

Natural Ventilation Design for the Indochina Market in Aranyaprathet, Thailand

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Abstract

This research investigates the cause of the ventilation problems of border markets in Aranyaprathet district, Thailand and shows how the new design of market prototype designed by the author can solve the problems by natural ventilation. In this study, the Indochina market is the new design outcome.

The Rong Kluea market in Aranyaprathet is well known as the country's largest border market. There are 5 other giant markets built gradually around the old market for several decades. The major problem of these border markets is that they lack wind blowing into the shopping arcade. The inside still air makes people feel hot and muggy.

The survey of several existing markets around the Rong Kluea market area shows that most of the building cases are very hot and humid. Even though, these older buildings are full of shaded roofs and openings above the roof throughout the market walkways, there is little air movement in most buildings in the market.

Literatures explain what the thermal comfort zone is, how to comfort people in such a hot place, how the wind can reduce the heat in tropical environments and how to bring the effective wind into buildings.

The methodology in this research is done in 5 steps. Firstly, the research teams start collecting data of the existing markets. Secondly, the data are analyzed to identify the problems of the existing markets. Thirdly, several models of building elements are created to be alternative designs. Then, the combination of the selective elements are implemented to be a market prototype. Lastly, the new designed market evaluated the effect of the wind into the building and the building nearby. The wind simulation tools used in this study is Computational Fluid Dynamics (CFD).

The new market prototype is designed by integrating the knowledge of natural ventilation in architecture. This study will tell about the process of making a new innovative market. The Indochina market is the result of this study.

Keywords: *Indochina market, wind, natural ventilation, comfort zone, building simulation, CFD*

1. Introduction

Since the Rong Kluea (the salt warehouses), located near Thai-Cambodia border in Aranyaprathet district, Thailand has been converted to the country's largest border market in 1991, the transformed market has known as one of the hottest places for shopping. From the observations and the complaints of people in the websites, the air quality inside the market is very warm and stuffy. The gradual expansions of the new markets around Rong Kluea market area during several decades have shown as the adaptive development of buildings for the better shopping environments. This study is to find out what makes people feel uncomfortable inside these markets.

The weather around the border markets in Aranyaprathet district, during the daytime in summer and rainy season, exceeds the limit of people's comfort zone, according to the researches. In such a hot and humid environment, theories of tropical design recommend that non-air-conditioned buildings need adequate natural ventilation to extend the limit of comfort zone which could make the shopping arcade more livable.

The weather report of Aranyaprathet shows that, in summer and rainy season, the average temperature from March to October is in between 28 - 32 °C and the humidity is in between 60 - 80 %. From the 10-year statistics, the yearly average temperature is 28.1 °C and humidity is 71 %. The highest monthly average is in April which is 30.1 °C. The major wind direction is from the West and the yearly average speed of 4.8 km/h (TMD, 2018). The market buildings in this area have to cope with this high temperature environment.

There is a lot of research of Thermal Comfort in Europe started in 1960's. The comfort zone of people are limited by the air temperature between 20 - 28°C and humidity between 20 - 80% (Olgay, 1963). In order to extend that limit of comfort zone, they need to get more ventilation (Givoni, 1969). Bringing wind into buildings is not only to give fresh air and reduce humid but make people feel cooler by increasing amount of heat transfer from human skin to surrounding air. Wind speed of 0.2 to 1 meter per second is suitable to make people feel comfortable and feel colder down for about 1 to 3 degrees Celsius (Lechner, 2001).

It is important to understand how ventilation help reducing the heat and extending the comfort zone especially in the tropical area. A research in Thailand in 2000's by Khedari with the Thai team shows the range of acceptable room temperature with a variety of wind speed from the fan. The acceptable Thai people in their environment are in higher temperature than the comfort zone of people in colder climate. Culture, economic, living habit and adaptability are the key differences. The research tells that the comfort zone of Thai people sitting in a warm classroom with fan blowing is in the range of temperature between 27.5 - 35.34 °C and humidity between 50 - 78 % at the wind speed of 0.20 - 2.30 m/s (Khedari, Yamtraipat, Pratintong & Hirunlabh, 2000).

Another Thai research by Tantasavasdi, "Natural ventilation design for houses in Thailand" tells that Thai people satisfy living in houses with air temperature between 29.1 - 31.3 °C and humidity between 50 - 80 % with wind speed between 0.20 - 1.00 m/s (Tantasavasdi, Srebric & Chan, 2001). This show that Thai people get used to living in their local natural environments with wind.

The ASHRAE standard, the 2010's research, shows that the operative temperature in higher indoor temperature is acceptable when the outside temperature is comparative higher. The acceptable operative temperature could be as high as 31.7 °C when the outdoor mean temperature is 33.5 °C. The average air speed from 0.6 to 1.2 m/s can also reduce the operative temperature from 1.2 - 2.2 °C (Ashrae, 2013).

In summary, according to the research, the comfort zone of people in the warmer regions is in a higher temperature range than that in the colder regions. However, providing natural wind through indoor activity areas is valuable for the open air buildings in the tropics.

