6°C (85.3°F). The total period of time that can use natural ventilation is approximately 1,825 hours a year (8,760 hours). In other words, it can be used around 21% of the whole year.

2. Time to operate for users. In most cases, largest openings are needed. The exception is only the time in zone 4 (Fig.6.11) where the air is too humid but cool. It is this short period in the night time of January from midnight to 8 a.m. that openings should not be opened to their full width to keep some heat in. In some hot afternoon hours, the users might need to turn on the air conditioning units. However, the air in the winter months is mostly tolerable under the maximum use of natural ventilation.
6.2 Further Research

Different Design of Stack Effect

The study of the stack effect does not support its use in the house because the effect is minimal comparing with the wind driven airflow. The reason is either the height is not adequate or the buoyancy effect counters the wind driven airflow (Fig.6.12). Further study can be made by testing with different height and different design. The outlet area could be only at the top level to eliminate the counteraction of both flows. An airfoil shaped structure similar to the one in Thomas Herzog’s exhibition center in Hanover can enhance the wind flow at the top openings by Bernoulli’s effect. It can also be tested with the CFD model whether it can improve the wind speed in the living space.

Natural Ventilation for Other Building Types

The study of natural ventilation for other building types in the same regions can be conducted using the same methodology as this research. The site planning study can be used for other large site planning projects such as university campus. Government buildings in Thailand tend to use natural ventilation rather than air conditioning systems. Therefore, it is essential to study the possibility to use this system to improve the comfort level.

Possibility to Use Natural Ventilation for the Whole Year

According to the research of Busch, the upper limit of thermal comfort can be as high as 31°C (87.8°F) under the wind velocity of 0.3 m/s for Thai people who are used to natural ventilation (1992). Based on Lechner’s table (table 2.1),
this 0.3 m/s wind has a cooling effect of 1.5 °C (2.7°F). Therefore, the limit for people who are used to natural ventilation (NV) is

\[31 - 1.5 = 29.5°C (85.1°F)\]

under stagnant air and

\[29.5 + 3.3 = 32.8°C (91.0°F)\]

under the wind velocity of 1 m/s. The value is higher than the upper limit for the people who are used to air-conditioning systems (A/C) which is 31.3°C (88.3°F) under the wind of 1 m/s that is used in this thesis. As discussed earlier, the upper limit from NV group cannot be used in this thesis since most people are still used to the air-conditioning environments. However, if the studies of other building types show the possibility to use natural ventilation in the urban environments, this limit can be claimed to be the thermal comfort zone for Thai house. Then natural ventilation can be used for a substantial period of the year. This could save a large amount of energy for cooling systems.

**The Study in Urban Scale**

Wind pattern in the urban area can be very hard to predict. High rise buildings can make a great impact on the local wind. Therefore, it is vital to study the wind pattern if natural ventilation be used in the urban area.

Energy consumption of large buildings in the city accounts for a large portion of the overall energy usage, especially for cooling systems. The main reason is that most designs do not respond to the hot climate. Passive cooling design strategies are ignored. Considering the overall systems (Fig.6.13), this type of design not only consumes more energy (W) but it also emits more energy and pollutants to the environment. It is therefore essential to search for solutions to achieve a climate responsive architecture for a city in the hot region.

![Fig. 6.13 Design for hot climate](image)
Appendix

Input file for site planning case 4 - Houses without trees

TALK=F;RUN(1,1);VDU=X11-TERM

TEXT(AIR FLOW ON SITE FOR THE NNE/SSW WIND)

REAL(UIN1, UIN2, UIN3, UIN4, UIN5, UIN6, UIN7, UIN8)
REAL(UIN9, UIN10, UIN11, UIN12, UIN13, UIN14, UIN15, UIN16)

UIN1=0.84
UIN2=0.98
UIN3=1.07
UIN4=1.14
UIN5=1.20
UIN6=1.25
UIN7=1.29
UIN8=1.33
UIN9=1.37
UIN10=1.40
UIN11=1.43
UIN12=1.46
UIN13=1.48
UIN14=1.51
UIN15=1.57
UIN16=1.63

UF=0.500
VF=0.866

NX=32
GRDPWR(X,NX,32.0,1.0)
NREGY=3
IREGY=1; GRDPWR(Y,5,12,0.1,1.5)
IREGY=2; GRDPWR(Y,83,83,0.1,0.0)
IREGY=3; GRDPWR(Y,3,5,0.1,1.5)
NREGZ=2
IREGZ=1; GRDPWR(Z,13,13,0.1,1.0)
IREGZ=2; GRDPWR(Z,3,7,0.1,1.5)

