Design Recommendation for Low Energy Thai Shophouse

Mr. Wattanavit Nilaphanpitak B.Arch. (Architecture)

A Thesis Submitted in Partial Fulfillment of the Requirements for
the Degree of Master of Science (Energy Management Technology)
School of Energy and Materials
King Mongkut's University of Technology Thonburi
2002

Thesis Committee

.... Chairman
(Assoc. Prof. Dr.Joseph Khedari, Ph.D.)

Jongjit Hirunlabh
.... Co-Chairman
(Assoc. Prof. Dr. Jongjit Hirunlabh, Ph.D.)

.... Member
(Assoc. Prof. Dr. Kraiwood Kiattikomol)

.... Member
(Asst. Prof. Dr. Suwimol Asavapisit, Ph.D.)

.... Member
(Dr. Kitchai Jitkhajornwanich, Ph.D.)

ISBN 974-9551-84-2

Thesis Title	Design Recommendation for Low Energy Thai Shophouse
Thesis Credits	12
Candidate	Mr. Wattanavit Nilaphanpitak
Thesis Advisors	Assoc.Prof.Dr. Joseph Khedari Assoc.Prof.Dr. Jongjit Hirunlabh
Program	Master of Science
Field of study	Energy Management Technology
Department	Energy Management Technology
Faculty	School of Energy and Materials
B.E.	2545

Abstract

The aim of this research is to solve the problem of Thailand shophouses, which is too high indoor air temperature and too low air change by using stack-based natural ventilation. First, the research begins with an investigation on the thermal behaviour both in hot and cool season, using a real three-storey shophouse where staircase acts as exhaust chimney. Next, two study models in 1:3 scale approximate were built to simulate the real shophouse, one of them was served as reference whereas the other was modified according to design solution. In this study, three main factors were examined: open/closed roof, with/without prevailing wind and sloped roof. The results of the various design solutions are as follows: opening the roof either horizontal or sloped one can reduce indoor air temperature about 0.1-1.3 °C both in open and closed roof condition. In addition, when solar radiation is low intensity or with high wind regime, small different of both open and closed roof were observed. In case of open and tiled roof, the higher is the tilt angle the better induced air flow. However, in terms of daylighting, design should be aware of solar radiation, which is more influential. Based on these observations, empirical methods were used to predict the performance of proposed design in the real shophouse condition. It was concluded that opened roof can reduce indoor temperature 2-4 °C during the hot season, and 1-2 °C in the cool season depending on the time of a day, incident solar radiation, air velocity and opening areas.

Finally, due to the simplicity of the design recommendations, it is expected that there must be an opening under the roof top level in order to lower the indoor air temperature, induced air flow rate and allow the adequate daylighting. Building standard have to be revised accordingly. In addition, the proposed design recommendation are expected to contribute to significant a saving of the energy consumption in residential Thai shophouses.

Keywords : Shophouse/ Natural ventilation/ Openings/ Stack effect/ Daylighting

หัวข้อวิทยานิพนธ์	แนวทางการออกแบบอาคารตึกแถวประหยัดพลังงานในประเทศไทย
หน่วยกิต	12
ผู้เขียน	นาย วรรธนวิชญ์ นิลพันธ์พิทักษ์
อาจารย์ที่ปรึกษา	รศ. ดร. โจเซฟ เคดารี
	รศ. ดร. จงจิตร์ หิรัญลาภ
หลักสูตร	วิทยาศาสตรมหาบัณฑิต
สาขาวิชา	เทคโนโลยีการจัดการพลังงาน
สายวิชา	เทคโนโลยีการจัดการพลังงาน
พ.ศ.	2545

บทคัดย่อ

ตึกแถวเป็นอาคารที่ถูกพัฒนาเพื่อตอบสนองความต้องการด้านประโยชน์ใช้สอยและด้านเศรษฐกิจเป็นหลัก ขาดการคำนึงถึงความต้องการพื้นฐานด้านกายภาพของผู้อยู่อาศัยในสภาพอากาศร้อนชื้นของประเทศไทย วัตถุประสงค์ของงานวิจัยนี้ คือ การหาแนวทางการแก้ไขปัญหาอากาศภายในอาคารร้อน และ การระบายอากาศต่ำในอาคารตึกแถวโดยใช้วิธีการระบายอากาศแบบธรรมชาติ

แนวทางการแก้ไขปัญหาเริ่มต้นด้วยการศึกษาพฤติกรรมการถ่ายเทความร้อนภายในอาคารตึกแถวจริงทั้งในช่วงฤดูร้อนและหนาว ซึ่งจากการศึกษาและเก็บข้อมูลพบว่าอากาศร้อนภายในลอยตัวขึ้นโดยผ่านทางช่องบันไดจากชั้นล่างถึงชั้นบนสุด หลังจากนั้นเป็นทำการทดลองโดยการสร้างหุ่นจำลองอาคารพาณิชย์-พักอาศัย 2 หุ่นมาตราส่วนประมาณ 1:3 เพื่อใช้ในการทดสอบ โดยหุ่นตัวแรกถูกปรับปรุงเพื่อลดความร้อน ส่วนอีกตัวใช้สำหรับเปรียบเทียบ ซึ่งมี 3 ตังแปรหลักที่ทำการศึกษา คือ การเปิด-ปิดหลังคา อิทธิพลของลมภายนอก และมุมลาดเอียงของหลังคา ผลการทดลองสรุปได้ดังนี้ ประการแรก การเปิดหลังคาสามารถลดอุณหภูมิอากาศได้ 0.1-1.3 องศาเซลเซียส ทั้งกรณีที่มีลมและไม่มีลม ประการที่สอง ในกรณีได้รับอิทธิพลของลมอุณหภูมิของอากาศภายในใกล้เคียงกับอุณหภูมิอากาศแวดล้อมทั้งกรณีเปิดและไม่เปิดหลังคา ประการที่สาม ในกรณีเปิดหลังคาความลาดเอียงของหลังคายิ่งชันอัตราการไหลยิ่งมาก แต่การเปิดหลังคาจำเป็นต้องป้องกันรังสีอาทิตย์ทั้งโดยตรงและสะท้อน นอกจากนี้โดยการคำนวณตามหลักคณิตศาสตร์และการอ้างอิงข้อมูลจากการทดลองคาดว่าการเปิดหลังคาในอาคารพาณิชย์-พักอาศัยจะสามารถลดอุณหภูมิได้ 2-4 องศาเซลเซียสในฤดูร้อนและ1-2 องศาเซลเซียสในฤดูหนาว ทั้งนี้ขึ้นอยู่กับช่วงเวลาของวัน อิทธิพลรังอาทิตย์ ความเร็วลมและขนาดช่องเปิด

ท้ายที่สุดนี้ การเปิดหลังคาสามารถลดอุณหภูมิภายใน เพิ่มอัตราการไหลของอากาศ และแสงธรรมชาติในอาคารได้ ซึ่งมีส่วนช่วยเพิ่มช่วงเวลาสภาวะน่าสบายทำให้ชั่วโมงการใช้เครื่องปรับอากาศลดลง โดยวิธีการนี้สามารถประยุกต์ใช้กับอาคารทั่วไปได้ และเพิ่มมาตรฐานอาคารตึกแถวในประเทศไทย

คำสำคัญ : ตึกแถว/ การระบายอากาศแบบธรรมชาติ/ ช่องเปิด/แสงสว่างธรรมชาติ

ACKNOWLEDGEMENTS

This thesis was prepared at the Building Scientific Research Center (BSRC) of the King Mongkut’s University of Technology Thonburi.

The author wishes to express his deepest gratitude to his advisor, Assoc.Prof.Dr. Joseph Khedari, for his generous advices, patient guidance and precious encouragement throughout the work.

He also wishes to express his gratitude to his Co-advisor, Assoc.Prof.Dr. Jongjit Hirunlabh for her warm encouragement and providing support throughout the entire period of this thesis.

Sincere thanks to Assoc. Prof. Dr. Kraiwood Kiattikomol, Asst.Prof.Dr. Suwimol Asavapisit and Dr. Kitchai Jitkhajornwanich not only for serving as thesis committee members but also for their taking interest and offering helpful criticism of the work.

Sincere thanks go to many colleagues from the Building Scienticfic Research Center (BSRC) whose valuable suggestions and helpful remarks are incorporated into this thesis; Weawsak Jompob, Sarachijti Rangsit, Maneewan Somchai, Puangsombut Witthaya, Khlaimongkol Itthisak, and also Kayam Dumrong, officer of the energy management division for supporting measured instrument.

Special thanks are due to Mr. Suwan Panuampai, the owner of the tested shophouse; and to his family for helping installing equipment for collecting data.

Finally, the author is grateful to his family’s member for their love, support, and encouragement thus led him to this stage of his study program.

CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

SYMBOL		**UNITS**
A	Effective cross-sectional area	m^2
A_i	Inlet cross section area of air flow	m^2
A_o	Outlet cross section area of air flow	m^2
A_r	Ratio of cross section area	
C_d	Coefficient of Discharge	
g	Gravity acceleration	m/s^2
H	Height	m
K	Coefficient of effectiveness	
m	Mass flow rate	kg/s
Q	Volumetric flow rate	m^3/s
T	Temperature	°C
T_o	Outlet temperature	°C
V	Outdoor wind speed	m/s

GREEK LETTER

β	Slope	degree
ρ	Density	kg/m^3

LIST OF TECHNICAL VOCABULARY AND ABBREVIATIONS

h = hour

m = metre

kg = kilogram

m^2 = square metre

m^3 = cubic metre

kg/s = kilogram per second

m/s = metre per second

m/s^2 = metre per second square

m^3/s = cubic metre per second

kg/m^3 = kilogram per cubic metre

CHAPTER 1 INTRODUCTION

By far, shophouse [1] is the kind of building found everywhere in Thailand urban areas, it is a high potential provable building utilized in Thailand for several periods. Shophouses have been developed rapidly due to the high economic growth. However, for economical cost and limited available land, its design is rather poor and does not respond to human comfort need [2]. First, due to the limited opening, there is too low air change rates and too high indoor temperature. To cope with this, using air conditioning has become popular to provide comfort, which leads to a high energy consumption for cooling. Second, most of shophouses do have only one façade, the other sides are interior opaque walls. Therefore, there is no sufficient daylighting; consequently, artificial lighting is used both day and night time.