The problems of uncomfortable spaces caused of insufficient ventilation flow in the markets need to be explored. In order to understand the performance of the existing market buildings, the case studies are selected by choosing typical forms of the 4 existing markets, including Rong Kluea Market, Golden Gate Plaza, Benjawan Market and Blue Roof Market. To find out the problems, the 4 cases need to be observed on site and simulated by computer simulation. This study is focused on investigation of the building forms that effect the ventilation flow.

The Indochina market is named after history. Indo-china is a name in the early nineteenth century as a French Colony in a region in Southeast Asia which is the land of mixed culture located in the middle of India and South of china, Including Vietnam, Cambodia and Laos. Indo-china markets are also commonly known as the border markets of miscellaneous merchandise from the Eastern countries of Thailand. In this study, the Indochina market is referred to the new designed market in Aranyaprathat district, Sa Kaeo province, Thailand. The locations of 4 existing markets and the Indochina market is also shown in Figure 1.



Figure 1 Location map of the 5 case studies in Aranyaprathet district (Google, 2018)

2. Objectives

The objective is to find solutions of natural ventilation flow for the new designed market. The study will investigate the qualities of air flow during the design process. The process of making the new market prototype is done by 5 steps. Firstly, the research teams start collecting data of the existing markets. Secondly, the data are analyzed to identify the problems of the existing markets. Thirdly, several alternative models of building elements are created and analyzed. Then, the combination of the selective elements are implemented to be a market prototype. Lastly, the new designed market evaluated the effect of the wind into the buildings. The wind simulation tool used in this study is Computational Fluid Dynamics (CFD).

The new designed building is a real project, “Indochina market”, designed by the author. The market consists of 12 single-story buildings with a total area requirement of 24,000 square meters. Each typical building requires a hundred retail shops. The design of the project is not just to find solutions for a single building but should also care about other buildings in the market as well. The study is emphasized on the building design for natural ventilation by using computer-aided design to analyze the ventilation needs of the market. The design goal is to create a good natural-ventilated market which comfort thousands of users in the market.

3. Materials and Methods

Process of the study is aimed to evaluate the natural ventilation efficiency of the existing markets and design a new market which interacts well with wind. The process of enquiry and design are divided into 5 parts as follow:

3.1 Collecting data

First step of the study is to collect the data from the existing markets by surveying built environments and observing the air conditions around the Rong Kluea area. The 4 case studies of the existing markets are Rong Kluea market, Golden gate plaza, Benjawan market and Blue roof market. The author’s team survey the architectural shapes of the markets and collects the air temperature, humidity and wind speed data inside and outside the markets. The measurements are done in 3 spots of each 4 markets at a level of 1-meter high from the ground. The tests are done within 3 periods of time in a day and 2 times a season during a year. The recorded data of the local weather are also researched by searching in the internet.

The case studies of the 4 existing markets show the shapes of buildings, activities and additional built forms reflecting the adaptive needs of the users in the market, as seen in Figure 2 - 5.



Figure 2 Case study No. 1, Rong Kluea Market



Figure 3 Case study No. 2, Golden Gate Market



Figure 4 Case study No. 3, Benjawan Market



Figure 5 Case study No. 4, Blue Roof Market

3.2 Identifying the problems

The processes of identifying the problems of the border markets are done by analyzing the collected data on site and simulating the ventilation flow into the model of building cases by using computer program, Computational Fluid Dynamics (CFD).

3.3 Alternative Designs

The design part is started by selecting the better design alternatives of each elements, include, roof shape, shop and walkway space, wall opening and roof opening. The selections of building elements is tested by CFD and compared among the design alternatives. The final selections will have better interactive effects of the wind flow.

3.4 Prototype Design

The market prototype is designed and implemented from the selective elements of alternative design. The final design of the prototype is rechecked and readjusted back and forth for the best results by the computer simulation. Then the final prototype are presented in 3D perspectives and models. After the approval by the client, the working drawings of the market are produced. Then the real market buildings are built by the contractor.

3.5 Design Evaluation

The final design is tested by a computer program. The testing subjects of the air atmosphere around the building prototype are ventilation flow, air pressure zone, wind direction and air speed zone. The analysis of the effect of the wind to the adjacent building in the market is another evaluation done by CFD. The measurement of the air condition on site at the built market is done in order to ensure the results of the design outcome.

4. Results and Discussion

4.1 Analyzing the data

The statistic data collected from the 4 existing case studies were analyzed. The temperature, humidity and wind speed of the markets are compared in the Chart 1, 2 and 3. The temperature differences of the inside and outside markets are the key of the study. From the observation, the average outside temperature was 34.1 °C and the average outside humidity was 57.1 %. The average outside wind speed was 0.52 m/s. The market temperature is sequentially shown from high to low; Benjawan Market, Blue Roof Market, Rong Kluea Market and Golden Gate Plaza (Chart 1). The market humidity is sequentially shown from high to low; Golden Gate Plaza, Rong Klua Market, Blue Roof Market and Benjawan Market (Chart 2). The result of wind speed comparison will be shown later in the design evaluation part (Chart 3).