SOLVE(P1 ,U1 ,V1, W1)
TURMOD(KEMODL)
ENUL = 1.45E-05
RHO1=1.2
FIINIT(U1 ) = 0.7

FIINIT(V1 ) = 1.2

XCYCLE=T

CONPOR(B1, 0.00,CELL , -1.5, -7.15, -3.8)
CONPOR(B1R1, 0.00,CELL , -1.6, -6.16, -9.9)
CONPOR(B1R2, 0.00,CELL , -1.4, -8.14, -10.10)
CONPOR(B1R3, 0.00,CELL , -1.2, -10.12, -11.11)
CONPOR(B1R4, 0.00,CELL , -1.3, -9.13, -12.12)
CONPOR(B1R5, 0.00,CELL , -1.1, -11.11, -13.13)

CONPOR(B2, 0.00,CELL , -13.21, -7.15, -3.8)
CONPOR(B2R1, 0.00,CELL , -12.22, -6.16, -9.9)
CONPOR(B2R2, 0.00,CELL , -14.20, -8.14, -10.10)
CONPOR(B2R3, 0.00,CELL , -16.18, -10.12, -11.11)
CONPOR(B2R4, 0.00,CELL , -15.19, -9.13, -12.12)
CONPOR(B2R5, 0.00,CELL , -17.17, -11.11, -13.13)

CONPOR(B3, 0.00,CELL , -29.32, -7.15, -3.8)
CONPOR(B3R1, 0.00,CELL , -28.32, -6.16, -9.9)
CONPOR(B3R2, 0.00,CELL , -30.32, -8.14, -10.10)
CONPOR(B3R3, 0.00,CELL , -32.32, -10.12, -11.11)
CONPOR(B3R4, 0.00,CELL , -31.32, -9.13, -12.12)

CONPOR(B4, 0.00,CELL , -5.13, -28.38, -3.8)
CONPOR(B4R1, 0.00,CELL , -4.14, -27.37, -9.9)
CONPOR(B4R2, 0.00,CELL , -6.12, -29.35, -10.10)
CONPOR(B4R3, 0.00,CELL , -8.10, -31.33, -11.11)
CONPOR(B4R4, 0.00,CELL , -7.11, -30.34, -12.12)
CONPOR(B4R5, 0.00,CELL , -9.9, -32.32, -13.13)

CONPOR(B5, 0.00,CELL , -21.29, -28.36, -3.8)
CONPOR(B5R1, 0.00,CELL , -20.30, -27.37, -9.9)
CONPOR(B5R2, 0.00,CELL , -22.28, -29.35, -10.10)
CONPOR(B5R3, 0.00,CELL , -24.26, -31.33, -11.11)
CONPOR(B5R4, 0.00,CELL , -23.27, -30.34, -12.12)
CONPOR(B5R5, 0.00,CELL , -25.25, -32.32, -13.13)

CONPOR(B6, 0.00,CELL , -1.5, -43.51, -3.8)
CONPOR(B6R1, 0.00,CELL , -1.6, -42.52, -9.9)
CONPOR(B6R2, 0.00,CELL , -1.4, -44.50, -10.10)
CONPOR(B6R3, 0.00,CELL , -1.2, -46.48, -11.11)
CONPOR(B6R4, 0.00,CELL , -1.3, -45.49, -12.12)
CONPOR(B6R5, 0.00,CELL , -1.1, -47.47, -13.13)