It is obvious that natural ventilation and daylighting are very attractive solutions for low energy consumption. However, using today design of shophouse, it is practically impossible to realize. The basic approach to natural ventilation in tropical climate should be done by cross ventilation, which may not be practical in many cases.

The purpose of this thesis is to identify the appropriate way to apply natural ventilation with sufficient daylighting without any significant change to the appearance of the shophouse. The aim is to enhance air motion and ventilation flow rate in the shophouse and to provide adequate daylighting without inducing any overheating.

1.1 Introduction to Thai shophouse [3]

The development of shop-houses in Bangkok has changed throughout different periods. The most significance relates to their function from bi-functional into multi-functional usage or mixed-use, Figure 1.1. Accordingly, the spatial division and the ownership patterns have been more complicated. They can be found as department stores, shopping centers, factories and clinics. There are also subdivision of internal space for rental purpose in individually single shop-house. In general, they can be classified into 5 categories as follows:

1. Residential mixed–use shophouse is mainly utilized to reside. And there are also other functions. They are generally found in high density such as commercial zone. Dormitory, flat and apartment can be classified in this type.

2. Commercial mixed-use shophouse is the type that the majority function is used for business activities. They are normally situated in central business center, for instance, department stores and shopping centers.
3. Industrial mixed-use shophouse: This type is used as a factory, which is installed with machines of more than two horsepower or required more than seven employee. It can be seen from printing to steel work factory.
4. Service mixed-use shophouse is mainly used for service business, for example, massage, night club, restaurant, clinic and so on. Some parts of the building are adapted to suit the user's requirement.
5. Other mixed-use shophouse is used for mixed activities apart from those mentioned above. These are wholesale storage, parking, garage with commercial and residential activities.

Figure 1.1 Typical shop-houses

[http://thaispecial.com/yolwaraj.com]

1.1.1 Feature of Conventional Shophouse

The size of shop-house, in general, is 3.5-5.6 m. in width and 8-20 m. depth for each unit. And the height of building is approximately 3-7 storeys. Façade of building is always narrow along the road. The size is a result of prefabricated construction system; moreover, shop-house in the same row must be constructed together, it means that whole building is in the same skeleton. Therefore shop-house is an economic building construction type. And because of shop-house is situated in the limited land; as a result, the area of building must be worthily utilized as much as possible in order to equivalent to opportunity cost of both real estate investor and house owner.

1.1.2 Building Regulations [4]

According to Bangkok Building Regulations, meaning of shop-house contains both residential and commercial accommodation, which is built continuously with more than two units. To enlarge the multipurpose area, inserting a mezzanine floor is often implemented. The mezzanine area must not exceed 40% of the total ground floor area, also this area must have a ceiling height not less than 5 m. The building regulations specify the following.

- Width of the building : the minimum plot width is 3.5 m.
- Staircase : the minimum width of staircase is 90 cm.
- Opening : there must be windows or door connected to external air not less than 20% of each floor
- Height: floor to ceiling should be followed the requirement as shown in table 1.1

Table1.1 Minimum floor to ceiling requirements from the building regulations [4]

Shop-house elements Ceiling height	Ground Floor Ceiling height	Upper floor	
		Natural ventilation	Air conditioning
Hall and commercial	3.50 m.	3.50 m.	3.00 m.
Living area	3.50 m.	3.00 m.	2.40 m.
Kitchen	2.40 m.	2.40 m.	2.40 m.
Toilet	2.00 m.	2.00 m.	2.00 m.

1.1.3 Electricity Use in Shophouse [5]

Various statistics on electricity use in residential housing are available among them that reported in [5], classified the shophouses in groups of electricity units consumed as 0-150, 151-300, 301-500, 501-1000, and more than1001 kWh /month. It was concluded that the average electrical energy use is approximately 724.00 kWh/month, at an average load factor of 41.39%. The maximum electrical energy demand in each group is between 22.00pm - 01.00 am, indicating that resident tend to use air conditioning at night. In fact, according to our investigation, shophouse owners used air conditioning at night to cope with the excessive indoor temperature resulting from the poor design.

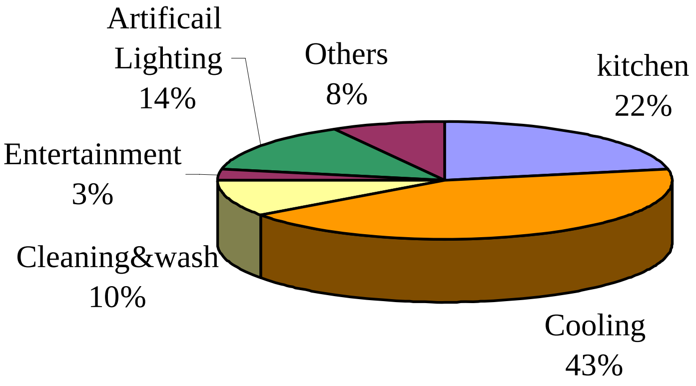


Figure1.2 Electrical energy use in a Thai shophouse [5]

1.2 Objective

The objective of this thesis is to develop a set of practical design recommendations for architects and shophouse builders. The guideline can be used during the design phase to build a reasonably comfortable building. These recommendations are aimed to

- To reduce heat gain and collected heat inside building by natural ventilation.
- To enhance air motion and ventilation rates
- To provide adequate daylighting.

1.3 Scopes of the Research

Actually, Thai shophouses have several forms and adaptations. In this study, we limit our investigation to the following:

- A three storey shophouse has a staircase acting as an exhaust chimney. It is mainly focused on the south façade building. However, roof opening can reduce indoor air temperature and enhance internal air flow, regardless of building directions.
- It is mainly focused on the effect of natural ventilation and building form, other variables such as material type, insulation thickness and etc are not included.
- Two study models are designed to represent the real three storey shouphouse. One of them will serve as a reference whereas the other will be modified for different testing conditions.
- The measured data for analysis will be indoor air temperature, air motion and daylighting.
- Tests will be conducted at the King Mongkut's University of Technology Thonburi.

1.4 Expected Benefit of the Study

The result of the study will be used as a new approach to modify the form of shophouse to be more suitable and sustainable under the tropical climate in Thailand. It is expected that the energy used for cooling the shophouse will significantly decrease.

CHAPTER 2 THEORETICAL ISSUE

Although the term passive cooling is widely used [6], it needs some clarification. This term applies to various simple cooling techniques that enable the indoor temperatures of buildings to be lowered through the use of natural energy sources. The term “passive” does not exclude the use of a fan or a pump when their application might enhance performance.

There are several kinds of passive cooling techniques such as nocturnal cooling, radiant cooling, evaporative cooling, earth cooling and ventilative cooling. A complete review of them is beyond the scope of this thesis.

For Thailand, it is well known that the most appropriate and least expensive is air ventilation. Natural ventilation is achieved by exploiting the pressure differences between the inlet and the outlet locations which provide the power to force the air through the building, Figure 2.1. There are two main ways which are wind (aeromotive force) and stack effect (thermal forces)

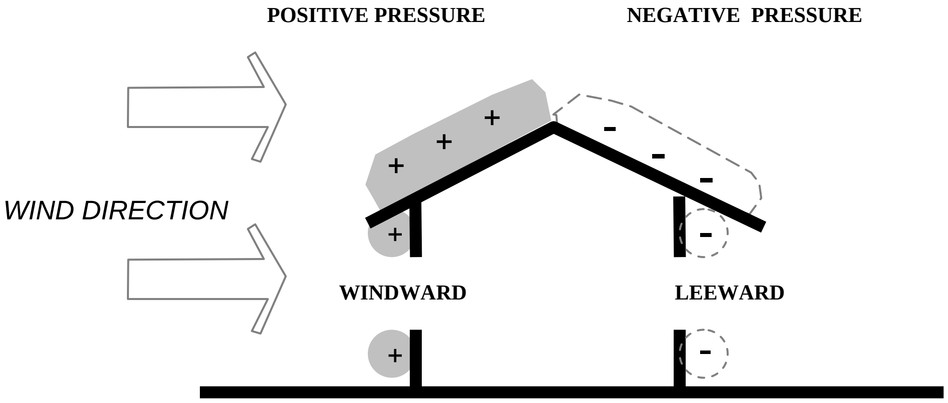


Figure 2.1 Pressure difference is the basic method of natural ventilation.

2.1 Natural Ventilation

In this section, we shall describe the basic techniques widely used.

2.1.1 Single-Sided Ventilation (Aeromotive Force) [7]

This is usually the simplest form of naturally ventilated building where a simple opening in the form of a window or a ventilation device such as a trickle vent on a wall is used to allow outdoor air to enter the building and room air to leave either from the same opening or from another opening situated on the same wall. Although this is a very common and inexpensive system, it is uncontrollable and can only be effective over a distance of about 6 m. from the opening itself. Furthermore, some single-sided openings, e.g. windows, are only suitable in moderate climates and are not suitable for winter ventilation.

2.1.2 Cross Ventilation (Aeromotive Force) [7]

For spaces of more than 6 m. deep a two-sided or cross ventilation will be required. This usually implies using the same openings as those used for a single-sided ventilation system but these are installed on two or more opposite walls. This method can be used for a depth of up to 12m and it is usually more effective than the single-sided ventilation because the wind pressure is more favourable for providing larger air flow rates hence more suitable for larger heat gains. However, this method also suffers from the same problems of air flow control as the previous method.

2.1.3 Stack Pressure (Thermal Force) [8]

The pressure due to buoyancy (stack effect) is an additional component which controls the air leakage through the envelope of a building. It arises due to the differences in temperature, and density, between the air inside and that outside of building. The variation of air density with temperature produces pressure gradients both within the internal and external zones and across the building fabric. When the inside air temperature is greater than that outside, cooler outside air leaks into the building through openings at the lower parts of the building and warm inside air escapes through openings at a higher level. A reversal of the flow direction occurs when the inside air temperature is lower than that outside. The height at which transition between inflow and outflow occurs is the neutral plane where the pressures inside and outside are equal. In practice, the position of the neutral plane is a function of the overall distribution and flow characteristics of the openings, which is seldom known, and the stack pressure is usually expressed relative to the position of the lowest opening or a convenient datum in the building.