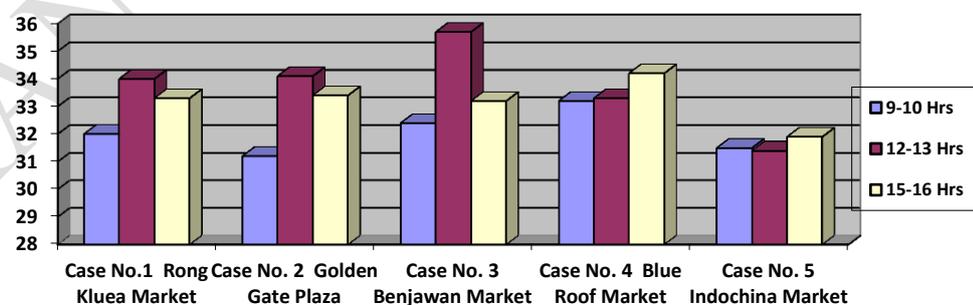


Chart 1 The comparison of temperature inside the markets during a day (°C)

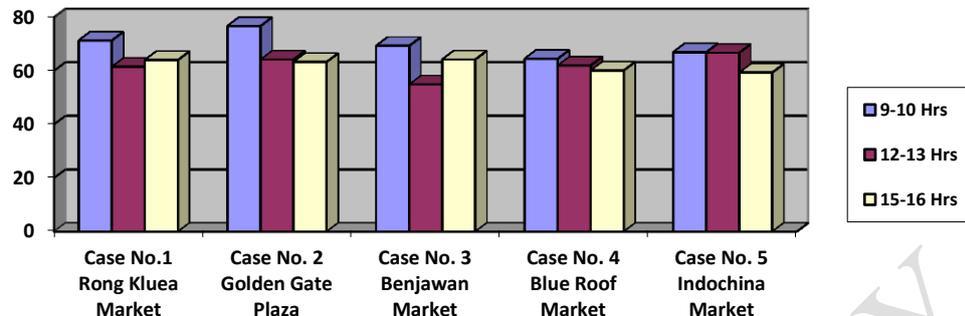


Chart 2 The comparison of the humidity inside the markets during a day (%)

From the reports of the air conditions inside the 4 existing market cases, the average inside temperature of all 4 markets was in between 32.9 - 33.8 °C which was very high above the acceptable operative temperature which is 31.7 °C according to the ASHRAE standard (Ashrae, 2013). These 4 buildings could reduce the heat just about 0.3 - 1.2 °C from the outside air temperature. This is a strong message to the researchers that the existing markets are very hot. And the talk of the town “The hot shopping place” could be the truth. The designing of new market must solve this critical high-heat problem.

The humidity inside the markets was vary between 54.9 - 76.7 % which is acceptable for the comfort zone standard which is in between 20 - 80% (Olgay, 1963). It is interesting that the bigger size and higher roof of the market building, the higher humidity the market has inside. This implies that the moisture can be stored better in the larger scale of the markets. The markets which contain higher heat tend to have lesser humidity as well. However, the further studies of the humidity are recommended.

From Chart 1 and 2, these can be initially concluded that the building case No. 5 performs better than cases No. 1 - 4. The new design building, Indochina Market, can reduce the heat well while the humidity remain in the comfort zone. These results will be discussed later together with Chart 3 in the design evaluation part.

4.2 Identifying problems

The evaluation results of the 4 old markets by wind simulation showed that Rong Kluea Market, Benjawan Market and Blue Roof Market don't have the wind pass through the walkway and shop areas because the enclosed walls of the shops block the wind. The wind from the open roofs blow down very little to the activity areas below according to the blocking of the solid wall of the shops. On the other hand, wind pass through the Golden Gate Plaza building quite well according to the wide opening in both sides of the shophouses. Unfortunately, the frontages of Golden Gate Plaza face outside the building without covered walkways. Visitors have to walk around outside the buildings under the sun. The evaluation results of the 4 existing markets are in Figure 6.