CONPOR(B7, 0.00,CELL , -13.21, -43.51, -3.8)
CONPOR(B7R1, 0.00,CELL , -12.22, -42.52, -9.9)
CONPOR(B7R2, 0.00,CELL , -14.20, -44.50, -10.10)
CONPOR(B7R3, 0.00,CELL , -16.18, -46.48, -11.11)
CONPOR(B7R4, 0.00,CELL , -15.19, -45.49, -12.12)
CONPOR(B7R5, 0.00, CELL, -17,-17, -47,-47, -13,-13)
CONPOR(B8, 0.00, CELL, -29,-32, -43,-51, -3,-8)
CONPOR(BBR1, 0.00, CELL, -28,-32, -42,-52, -9,-9)
CONPOR(BBR2, 0.00, CELL, -30,-32, -44,-50, -10,-10)
CONPOR(BBR3, 0.00, CELL, -32,-32, -46,-48, -11,-11)
CONPOR(BBR4, 0.00, CELL, -31,-32, -45,-49, -12,-12)
CONPOR(B9, 0.00, CELL, -5,-13, -64,-72, -3,-8)
CONPOR(B9R1, 0.00, CELL, -4,-14, -63,-73, -9,-9)
CONPOR(B9R2, 0.00, CELL, -6,-12, -65,-71, -10,-10)
CONPOR(B9R3, 0.00, CELL, -8,-10, -67,-69, -11,-11)
CONPOR(B9R4, 0.00, CELL, -7,-11, -66,-70, -12,-12)
CONPOR(B9R5, 0.00, CELL, -9,-9, -68,-68, -13,-13)
CONPOR(B10, 0.00, CELL, -21,-29, -64,-72, -3,-8)
CONPOR(B10R1, 0.00, CELL, -20,-30, -63,-73, -9,-9)
CONPOR(B10R2, 0.00, CELL, -22,-28, -65,-71, -10,-10)
CONPOR(B10R3, 0.00, CELL, -24,-26, -67,-69, -11,-11)
CONPOR(B10R4, 0.00, CELL, -23,-27, -66,-70, -12,-12)
CONPOR(B10R5, 0.00, CELL, -25,-25, -68,-68, -13,-13)
CONPOR(B11, 0.00, CELL, -1,-5, -79,-87, -3,-8)
CONPOR(B11R1, 0.00, CELL, -1,-6, -78,-88, -9,-9)
CONPOR(B11R2, 0.00, CELL, -1,-4, -80,-86, -10,-10)
CONPOR(B11R3, 0.00, CELL, -1,-2, -82,-84, -11,-11)
CONPOR(B11R4, 0.00, CELL, -1,-3, -81,-85, -12,-12)
CONPOR(B11R5, 0.00, CELL, -1,-1, -83,-83, -13,-13)
CONPOR(B12, 0.00, CELL, -29,-32, -79,-87, -3,-8)
CONPOR(B12R1, 0.00, CELL, -28,-32, -78,-88, -9,-9)
CONPOR(B12R2, 0.00, CELL, -30,-32, -80,-86, -10,-10)
CONPOR(B12R3, 0.00, CELL, -32,-32, -82,-84, -11,-11)
CONPOR(B12R4, 0.00, CELL, -31,-32, -81,-85, -12,-12)
CONPOR(BF1, 0.00, CELL, -13,-21, -79,-87, -3,-8)
CONPOR(BF2, 0.00, CELL, -13,-21, -79,-87, -6,-7)
CONPOR(BR1, 0.00, CELL, -12,-22, -78,-88, -9,-9)
CONPOR(BR2, 0.00, CELL, -14,-20, -80,-86, -10,-10)
CONPOR(BR4, 0.00, CELL, -15,-19, -81,-85, -12,-12)
CONPOR(BR5, 0.00, CELL, -17,-17, -83,-83, -13,-13)

INLET (LOWIN1 , SOUTH, 1, NX, 1, 1, 1, 1, 1, 1)
VALUE (LOWIN1 , P1 , UIN1*1.2)
VALUE (LOWIN1 , U1 , UIN1*UF)
VALUE (LOWIN1 , V1 , UIN1*VF)
VALUE (LOWIN1, KE, 0.001*UIN1*UIN1)
VALUE (LOWIN1, EP, 0.001*UIN1*UIN1)

INLET (LOWIN2 , SOUTH, 1, NX, 1, 1, 2, 2, 1, 1)
VALUE (LOWIN2 , P1 , UIN2*1.2)
VALUE (LOWIN2 , U1 , UIN2*UF)
VALUE (LOWIN2 , V1 , UIN2*VF)
VALUE (LOWIN2, KE, 0.001*UIN2*UIN2)
VALUE (LOWIN2, EP, 0.001*UIN2*UIN2)

INLET (LOWIN3 , SOUTH, 1, NX, 1, 1, 3, 1, 1, 1)
VALUE (LOWIN3 , P1 , UIN3*1.2)
VALUE (LOWIN3 , U1 , UIN3*UF)
VALUE (LOWIN3 , V1 , UIN3*VF)
VALUE (LOWIN3, KE, 0.001*UIN3*UIN3)
VALUE (LOWIN3, EP, 0.001*UIN3*UIN3)

INLET (LOWIN4 , SOUTH, 1, NX, 1, 1, 4, 1, 1, 1)
VALUE (LOWIN4 , P1 , UIN4*1.2)
VALUE (LOWIN4 , U1 , UIN4*UF)
VALUE (LOWIN4 , V1 , UIN4*VF)
VALUE (LOWIN4, KE, 0.001*UIN4*UIN4)
VALUE (LOWIN4, EP, 0.001*UIN4*UIN4)

INLET (LOWIN5 , SOUTH, 1, NX, 1, 1, 5, 1, 1, 1)
VALUE (LOWIN5 , P1 , UIN5*1.2)
VALUE (LOWIN5 , U1 , UIN5*UF)
VALUE (LOWIN5 , V1 , UIN5*VF)
VALUE (LOWIN5, KE, 0.001*UIN5*UIN5)
VALUE (LOWIN5, EP, 0.001*UIN5*UIN5)