2.2 Natural Ventilation in Building Design [9]

Designing a building for optimum natural ventilation means paying much more attention to the various aspects related to airflow movement around and within the building than in generally paid by professionals in current practice.

The aspects of building design related to air movement can be grouped according to their relation to:

- The form of building envelope.
- The internal distribution of spaces and functions.
- The dimensions and locations of openings.
- The effect of fly screens in ventilation.

2.2.1 The Form of Building Envelope [9]

The wind velocity and pressure fields around a building are greatly affected by the form of the building envelope and in particular by:

2.2.1a The Building Height

Changing the height of a building, while keeping length and width unchanged, will produce and increase in depth of the downwind wake without variation of shape. In addition, the wind velocity increases at higher levels inducing an increased airflow rate through the windward openings of the top floors and higher suction at the side walls.

As the building is increased in height, the distribution of the airflow paths around and within it changes. The amount of air passing around the sides of the building increases in proportion to the amount of air traveling over it. This causes less upward air movement through the openings placed on the lower two-thirds of the building windward façade, with a direct influence on the airflow within the spaces inside. The top third of the windward façade of a building will always experience upward airflow, regardless of the height of the building.

Increasing the height of a multistory building causes an additional strengthening of the stack airflow through stairwells and other shafts. This effect can be used for ventilation purposes when the wind flow is weak. However, above a certain height, stratification of air density and temperature may cause an excess in temperature differential between the bottom and the top of a building, which may not be easily eliminated by passive means.

2.2.1b The Roof Form

The form of a roof in a building affects the shape and size of the downwind eddy, as well as the wind pressure distribution on the roof and on the upper parts of the facades. Consequently, the air flow beneath the roof, through attic spaces and rooms located on the upper floor, is modified.

A flat roof, a single-slope roof with a pitch up to 15° or a single-slope roof facing downwind has negative pressures over all the surface at any angle of the oncoming wind. Any opening located in one of these types of roof experiences suction and therefore has the function of an airflow outlet. Above a 15° pitch, when the wind angle is perpendicular to the eaves line, the pressure becomes positive: at a tilt angle of about 15°, in the middle of the slope; at a tilt angle of about 35° over all the surface of the slope.

Both slopes of a double-slope roof are under negative pressure over all their surfaces up to a pitch of 21°, regardless of wind direction. The leeward slope of a double-slope roof is always under negative pressure, regardless of roof pitch. On the windward slope, with wind perpendicular to the eaves line, pressures become positive: at a pitch of about 21°, in the middle of the slope, and at a pitch of about 33°, also near the eaves. Near the ridge, pressure is positive for pitches of between 30° and 41° and negative above 41°.

When the angle of incidence of the wind is 30° to the normal to the eaves line, the windward slope of a double-slope roof is under positive pressure: above a pitch of 22°, in the middle of the slope, and above a pitch of 30°, also near the eaves. Near the ridge, pressure is positive for pitches of between 35°and 50° and negative above 50°.

When the angle of incidence of the wind is 60° to the normal to the eaves line, the windward slope of a double-slope roof is under positive pressure in the middle of the slope and near to the eaves, above a pitch of 30°. The area near to the ridge is under negative pressure up to pitches of over 50°.

Obviously, when a building is surrounded by high rise buildings, the previous analysis no more valid. Discussion of the resulting flow is much more complicated and detailed information on the site should be given. In any way, in condensed areas such as Bangkok, wind regimes are considerably reduced and stack effect design is preferred.

2.2.2 Distribution of Internal Spaces [9]

Interior spaces need to be properly distributed in order to achieve an effective use of natural ventilation. The function of each space, the layout and orientation of the building, and the position of the openings, all are important factors to be considered and, if possible, dealt with in an integrated way.

2.2.2a Horizontal Distribution

The horizontal, or plan, distribution of the internal spaces in a building should principally take cross ventilation into account.

In residential apartment buildings, kitchen and bathroom should be placed on the leeward side of the building, with large windows functioning as outlets of an airflow coming as directly as possible from rooms located on the opposite windward side. This layout allows good ventilation while avoiding transport of odours from kitchen and bathroom to other rooms.

Partitions perpendicular to the airflow path should be kept at a functional minimum in order to limit the obstructions to the flow. In addition, the placement of furniture in a room should be designed in a way that reduces the possibility of hindering the air movement within and across the room.

2.2.2b Vertical Distribution

The vertical distribution of the internal spaces in a building is basically influenced by the air movement created by stack ventilation.

In a two-storey single-family house, spaces generating high thermal gains, such as a kitchen or computer office, should not be placed on the upper level. Furthermore, the living spaces located on the upper level should not be direct communication with the lower level in order to avoid warmed and polluted air from below entering the upper rooms. If the staircase connecting two levels is open, a ventilated filter room should be separated from the rooms on the upper level.

In multi-storey residential or office buildings, particular attention should be paid to the placement of stairwells and other shafts, which should function as exhaust-stack ventilation systems in order to avoid warm air entering the top apartments or office rooms. The outlet openings of the shafts should be positioned on the leeward side of the building, significantly above the top floor level; the inlet openings of the apartment or office rooms should be placed on the windward side of the building.

2.2.3 Position and Size of Openings [9]

The following recommendations should be considered when positioning and sizing the openings of a building:

- Outlet openings should be equal to or greater in size than inlet openings in order to avoid excessive air velocities with a limited airflow rate.
- For occupant cooling purposes, openings should be placed at occupant height (Figure 2.2a)
- For structural cooling requirements, the position of openings should be closer to the thermal exchange surfaces (wall, ceiling or floor) (Figure 2.2b and 2.3)
- The vertical position of inlet openings in two-storey dwellings or high spaces should be lower than the position of outlet openings in order to avoid a conflict between cross ventilation and the stack effect.
- In single-sided ventilation, more than one opening should be provided to a room; these openings should be placed far apart so that a better use of skewed winds can be made; wind deflectors can be used to enhance ventilation within the room.
- When stack ventilation is used in multi-storey buildings, outlet openings should be located in the leeward side of the building; the height of their position and the size of the overall opening area should be chosen as a means of controlling the neutral pressure level and thereby enhancing the ventilation of the spaces.

When structural cooling is foreseen, the building should be relatively massive and a large surface area of the thermal mass should be exposed to the indoor air. This means that suspended ceilings cannot be installed if the ceiling is night ventilated, and similarly elevated (secondary) floors cannot be used if the floor is night ventilated.

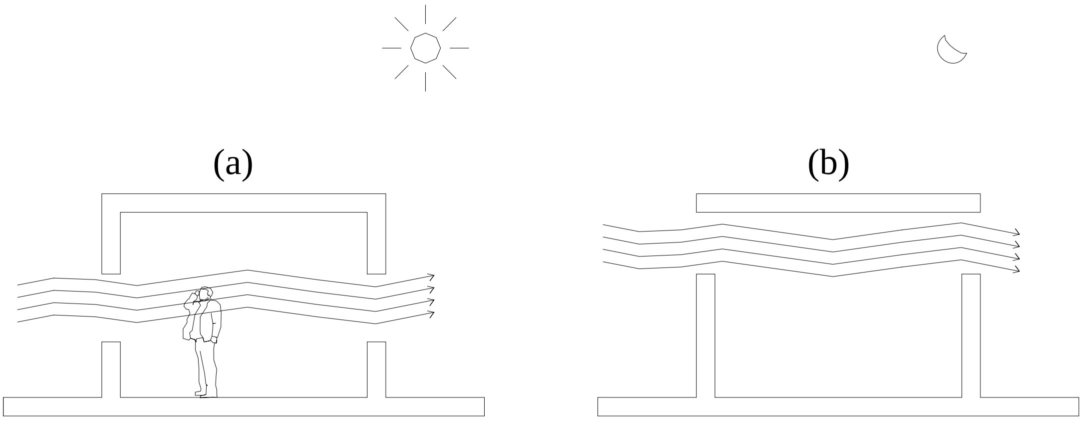


Figure 2.2 Position of an opening for (a) optimum body cooling and (b) structural cooling [9]

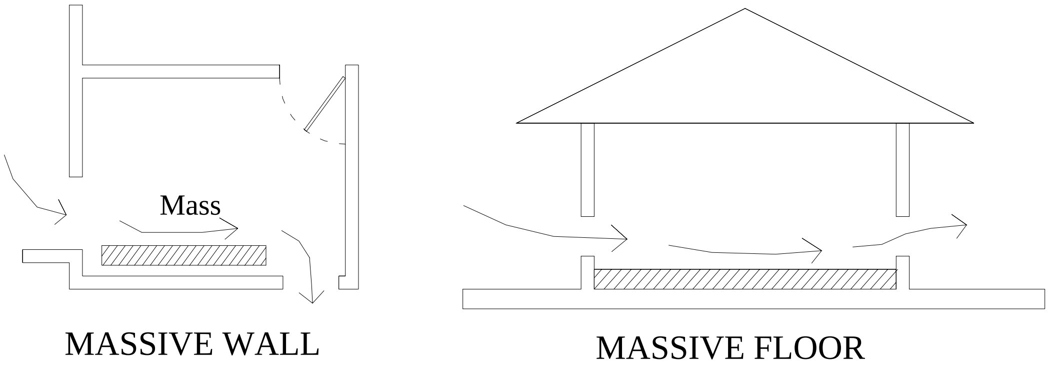


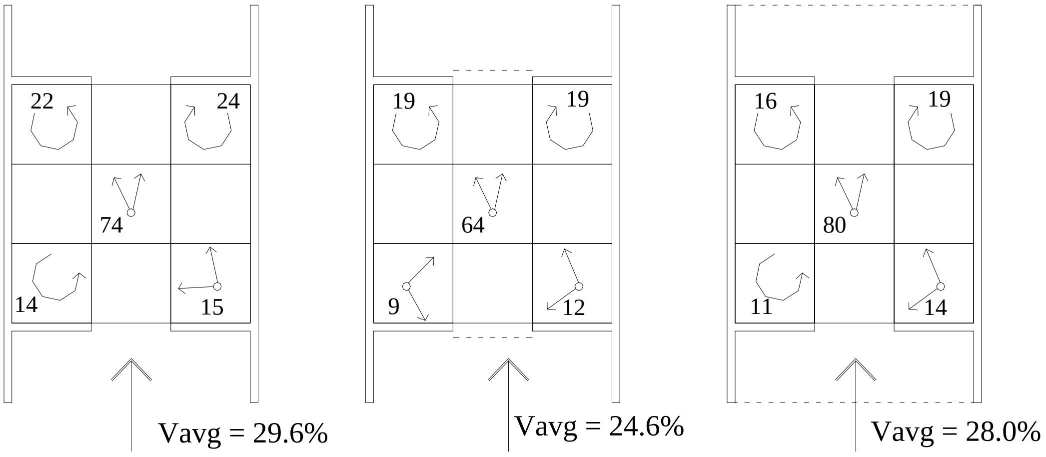
Figure 2.3 Night flushing of exposed surfaces of thermal mass [9]

2.2.4 Effect of Fly Screens in Ventilation [6]

In hot humid weather of Thailand fly screens in the openings are essential. However, from the point of view of ventilation, the air flow is reduced.