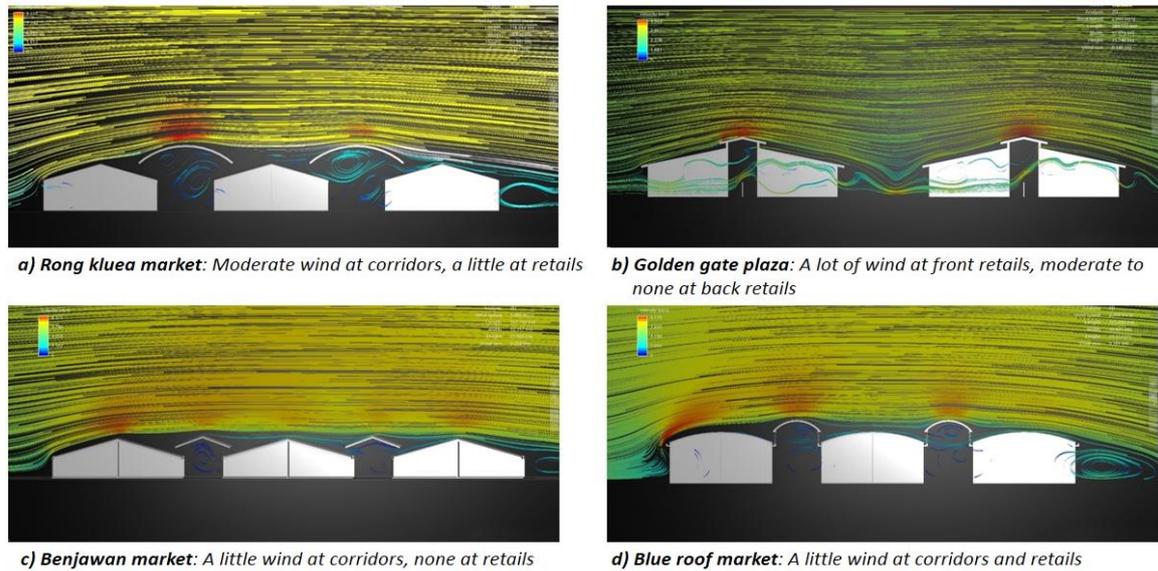


Figure 6 Analysis of ventilation inside the 4 markets (Wind speed of 2 m/s from left to right)

4.3 Alternative Designs

The new design of Indochina Market is a combination of the selected building elements that promote effective winds into the building especially at the walkway and shop areas. Strategies for wind ventilation are explored include building forms, internal spaces, wall openings and rooftop ventilation (Autodesk, 2013). The 4 concepts of forms will be selected from the comparison of each 3 alternatives simulated the air flow by Computational Fluid Dynamics (CFD). The simulations set the outside wind at a speed of 2 m/s flowing from left to right side. The effect of the wind directions can be seen by the line directions. And the speed of wind can be seen respectively from high to low which are the colors of red, yellow, green, light blue and dark blue. The 4 types of the element alternatives and the selections are as follow:

1) Types of roofs

Alternatives of the basic roof forms are lean-to roof, gable roof or curved roof. All alternatives have the same width and height of the roof. The comparison of the simulations show turbulent wind behind the alternative roofs. The wind passes through the curved roof smoothly and takes the fewest distance of the turbulent zone. This will give a better chance for other buildings at the downward side to get the full air intake. Therefore, the selection is the curved roof, See Figure 7.

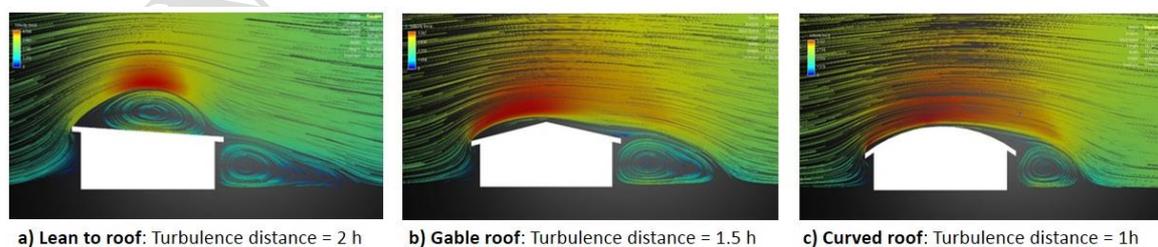


Figure 7 Analysis of the wind turbulence distances by 3 roof types (Wind speed of 2 m/s from left to right)

2) Types of spaces

Alternatives of the shopping spaces are flat space (Horizontal space), elevated space (Vertical space) or combining spaces. From the basic arrangements of shop and walkway spaces, Flat spaces are commonly found in Rong Kluea area according to the minimum requirement of the old markets. There is no cross ventilation at all because the solid walls of the shops block the wind. The elevated walkway spaces

are found after the renovation of the salt storehouses to the covered way market. Although the elevated roofs open to catch the upper wind, the ventilation at the walkway is just moderate. The third alternative is combined spaces which is the idea of separation of shops as kiosks and under a giant roof. The combination of horizontal and vertical spaces with a high roof makes the wind flow well in all over the building. As a result, the selection is the combination of spaces, see Figure 8.