INLET (LOWIN6 , SOUTH, 1, NX, 1, 1, 6, 1, 1, 1)
VALUE (LOWIN6 , P1 , UIN6*1.2)
VALUE (LOWIN6 , U1 , UIN6*UF)
VALUE (LOWIN6 , V1 , UIN6*VF)
VALUE (LOWIN6, KE, 0.001*UIN6*UIN6)
VALUE (LOWIN6, EP, 0.001*UIN6*UIN6)

INLET (LOWIN7 , SOUTH, 1, NX, 1, 1, 7, 1, 1, 1)
VALUE (LOWIN7 , P1 , UIN7*1.2)
VALUE (LOWIN7 , U1 , UIN7*UF)
VALUE (LOWIN7 , V1 , UIN7*VF)
VALUE (LOWIN7, KE, 0.001*UIN7*UIN7)
VALUE (LOWIN7, EP, 0.001*UIN7*UIN7)

INLET (LOWIN8 , SOUTH, 1, NX, 1, 1, 8, 1, 1, 1)
VALUE (LOWIN8 , P1 , UIN8*1.2)
VALUE (LOWIN8 , U1 , UIN8*UF)
VALUE (LOWIN8 , V1 , UIN8*VF)
VALUE (LOWIN8, KE, 0.001*UIN8*UIN8)
VALUE (LOWIN8, EP, 0.001*UIN8*UIN8)

INLET (LOWIN9 , SOUTH, 1, NX, 1, 1, 9, 1, 1, 1)
VALUE (LOWIN9 , P1 , UIN9*1.2)
VALUE (LOWIN9 ,U1 , UIN9*UF)
VALUE (LOWIN9 ,V1 , UIN9*VF)
VALUE (LOWIN9, KE, 0.001*UIN9*UIN9)
VALUE (LOWIN9, EP, 0.001*UIN9*UIN9)

INLET (LOWIN10 ,SOUTH, 1, NX, 1, 1, 10, 10, 1, 1)
VALUE (LOWIN10 ,P1 , UIN10*1.2)
VALUE (LOWIN10 ,U1 , UIN10*UF)
VALUE (LOWIN10 ,V1 , UIN10*VF)
VALUE (LOWIN10, KE, 0.001*UIN10*UIN10)
VALUE (LOWIN10, EP, 0.001*UIN10*UIN10)

INLET (LOWIN11 ,SOUTH, 1, NX, 1, 1, 11, 11, 1, 1)
VALUE (LOWIN11 ,P1 , UIN11*1.2)
VALUE (LOWIN11 ,U1 , UIN11*UF)
VALUE (LOWIN11 ,V1 , UIN11*VF)
VALUE (LOWIN11, KE, 0.001*UIN11*UIN11)
VALUE (LOWIN11, EP, 0.001*UIN11*UIN11)

INLET (LOWIN12 ,SOUTH, 1, NX, 1, 1, 12, 12, 1, 1)
VALUE (LOWIN12 ,P1 , UIN12*1.2)
VALUE (LOWIN12 ,U1 , UIN12*UF)
VALUE (LOWIN12 ,V1 , UIN12*VF)
VALUE (LOWIN12, KE, 0.001*UIN12*UIN12)
VALUE (LOWIN12, EP, 0.001*UIN12*UIN12)

INLET (LOWIN13 ,SOUTH, 1, NX, 1, 1, 13, 13, 1, 1)
VALUE (LOWIN13 ,P1 , UIN13*1.2)
VALUE (LOWIN13 ,U1 , UIN13*UF)
VALUE (LOWIN13 ,V1 , UIN13*VF)
VALUE (LOWIN13, KE, 0.001*UIN13*UIN13)
VALUE (LOWIN13, EP, 0.001*UIN13*UIN13)

INLET (LOWIN14 ,SOUTH, 1, NX, 1, 1, 14, 14, 1, 1)
VALUE (LOWIN14 ,P1 , UIN14*1.2)
VALUE (LOWIN14 ,U1 , UIN14*UF)
VALUE (LOWIN14 ,V1 , UIN14*VF)
VALUE (LOWIN14, KE, 0.001*UIN14*UIN14)
VALUE (LOWIN14, EP, 0.001*UIN14*UIN14)

INLET (LOWIN15 ,SOUTH, 1, NX, 1, 1, 15, 15, 1, 1)
VALUE (LOWIN15 ,P1 , UIN15*1.2)
VALUE (LOWIN15 ,U1 , UIN15*UF)
VALUE (LOWIN15 ,V1 , UIN15*VF)
VALUE (LOWIN15, KE, 0.001*UIN15*UIN15)
VALUE (LOWIN15, EP, 0.001*UIN15*UIN15)

INLET (LOWIN16 ,SOUTH, 1, NX, 1, 1, 16, 16, 1, 1)
VALUE (LOWIN16 ,P1 , UIN16*1.2)
VALUE (LOWIN16 ,U1 , UIN16*UF)
Reference


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