Using fly screen, the area of a fly screen must be larger than the area of the opening itself, for example a screen would placed over a terrace in front of the openings- the reduction in airflow would be minimized.

From figure 2.4 shows the average data of tests with one inlet and one outlet when wind direction was directly to the building. The indoor average velocity in percent of external wind speed decreased when screens have been added. However, it is still relatively important.



NO FLY SCREENS

WITH FLY SCREENS
CLOSE TO WINDOW

WITH FLY SCREENS
IN FRONT BALCONY

Figure 2.4 Effect of fly screens on indoor air speed (percent of outdoor speed at the same level).

2.3 The Malqaf (Wind Catcher) [10]

The malqaf or wind catcher has been used since 1300BC by the ancient Egyptians in the 19th Dynasty as illustrated in Figure 2.5 and has been rapidly developed in several areas, including the Arab World. It consists of a shaft rising high above the building with a windward opening to catch the prevailing wind, which is stronger and cooler. The air scoop at the top is usually inclined to the prevailing wind and constructed from brick, timber and the like. The air flow is directed down the shaft, which is usually an air cavity between two skins of a party wall, and into the building which it ventilates, finally being evacuated by suction through a separate vent to the leeward. The internal party wall, cooled naturally during the night through ventilation and shielded from the sun during the day, acts as a cooling element to the interior. Further, air passing down the shaft is cooled by conduction as a result of coming into contact with the cold surfaces of the party wall. With such a system, ordinary windows are not required to provide ventilation.

The malqaf, however, is fixed in place and carefully orientated at an angle to catch the prevailing winds, which may significantly alter in relation to the surrounded buildings, and indeed the building itself. The disadvantage of the malqaf is that, unable to rotate, it can only catch the prevail wind. Its principle function, therefore, is as a climate modifier.

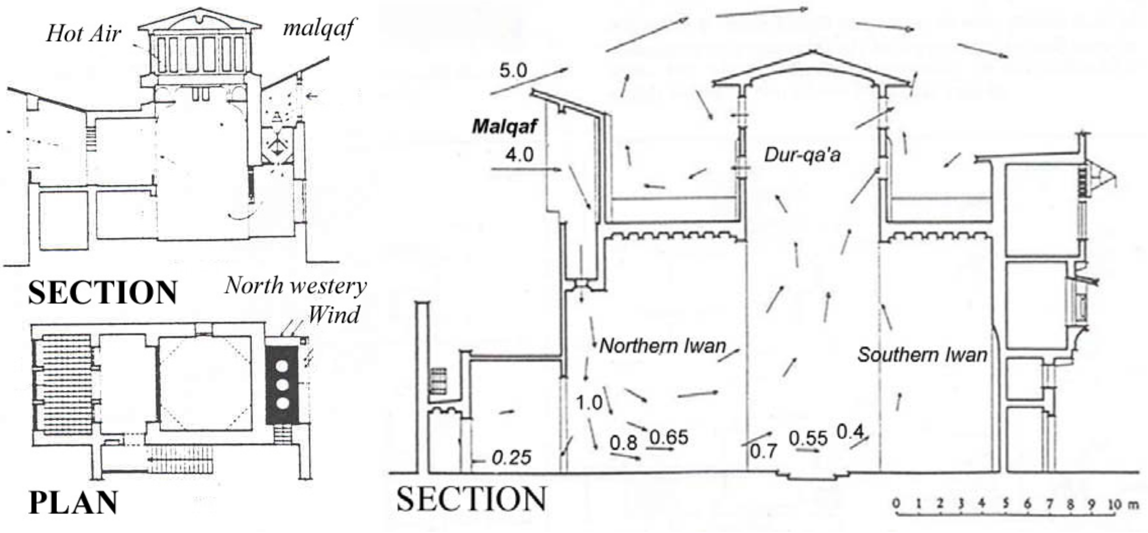


Figure 2.5 Malqaf with wetted baffles and a wind –tower by Hassan Fathy [10]

2.4 Precious Studied on Natural Ventilation

The literature is rich and various reviews are already available in many text books and papers. That is why we limit our review to some papers, the closet to our research objectives.

Jayanetra [2] studied the performance of natural ventilation in the Thai shophouse. The study considered the ventilation rate in the existing shophouse and how the alteration of building parameters might assist in enhancing the ventilation rate. The improvement of ventilation rate, i.e. the effects of the details of the openings, orientation of the building, and location have been simulated by BREEZE 6.32, a software developed by Building Research Establishment (BRE),

The results arrive from on the monitoring of two selected shophouses and the predicted ventilation rate from BREEZE. This study has found that there is a lack of air movement in both shophouses resulting in the occupant discomfort. The overall amount of airflow is adequate for controlling pollution but is poor in terms of air movement for human thermal comfort.

In conclusion, the configuration of the selected shophouses is not appropriate for the location in the urban environment of Bangkok. Due to small diurnal temperature range and lack of prevailing wind, cross ventilation strategy is difficult to accomplish. To provide effective cross ventilation with this type of configuration of shophouses, it would be better to locate it in an open area such as a suburb. For shophouses located in the urban area some mechanical means are needed, which is common, whereas for the buildings in suburbs, natural ventilation can be implemented more effectively.

For ten years approximately, the Building Scientific Research Center (BSRC) of King Mongkut's University of Technology Thonburi has conducted a series of field investigation using the solar chimney ventilation based concept. A significant number of master and doctoral these were completed with a large number of research papers. For example: a Study of a Roof Solar Collector toward the Natural Ventilation of New Habitation [11]; Ventilation Impact of Solar Chimney on Indoor Temperature Fluctuation and Air change in a School Building [12]; Field Measurement of Performance of Roof Solar Collector [13]; Designing of a Thai Bio-Climatic Roof [14]; A simple Ventilation Means and an Efficient Insulating Materials [15]; An Adapted Model of Passive Roof Solar Collector for New Houses with Respect to Traditional Thai Style [16]; Feasibility Study of Night Radiation Cooling in Thailand [17]. With these various solar chimney design such as the roof solar collector, Modified Trombe Wall, Trombe Wall, Metallic Solar wall, BSRC proved the feasibility for solar chimney to reduce heat gain in a house by producing natural ventilation. The above studies were conducted using a single-room school house of approximately 25 m^3 volume [12]. Also experimental observations indicated that opening the window and door (single-side ventilation) is less efficient than using solar chimneys. In other words temperature difference between room and ambient is higher than that obtained from solar chimney. The air change rate varied between 8-15 air change per hour. It is therefore expected to be well appropriate for any type of areas and buildings such as shophouses.

More recently, BSRC has developed an original configuration of bioclimatic design that can permit, in addition to the above advantage, to admit daylighting without any overheating, Waewsak [14].

It should be pointed that BSRC approach is to use common modern styles and construction materials available in the market.

It is evident that several research works were conducted worldwide on the solar chimney based ventilation system. Among them, there is a study conducted by Bansal [18] who developed a mathematical model for a solar chimney used to enhance the effect of thermally induced ventilation in buildings. The model takes into consideration different sizes of the openings of a solar chimney with varying values of the discharge coefficients. Numerical calculations performed for different values of ambient temperature and solar radiation showed that a solar collector area of 2.25 (m^2) with room 4x4x4m is able to induce an air flow between 140 (m^3/h) to 330 (m^3/h) for solar radiation of 200 (W/m^2) and 1000(W/m^2) respectively.

When a solar chimney has coupled with a wind tower [19], it was estimated that the effect of a solar chimney is relatively much higher for lower wind speeds. For ambient wind speed of 1.0 m/s for example, the wind tower alone creates a mass flow rate of 0.75 kg/s only, while the solar chimney assisted system it is able to create an air flow up to 1.4 kg/s at 700W/m^2 incident solar radiation. The authors also suggested the concept of combined effect of aeromotive and thermal forces to create airflow in a building. For the calculation in a wind tower, thermal forces are negligible, whereas in a solar chimney the dominant airflow is created by thermal buoyancy.

An other important work was reported by Peppes and Santamouris [20] who developed a more accurate model for the estimation of buoyancy air flow through horizontal openings, by focusing on the impact of several parameters on the phenomenon, such as complex geometries inside real buildings, instability of flow and interchange of fluids at the openings. A series of experiments was performed in order to study the coupled flows of mass and heat between the three floors of a full-scale residential building. A single tracer gas decay technique was adopted. Air flow rates through the specific stairwell were estimated using the computational fluid dynamics (CFD) method. These rates showed very good agreement with the corresponding values provided by the formulas, proposed in an earlier study.

Also, it is worth to mention the work done by Parker [21] who described the measured air-conditioning and thermal performance of a typical Thai single family residence. Although the measurements represent a single case study, it is the first time that an analysis has been performed on a Thai House with typical modern construction. In such building, the lack of building thermal insulation such as attic radiant barrier or white-colored reflective roof surfaces, the utilization of non-ducted air-conditioning equipment and the night-only usage patterns are quite different from conditions prevailing in Western-style buildings. The results showed that reduction to ceiling heat transfer in residential Thai building is fundamental to improving cooling energy efficiency.

Tantasavasdi [22] explored the potential of using natural ventilation as a passive cooling system for new house designs in Thailand. The characteristics of past and present Thai houses are analyzed in terms of climate, culture, and technology. Based on the thermal comfort requirements for the Thai people and the climate conditions in Bangkok, the study found that it is possible to use natural ventilation to create a thermally comfortable indoor environment in houses in a Bangkok suburb during 20% of the year. This study also developed comprehensive design guidelines for natural ventilation at both the site planning and individual house levels by using computational fluid dynamics.