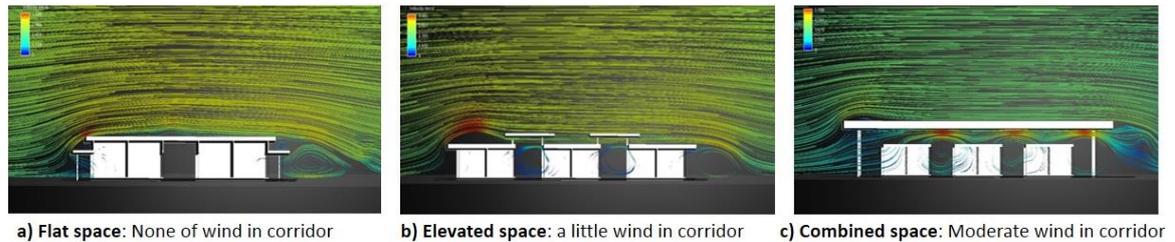


Figure 8 Analysis of the wind effects in walkways by 3 types of spaces (Wind speed of 2 m/s from left to right)

3) Types of wall openings

Alternatives are high-level opening, middle-level opening or low-level opening. The alternative openings are restricted by the proportion 1:2 ratio of the opening in section relating to total height of wall. The 3.5 meter high openings are set in 3 different levels which is at high, middle and low levels. The high-level opening makes the wind flow over the shops and walkways very fast but flow a little down to the activity level. The middle-level opening lets the wind flow down in the middle of the building in moderate speed. The low-level opening provide both direct and turbulent winds to all activity areas which is the most effective alternative. Accordingly, the selection is the low-level openings, as seen in Figure 9.

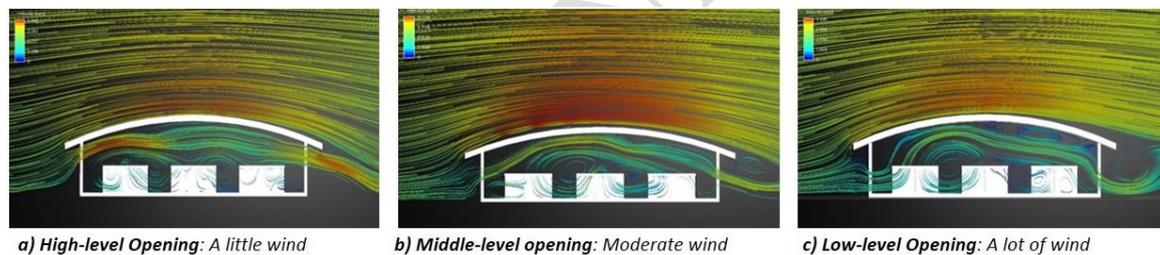


Figure 9 Analysis of the wind at ground level by 3 types of wall openings (Wind speed of 2 m/s left to right)

4) Types of roof openings

Alternatives of the roof openings are roof-top openings, under-roof openings or combination of openings. The roof-top opening creates a little air movement inside the building. The under-roof opening lets the wind flow moderately under the roof. The hot air under the roof is blown down to the floor which may cause the higher temperature at the shopping areas. The combination of both types of openings give the wind flow fluidity with additional of vertical upward wind direction. In order to get rid of hot air under the roof, both openings work together well in pushing the inside air upward though the rooftop. As a result, the selection is the combination of roof-top and under-roof openings, as seen in Figure 10.

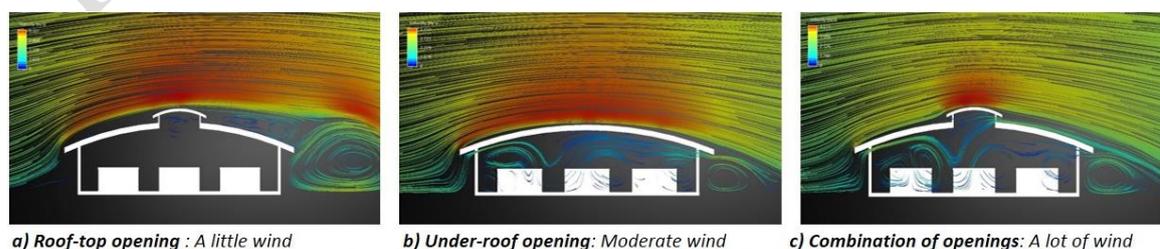


Figure 10 Analysis of the roof ventilation by 3 types of roof openings (Wind speed of 2 m/s left to right)

4.4 Prototype Design

The Indochina Market prototype is mocked up by computer modeling. After the best alternative design elements are selected, the prototype of the market is created by combining those selected elements. The building prototype will be consist of the curved roof, the combination of market horizontal and vertical spaces, the low-level openings and the combination of roof-top and under-roof openings.

The simulation of the market prototype show the combination of what the design needs to be in order to be successful. There is a lot of wind flow through the building. The curve roof guide the wind flow smoothly along the roof. The blending of horizontal and vertical spaces of the retail shops and walkway and the giant space above generate the rotating wind. Like chain belt rotating in a machine gear, the spinning wind distribute the air ventilation to all area of the market. The majority of the wind entering the low-level wall opening give gigantic power to generate the wind machine above the arcade area. The cross ventilation through the breathing walls of shops also helps moving the air at shopping zone. The openings under the roof and at the top of the roof give the direct wind from outside to get rid of the hot air beneath the roof, separated from the wind from the low openings. The 4 separating levels of the winds coming inside perform different roles of ventilation in the market prototype. In summary, the integration of selected elements is a successfully combination which makes the prototype high performance, see figure 11.