The work reported by Ajibola [23] indicated that a design of windows in modern buildings in a warm, humid climate, influenced either by the use of physiological and psychological comfort or aesthetically appealing fenestration. In the past few years in Nigeria, emphasis has been laid on the latter, while the former, which is the primary objective of building design, has been relegated to the background. The research examined the factors contributing to the effective ventilation of spaces in a warm, humid climate using buildings in government residential areas as a case study. He concluded that most spaces in modern building are not adequately ventilated and recommended that effort should be directed towards the use of windows to achieve physiological comfort.

2.5 Mathematic Model

The volumetric air flow rate between the two floors (buoyancy-driven stairwell flow) [18] can be approximated using the following found

$$Q = 0.1469\ A\ (gH)^{1/2}\ (\Delta T/T)^{0.3} \qquad (2.1)$$

Q = Volumetric flow rate (m^3/s)
0.1469 = Coefficient of buoyant air flow through stariwell
A = Effective cross-sectional area of the opening connection the floors (m^2)
H = Height (m)
g = Acceleration due to gravity (m/s^2)
ΔT = Average air temperature difference between two adjacent floors (°C)
T = Mean absolute air temperature of two adjacent floors(K)

The air flow rate due to wind force can be estimated as: [6]

$$Q = KAV \qquad (2.2)$$

Q = Volumetric flow rate (m^3/s)
K = Coefficient of effectiveness (0.5-0.8)
A = Area of smaller opening (m2)
V = Outdoor wind speed (m/s)

The Air flow rate induced by a tilted roof chimney (thermal force) can be calculated the formula suggested by Bansal [16]

$$Q= C_d A_o \{2(\Delta T/T_o) g H \sin\beta\}^{1/2} \{(1+A_r^2)\}^{1/2} \qquad (2.3)$$

Q = Volumetric flow rate (m^3/s)
C_d = Coefficient of Discharge (0.5-0.8)
A_o = Outlet cross section Area of flow (m^2)
A_i = Inlet cross section Area of flow (m^2)
ΔT = Temperature difference (°C)
T_o = Outlet temperature (°C)
H = Height (m)
g = Acceleration due to gravity (m/s^2)
β = Slope (degree)
A_r = A_o/A_i

CHAPTER 3 METHODOLOGY

The problem of shophouse as mentioned in chapter one is the very low ventilation rate and the high indoor temperature. Obviously, the best way to arise the thermal performance of a building and the benefit of design solutions as well is to conduct field tests using a real building. However, the experiment can not be done in real shophouse where inhabitant still lives. In addition it necessitates a long time test period that largely exceeds the scope of this master thesis. To cope with this problem, our methodology is as follows: First, we will collect hourly indoor condition in a real shophouse. The collected data will help us to better understand the thermal behaviour of the house and to find out appropriate solutions. Next, two study models in 1:3 scale approximately will be used to simulate the shophouse and the modified one according to the proposed design solution. Six practical designs will be tested and analyzed. The comparison between the recorded daily data will permit us to propose the most appropriate method to be recommended for constructing Thailand shophouses in order to be more comfortable with a less demand for electricity.

3.1 Description of the Selected Shophouse

The selected shophouse is a common naturally ventilated three storey building where the staircase acts as an exhaust chimney. It is located on soi Charaenkrung107 in the Bangkok Metropolitan area. The house has a southern façade and the north is a canal. Figure 3.1 shows the location of the shophouse and Figure 3.2 gives view of building. The ground floor, see figure 3.3, consists of pharmacy, dining area and kitchen. On the second floor, there are a bed room and a multipurpose area. The third floor includes a master bedroom, working area and a balcony. The structure of building is reinforced concrete with brick masonry wall. The roof on the top is flat slab, without neither insulation nor attic ventilation. The master bedroom ceiling is 9mm gypsum board.

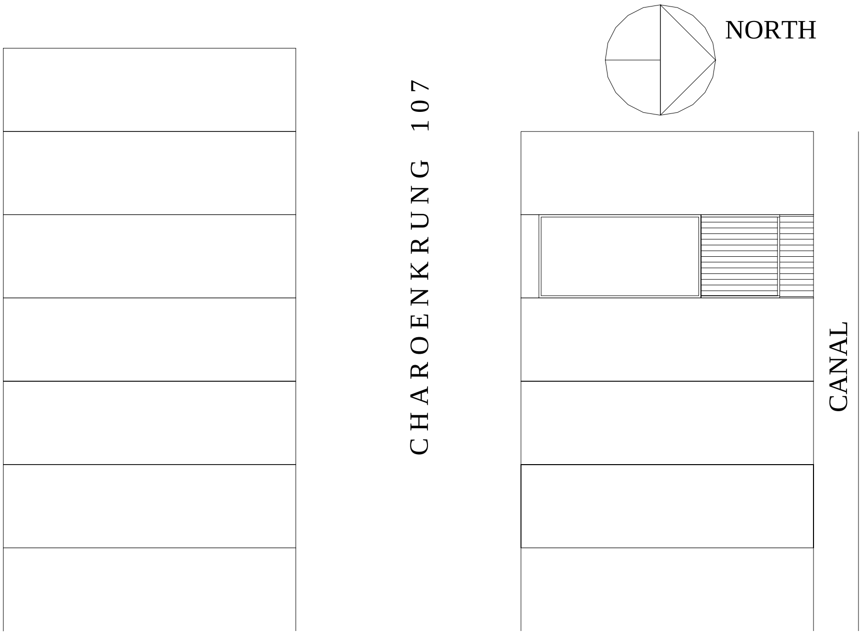


Fig 3.1 Location of the shophouse

Figure 3.2 Left side - view to the canal on the back side and

Right side-view from the road (the south façade) on the front

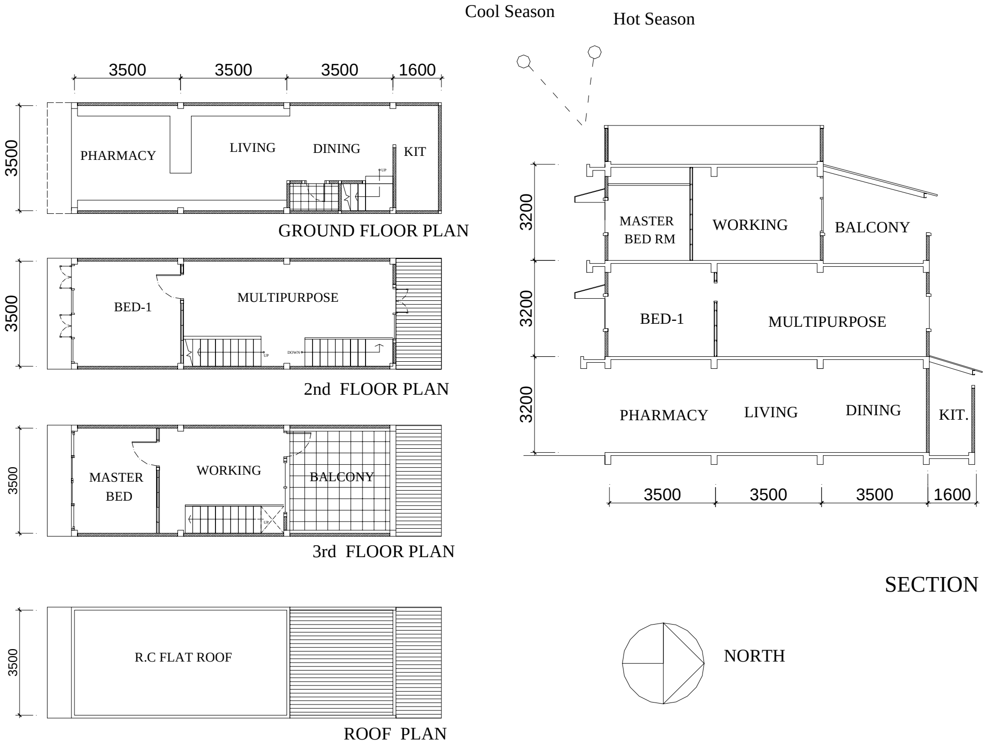


Figure 3.3 Plan and Section of shophouse

3.2 Description of the study models

The design of the study models was made not only to simulate the shophouse, but also be to permit us to make various modifications according to our design including of openings, wall and roof, figure 3.4. First of all, each model has four openings (size 0.4x1.0m) located at the northern and southern sides and two attic openings (size 0.2x1.0m). Secondly, the walls held on wood truss were built using cement board 4mm thick, whose properties are almost the same as those of concrete. The eastern and western walls were protected from the sun using an external wall layer 10 cm spaced from the internal walls (see Figure 3.5). In this case, the double walls concept acts as a solar chimney vented insulation material which has been extensively studied by researchers from BSRC. In fact, in the real shophouse heat transfer from these long sided walls can be neglected because they are blocked by the neighbor right and left shophouses. Finally, the tilt roof can be adjusted (Figure 3.4 and3.5) from 0°(flat roof) to 25°, tilt angle with both closed and open configurations.