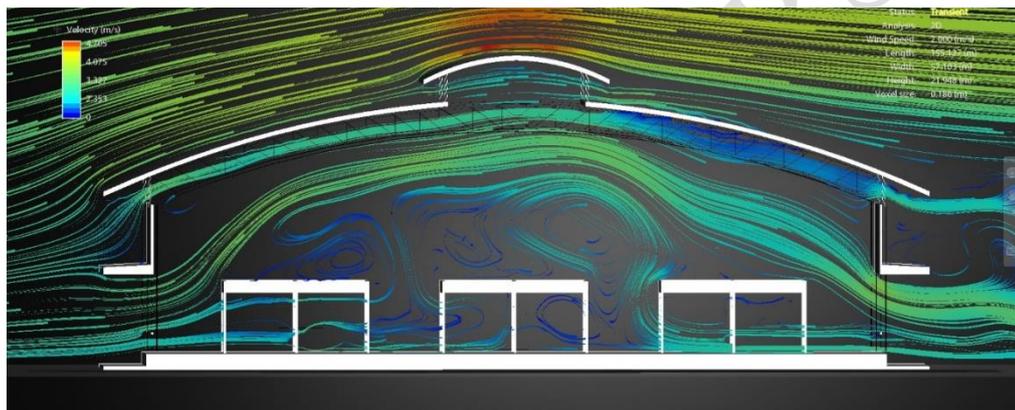


Figure 11 The ventilation flow inside the market prototype (Wind speed of 2 m/s left to right)

In order to complete the design in all dimensions, the perspective illustrations and the mock-up model of the market building have to be made, as seen in Figure 12. The architecture has to meet all other requirements in real situations. The functions, aesthetic, engineering, financial and marketing of the market have to be concerned. The architecture model is built in the scale of 1:50 to convince the client and the market customers by seeing all parts of the market. For the wind study process, the model was also tested by putting the fan at one side and blowing the smoke into the model. Then observing the air movement through the model is observed. Unfortunately the results of this wind tunnel test was not recorded.



Figure 12 The perspective illustration and architecture model of the Indochina Market

4.5 Architectural Design

After approval from the client, the prototype design is developed to the architectural drawings for building construction of the Indochina Market. The actual size of the market building is 30 meter-wide, 66 meter-long and 13 meter-high. There are 2 main entrances at both ends of the building with large canopies and 2 accesses in both left and right sides of the building. All sides have the same large openings in case of changing directions of the wind. The facade of the building is consisted of metal louver and plexiglass instead of solid wall. The breathing louver allow the wind to pass through whereas the unbreakable transparent plexiglass screen the sunlight to the market. The curved roof of the market is made of metal sheet and protected the heat by the insulation of PE (Polyethylene) foam and foil. There are 2 levels of 2-meter cantilevered awning and overhangs at all side of the building. The exposed structure of the building also give freedom to the air movement. The giant shelters of the Indochina Market are shown in Figure 13.



Figure 13 Indochina Market, views around a typical building

The market planning consist of 12 buildings. The spacing between buildings in the market, consisted of roads, car parks and trees, is 16-meter wide which is wider than the height of the buildings. These open spaces could recover the wind speed passing above the upward building to the ground level of the next downward building. Some trees in the middle of the open spaces also help screening the open space pavements from the heat which could cause hot air coming to buildings. Additionally, there are 10 meter wide covered ways between buildings which are built later to accommodate people walking across the roads. The lay-out plan and the bird eye's view of the project are illustrated in Figure 14.



Figure 14 Indochina Market, The lay-out plan and the overall perspective of 12 buildings

The detail designs of the Indochina Market planning are followed. Retail shop enclosures don't have to be solid anymore because there are already protected the sun and rain by a giant roof. Like kiosks, the walls and ceiling of the shops can be just open and partitioning by iron mesh or expanded metal. Then, the airy skins make all spaces inside the building connected and having more free-flow ventilation. The free-flow interior space concept of the first design and the built retail shops are shown in figure 15.



Figure 15 The early interior concept and the built environment of the shopping arcade

4.6 Design Evaluation

1) Evaluation by Simulation

In the process of designing the prototype, the design has been adjusted simultaneously with the wind simulation until it works best (as seen in Figure 11). The Computational Fluid Dynamics (CFD) is a powerful tool which allow the readjustment of the forms, openings and spaces of the prototype. It gives the results of the wind effects promptly whether designs are suitable for the criteria.

The air effects between buildings in the market have also been studied. There are 4 categories in the simulation of the 2 buildings which are ventilation flow, air pressure zone, wind direction and air speed zone, as seen in Figure 16. The results of the simulation show that the first building at the upward wind does not block the wind coming to the second building at the downward wind. Instead, the low air pressure in between buildings bring both the wind passing through the first building opening and the wind coming from above the curved roof to fulfill the air in the front the second building façade as seen by the high air pressure zone. The analysis of the air flow tells that both buildings have quite the same pattern of wind speed. Therefore, the distance between the buildings is acceptable for recovering the speed of wind into the next building.