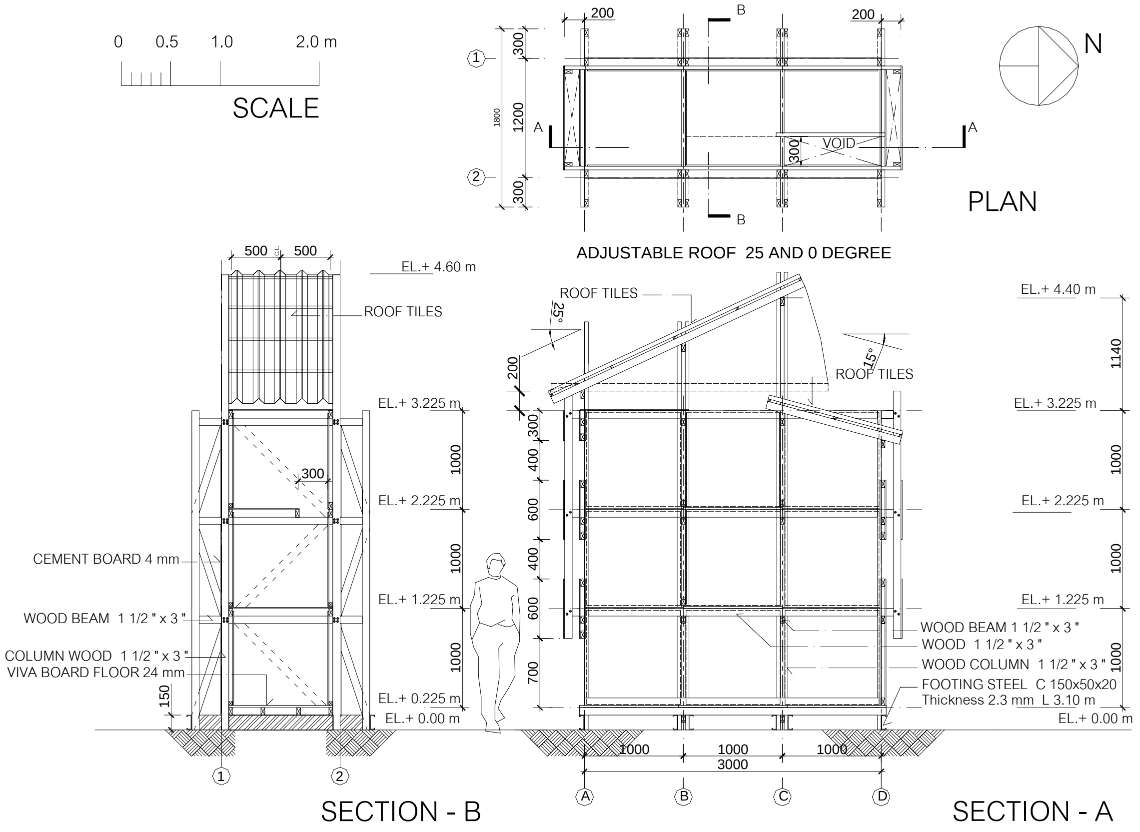


Figure 3.4 Dimensions of the model

Figure 3.5 The two study models

3.3 Instruments and Measurement

In this study, four instruments are used to collect data of air temperature, relative humidity, velocity and indoor illuminance. Thermocouple type K are used to measure temperature connected to a data logger (Figure 3.6) range of 0-1250 °C (for calibration see appendix A). Hot wire anemometer (Figure 3.7) is used to measure air velocity in the range of 0-3 m/s, with an approximate error value of 2%. Lux meter (Figure 3.8) was used to measure the indoor illuminance. Finally, Testoster 175-2 (Figure 3.9) was used to record air temperature and relative humidity.

Table 3.1 Instrument in experiment

Parameter	Instrument
1. Temperature	Thermocouple type K, Data logger 12 channels
2. Temperature & humidity	Testostor 175-2
3. Air velocity	Hot wire anemometer
4. Illuminance	Lux meter

Figure 3.6 Datalogger 12 channel

Figure 3.7 Hot wire anemometer

Figure 3.8 Lux meter

Figure 3.9 Testostor 175-2

3.4 Data Collection

In this experiment, there are two kinds of measurement. The first is field test using a real shophouse while the other is field test using the study models for different conditions.

3.4.1 Field test measurement

The field test is to collect hourly temperature data two different periods namely on January 14-18,2002 (cool season) and on May 4-7,2002 (hot season) in real shophouse. Figure 3.10 shows position of air temperature measurement. The explanation of symbols used is given in Table 3.2

Table 3.2 Abbreviation used in experiments (Field test)

Tg	Temperature of air on ground floor (dining area)
$T\ 2^{nd}$	Temperature of air on the second floor (multipurpose area)
$T\ 2^{nd\ ,n}$	Temperature of air on the second floor (multipurpose area) on the north side
$T\ 3^{rd}$	Temperature of air on the third floor (working area)
T st, bottom	Temperature of air at the bottom of staircase
T st, mid	Temperature of air on the middle of staircase
T st, top	Temperature of air on the top of staircase
Tmst,bed	Temperature of air masterbed room on the 3rd floor
Tbed	Temperature of air bed room on the second floor
Tamb	Temperature of air ambient measured at the balcony

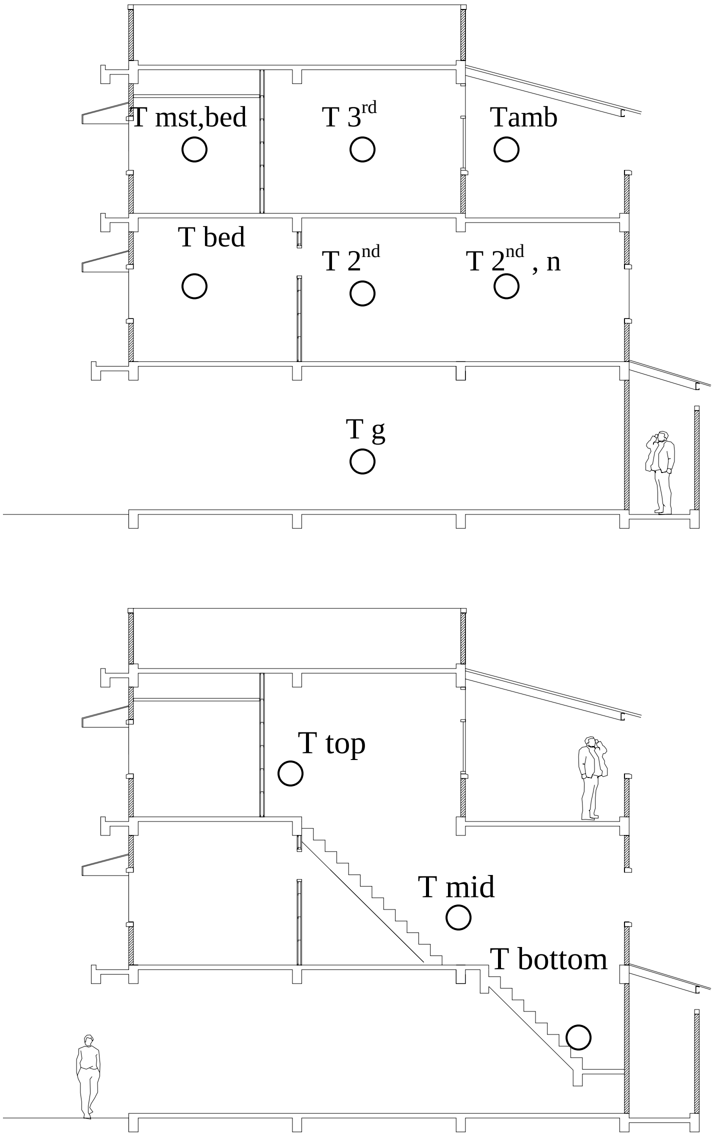
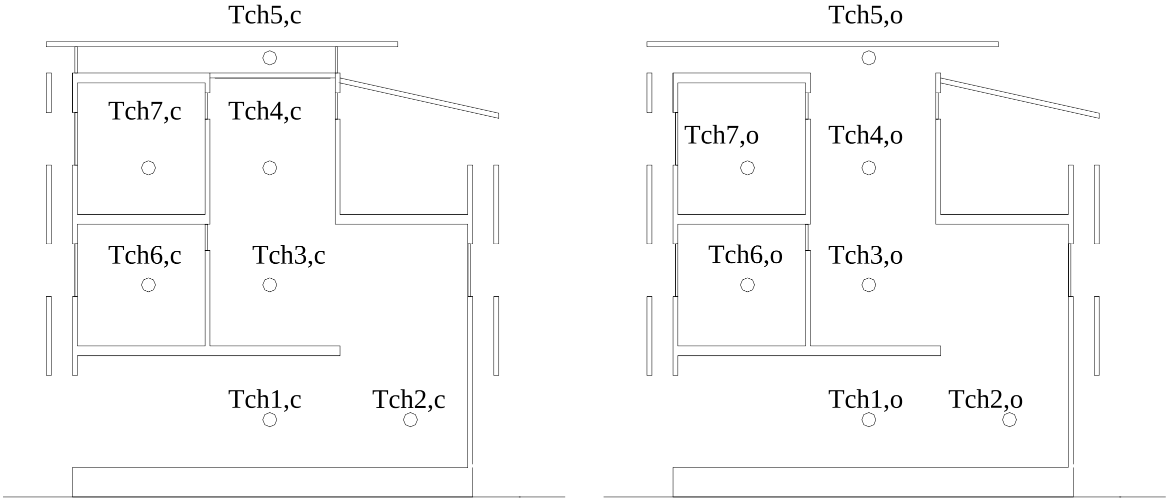


Figure 3.10 Measuring points in the shophouse (Field test)

3.4.2 Study model test measurement

The two models are tested simultaneously in the same surroundings. In each test, one has always a closed roof whereas the other has always an opened roof. In a model, there are seven points where air temperature are measured as précised in figure 3.11. Table 3.3 gives the abbreviation of symbols used.



CLOSE ROOF OPEN ROOF

Figure 3.11 Position of measurment in the two models (model test)

Table 3.3 Abbreviation used in experiments

$T_{ch1,c}$	Air temperature on ground floor, closed roof
$T_{ch2,c}$	Air Temperature on ground staircase, closed roof
$T_{ch3,c}$	Air Temperature at 2nd floor staircase, closed roof
$T_{ch4,c}$	Air Temperature at 3rd floor staircase, closed roof
$T_{ch5,c}$	Air Temperature at above ceiling, closed roof
$T_{ch6,c}$	Air Temperature at 2nd floor closed room, closed roof
$T_{ch7,c}$	Air Temperature at 3rd floor closed room, closed roof
$T_{ch1,o}$	Air Temperature on ground floor, opened roof
$T_{ch2,o}$	Air Temperature on ground staircase, opened roof
$T_{ch3,o}$	Air Temperature at 2nd floor staircase, opened roof
$T_{ch4,o}$	Air Temperature at 3rd floor staircase, opened roof
$T_{ch5,o}$	Air Temperature at above ceiling, opened roof
$T_{ch6,o}$	Air Temperature at 2nd floor closed room, opened roof
$T_{ch7,o}$	Air Temperature at 3rd floor closed room, opened roof

To study effect of various parameter such as open-closed roof (attic ventilation), flat/sloped roof and with/without cross ventilation or not, six test conditions were considered as described in Table3.4 and illustrated in Figure 3.12.

Model test–1: This test aims to study the effect of open flat roof compared with closed flat roof. It is found that the air flow induced by the buoyant force would help to decrease the indoor temperature. The test is done by collecting data of temperature and relative humidity.

Model test–2: is to investigate the performance open flat roof with a prevailing wind compared with closed flat roof. Obviously, the effect of cross ventilation is expected to be much higher than buoyancy effect. The test is done by collecting data of temperature, relative humidity and air velocity.

Model test-3: aims to compare the effect of air gap insulation layer to indoor temperature between a still air in lean-to roof and a motive air in open flat roof. The result will be compared with the result of the Test-1 to investigate performance of still air gap insulation layer between closed lean-to roof and closed flat roof, in the condition of no wind. Data of temperature and relative humidity are recorded.

Model test-4: The objective of this test is to analyze the effect of air gap insulation layer between a still air in lean-to roof and a motive air in open roof. The result will be compared with the result of Test –2 to investigate performance of still air gap insulation layer between closed lean-to roof and closed flat roof. Data of temperature, relative humidity and air velocity are recorded.

Model test-5: It aims to study the effect of slope to decrease indoor temperature by comparison with the result of Test-1. The test is conducted by collecting data of temperature and relative humidity.

Model test-6: It is assumed to simulate the real shophouse condition, where only one-third of all windows area on the back side or the north side is open. The size of opening of the both models is (0.4x0.4 m^2) on the north side. One model is assumed as the real existing condition, i.e. closed flat roof, the other is open lean-to roof. Data of temperature, air velocity and day lighting is also recorded.

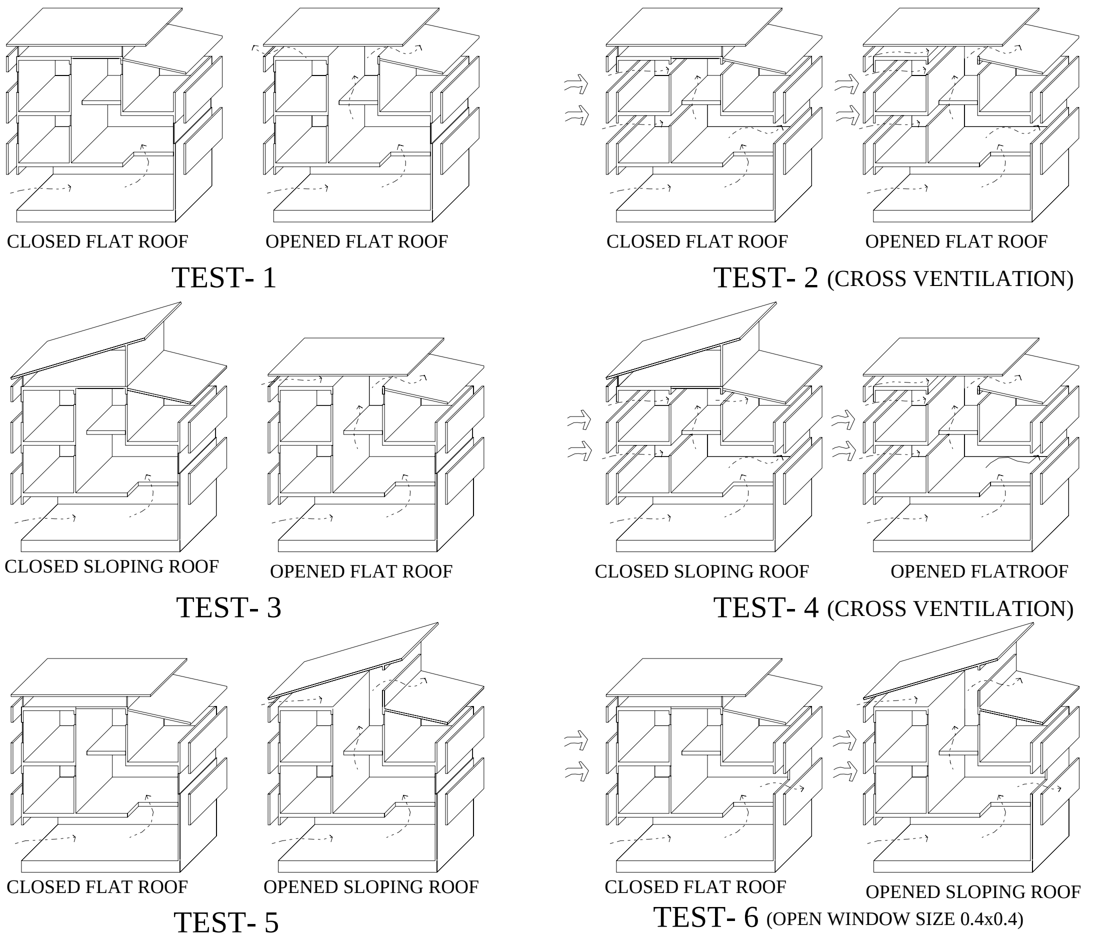


Figure 3.12 The six test conditions

Table 3.4 Conditions of model test

TEST	DATE	CONDITION						DATA COLLECTION		
		Closed Roof(1)		Opened Roof (2)		* Cross Ventilation		Temperature& RH%	Air Velocity	Illuminance
		Flat	Slope	Flat	Slope	Cross	No cross	(^{O}C)	(m/s)	(LUX)
1	MAY 23-25,2002	X		X			X	X		
2	MAY 28-31,2002	X		X		X		X	X	
3	JUNE 4-7,2002		X	X			X	X	X	
4	JUNE 10-12,2002		X	X		X		X	X	
5	JUNE 14-17,2002	X			X		X	X		
6	JUNE 17-20,2002	X			X	X		X	X	X

*Cross ventilation means that wind can pass through the building from the south to the north side opening.

CHAPTER 4 RESULTS AND DISCUSSION

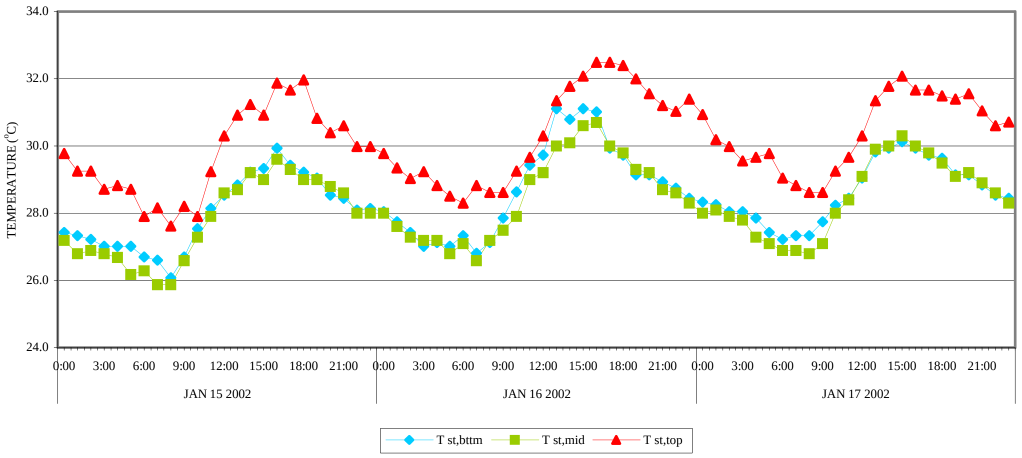
This chapter deals with the result. There are two main parts. The first concerns the result of the field test both in hot and cool season (4.1). The other is the result of models tests (4.2 and 4.3), which include the result of air temperature, air flow rate and daylighting of model test. And at the end of this chapter, it concludes all of the results.

4.1 The results of field test

Figure 4.1 and 4.2 shows hourly variation of air temperature at staircase in the hot and cool seasons, while Figures 4.3 and 4.4 shows relative of air temperature to solar intensity, ambient relative humidity and different floor level. Obviously almost during the whole days except in the morning (7:00-9:00), air temperature at the top is higher than that at the middle and bottom approximately two degree (0-2 °C) in cool season (Figure 4.1) and three degree (0-3 °C) in hot season (Figure 4.2). The temperature difference at the top between hot and cool season is about 2-4 °C (the temperature at the top is 28-32 °C in cool season and 28-36 °C in hot season).

Staircase air temperature of the ground and the second floors is slightly different, which is evident due to the stack buoyant force. Temperature difference between the hot and cool season is 2 °C (temperature at the middle and bottom varied between 26-31 °C in cool season and 28-33 °C in the hot season).

It could be concluded that the higher incident solar radiation, the hotter the day. And the hotter time, the higher difference between bottom and the top.



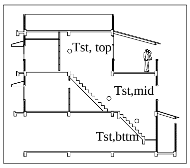


Figure 4.1 Hourly variation of staircase air temperature during the cool season

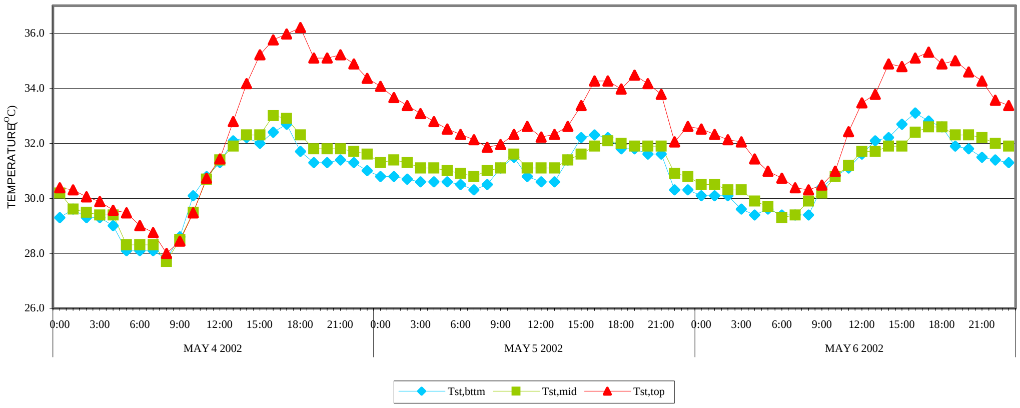


Figure 4.2 Hourly variation of staircase air temperature during the hot season

The previous analysis is still valid for the temperatures of different floors and seasons. However, during the cool season the temperature difference at staircase (0.3 - 2 °C) is much higher than the temperature difference at ground, 2nd and 3rd floor (0 - 1°C), Figure 4.3. Also, the air temperature at the top staircase (32 °C) is one degree higher than that at the third floor, 32 and 31°C respectively. This difference clearly demonstrates how heat from the ground and the second floors transfers to the third floor through the staircase acting as an exhaust chimney.