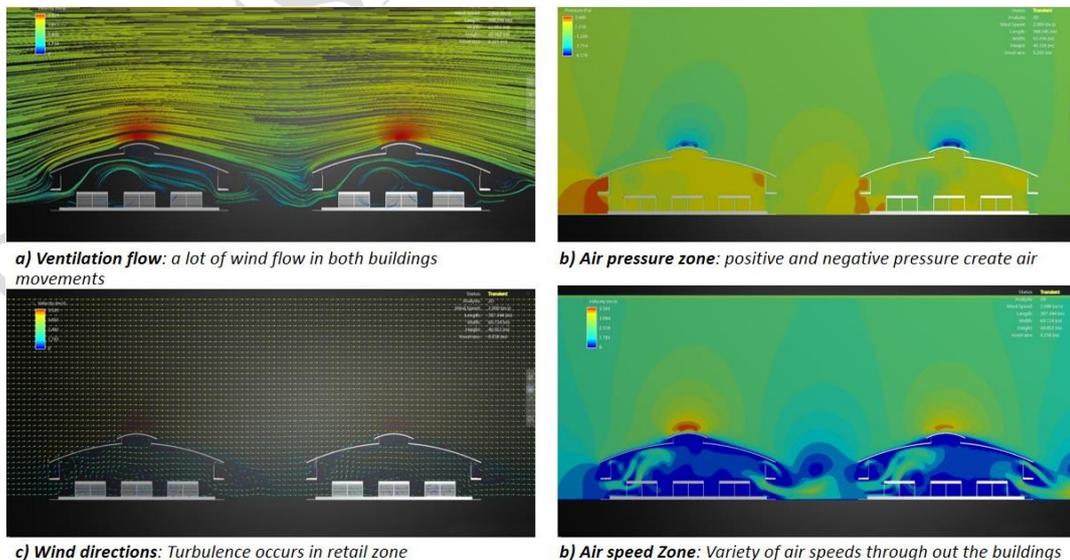


Figure 16 The effects of winds between buildings in the market (Wind speed of 2 m/s left to right)

2) Evaluation by measuring on site

From the results and discussion part in Chart 1, the researchers can also see the results of the temperature in the Indochina Market. The temperature of the new design market is much lower than the others. The average temperature inside is 31.6 °C whereas the outside temperature is 34.1 °C. This tells that the new market can reduce as much as 2.5 °C from the outside temperature. This implies that the high roof of the giant building of the Indochina Market can provide the cooler space compared to the other markets.

The most important design evaluation done by the same investigation of the 4 existing cases is the wind speed test. The wind speed evaluation was measured at the same day of investigating the temperature and humidity of the case studies. After results of the wind evaluation were compared, the performance of catching the wind of the 5 markets can be seen sequentially from the high to the low as follow: Indochina Market, Golden Gate Plaza, Benjawan Market, Blue Roof Market and Rong Kluea Market (Chart 3).

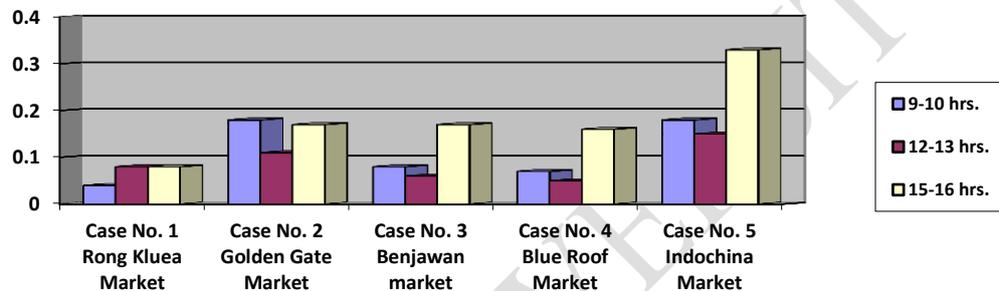


Chart 3 Comparison of the wind speed (m/s) inside the 5 markets during a day

The results of the wind analysis tell that Indochina Market has the best performance among the case studies. The average wind speed inside the Indochina Market in 3 periods of time during a day is from 0.15 to 3.33 m/s and the daily average of the wind speed is 0.20 m/s which is the best among the market cases. However, this should be noted that the data is collected during just several days of the year. According to the study, the average speed of the outside wind is quite low at 0.51 m/s. If the average speed of the outside wind is substituted by the yearly average wind speed from the local weather record which is 1.33 m/s (4.8 km/h), the ventilation flow inside would be much higher. Since the speed of the wind at the shopping area is the key of success for the market design, the new designed market is the winner among the market case studies.

Furthermore, comparing the results of the wind speed to the temperature and the humidity of the market cases (Chart 1, Chart 2 and Chart 3) tells that the higher the wind in the markets, the lesser the temperature and the humidity in the markets. As the result, it shows that the wind plays a major role in reducing temperature and heat perception inside the markets.

In summary, Indochina Market is the best market in Aranyaprathet in terms of having the best natural ventilation performance. Therefore, the design outcome from the process of analyzing the wind is achieved.

5. Conclusion

After gathering the scientific data from 4 existing border markets, it is clear that many cases of the older markets have a condition of hot and humid air and lack of ventilation flow inside the buildings. The researchers also learnt that cross natural ventilation is an effective way to reduce heat in tropical buildings.

From the process of inquiry, computer simulations revealed the problems of the wind flow inside the older building cases of the border markets. These makes the researchers understand why the heat is collected in the building and make people feel uncomfortable. It is understandable why building needs natural ventilation and how building elements effect the wind.

The design techniques of catching the wind into the building is developed through the design process, helpfully by Computational Fluid Dynamics (CFD). The CFD could be more widely used in design

for ventilation in the future. Architects or anyone interested can evaluate the interaction of the wind into spaces and forms. The process of making the market by CFD can help designers a lot during the design process and get the answer immediately and directly to what they need in market buildings.

It is important to consolidate the design concepts by testing the alternative designs of the prototype. The final design is an innovative architecture which is one of the author's pride. The successful Indochina Market was built in 2014 and it comforts thousands of people in the opening year.

However, the further studies of the natural ventilation are recommend. Other ventilation design techniques should be studied to fulfill the design of the market, such as the movement of the air by the temperature difference or stack ventilation. On the other hand, other indicators for the market qualities, such as reduction of heat gain or natural lighting in market buildings, would also be interesting for the market design studies as well.

6. Acknowledgements

The researcher would like to thank the following places, organizations and people for their contribution to my research paper;

Firstly, thanks Rong Kluea Market, Golden Gate Plaza, Benjawan Market, Blue Roof Market and Indochina Market, where the study took place for this research, Indochina Market Trade Center (Aranyaprathet) Co., Ltd. who is a client of the researcher and AUTODESK for the Autodesk Flow Design software that was used in this research.

Secondly, thanks Ass. Prof. Dr. Narupol Chaiyot, dean who promoted this research. Rangsit Research Institute (RRI) who supporting this research funding. Asst. Prof. Somsarit Tanaphan, Asst. Prof. Dr. Paikarn Raksasutthiphon, Asst. Prof. Suwicha Benjaporn and Asst. Prof. Walaiporn Nakapan for giving advise in the research writing and Mrs. Nattinee Atthakorn who was a research assistant.

Thirdly, thanks Faculty of Architecture, Rangsit University (RSU) where the researcher has instructed for 25 years, Council of Thailand who gave the researcher an architect license so the researcher's architecture inventions could be realized, Department of Architecture, Faculty of Architecture, Chulalongkorn University where the researcher graduated with a Bachelor Degree of Architecture (B.Arch), Massachusetts Institute of Technology (M.I.T.) where the researcher graduated with a Master degree of Science in Architectural Studies (S.M.Arch.S.) and Prof. Dr. Eric Dluhosch who was the researcher's thesis advisor at M.I.T. and who directing the researcher in the field of building technology.

Last but not least, thanks Assoc. Prof. Dr. Songkoon Atthakorn who is the researcher's father, professor, boss and best friend who inspired the researcher to the architecture world of education.

7. References

- Ashrae. (2013). ANSI/ASHRAE Standard 55-2013, *Thermal Environmental Conditions for Human Occupancy*. ASHRAE.
- Autodesk. (2013) Wind Ventilation. *AUTODESK Sustainability Workshop*. Retrieved January 8, 2018, from <https://sustainabilityworkshop.autodesk.com/buildings/wind-ventilation>.
- Givoni, B. (1969). *Man, Climate and Architecture*. Amsterdam - London - New York: Elsevier Publishing Company Limited.
- Khedari, J., Yamtraipat, N., Pratintong, N., & Hirunlabh, J. (2000). Thailand ventilation comfort chart. *Energy and Buildings* (vol 32, pp. 245-249).
- Lechner, N. (2001). *Heating, Cooling, Lighting : Design Methods for Architects*. New York: John Wiley & Sons.
- Olgyay, V. (1963). *Design with the Climate* (p. 190). Princeton, New Jersey: Princeton University Press.
- Tantasavasdi, C. Srebric, J. and Chan, Q. (2001). Natural ventilation for houses in Thailand. *Energy and Buildings* (vol 33, pp. 815-824).
- Google maps. (2018). rong kluea market, aranyaprathet. Retrived January 10, 2018, from <https://www.google.co.th/maps/search/rong+kluea/@13.9492531,101.5824255,9z/data=!3m1!4b1>.
- Thai Meteorological Department, TMD. (2018). Yearly statistics data classified by year, Aranyaprathet 2008-2017. *Thai Meteorological Department Automatic Weather System*. Retrieved January 10, 2018, from http://www.aws-observation.tmd.go.th/web/reports/winddir_year.asp.