It should be pointed out that there is a big time lag between the maximum solar radiation (500-600 W/m^2) at noon and the maximum indoor temperature at 18:00 about 6 hours. This is due to the effect of heat capacity of building materials (brick masonry wall and concrete structure), the non-use of insulation and mainly, the poor ventilation.

This observation confirms our investigation about the reason of using air conditioning at night.

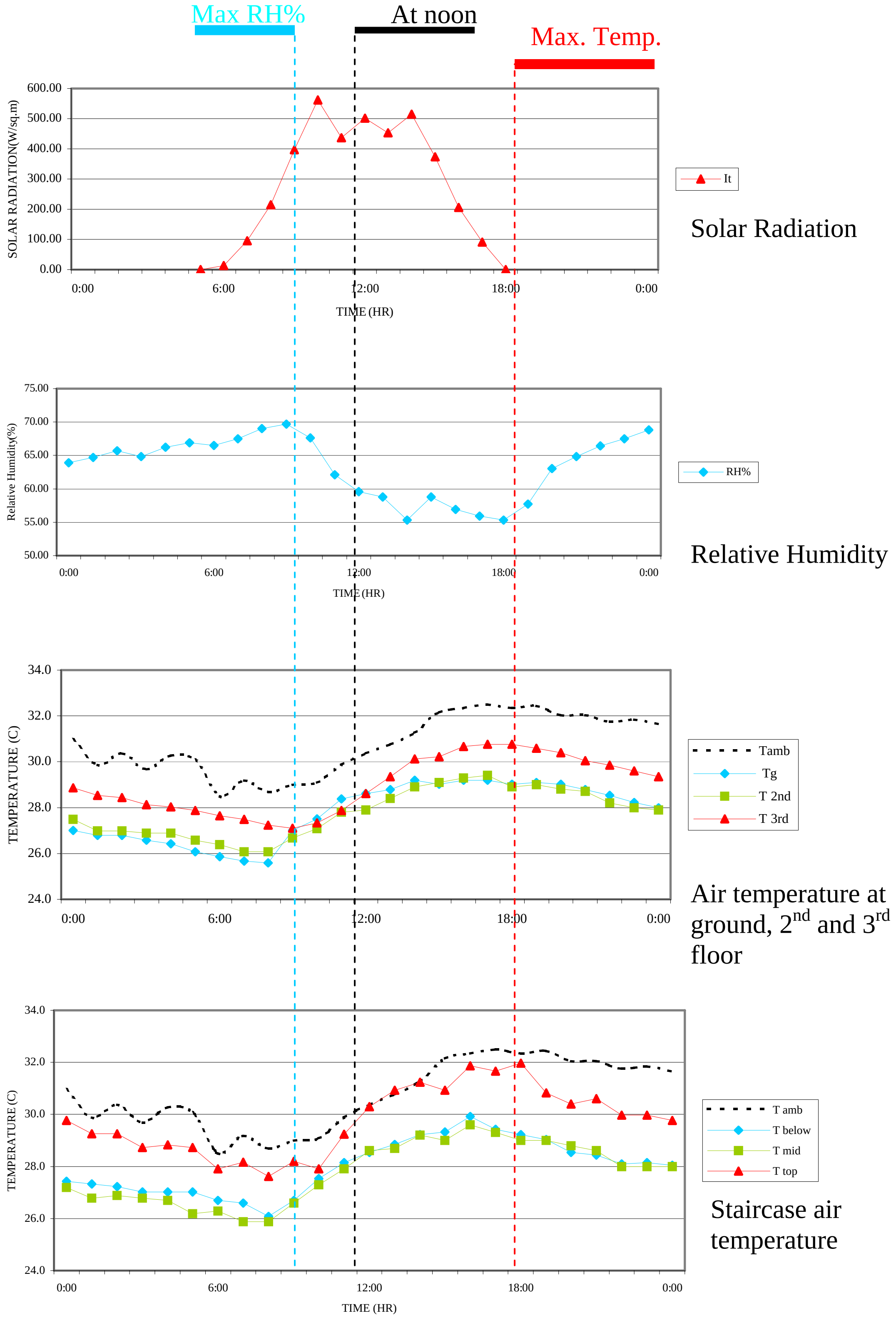


Figure 4.3 [Cool Season] Hourly variation of staircase air temperature at ground, 2nd, 3rd floor with ambient relative humidity and solar radiation on horizontal plane on January 15,2002

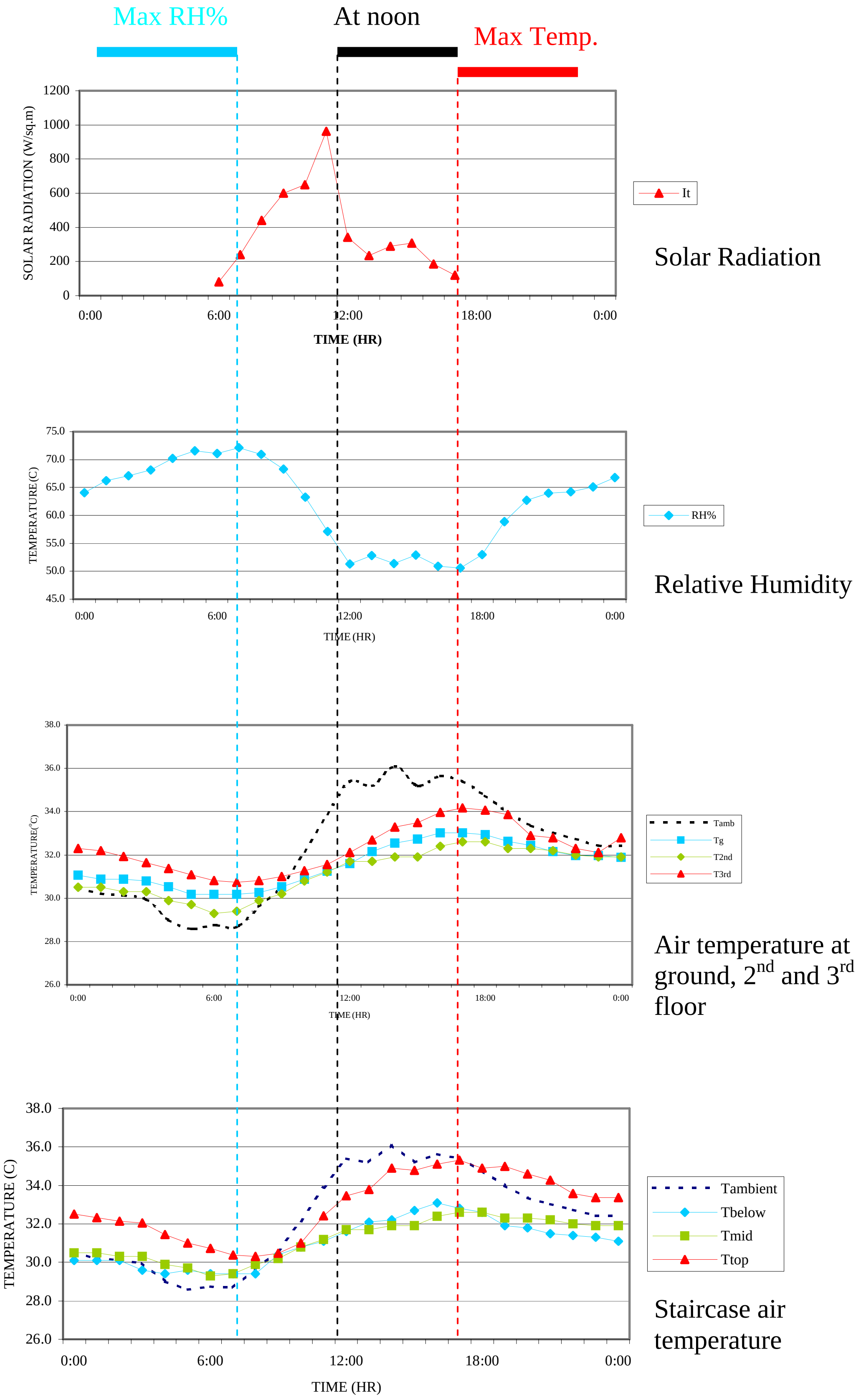


Figure 4.4 [Hot Season] Hourly variation of staircase air temperature at ground, 2nd, 3rd floor with ambient relative humidity and solar radiation on horizontal plane on May 6,2002

During the hot season, Figure 4.4, the staircase air temperature difference (bottom-to-top) is higher than temperature difference of ground to the 3rd floor, (0-2 °C) and (0–3 °C) respectively. The temperature at the top of staircase is 35.2 °C, while that on the third floor is 34 °C.

The time lag between the high solar radiation (1000 W/m^2) at noon and the maximum indoor air temperature at 18:00 was six hours. The variation of indoor is more or less the same as temperature variation.

Figure 4.5 shows thermal performance in the shophouse relate to position and time. It can be seen that heat transfers through the house from the south and air temperature of the third floor is higher than the ground and the second floor, indicating the poor design and the low ventilation rate. That is why this floor is only used during the nighttime.

Hot season $\Delta T = T_{day} - T_{night}$

1 °C	2 °C	3 °C
2 °C	2 °C	2 °C
	2 °C	

Day time

$\Delta T = T_{hot} - T_{cool}$

2 °C	4 °C	3 °C
3 °C	3 °C	3 °C
	4 °C	

$\Delta T = T - T_{amb}$

2°C	2 °C	0°C
2 °C	2 °C	1 °C
	1 °C	

Temperature Color

🟥	33 - 35 °C
🟧	31 - 33 °C
🟨	29 - 31 °C
🟦	27 - 29 °C
🟦	25 - 27 °C

Cool season $\Delta T = T_{day} - T_{night}$

2 °C	2 °C	2 °C
2 °C	2 °C	1 °C
	1 °C	

Night time

$\Delta T = T_{hot} - T_{cool}$

3 °C	3 °C	2 °C
3 °C	3 °C	2 °C
	3 °C	

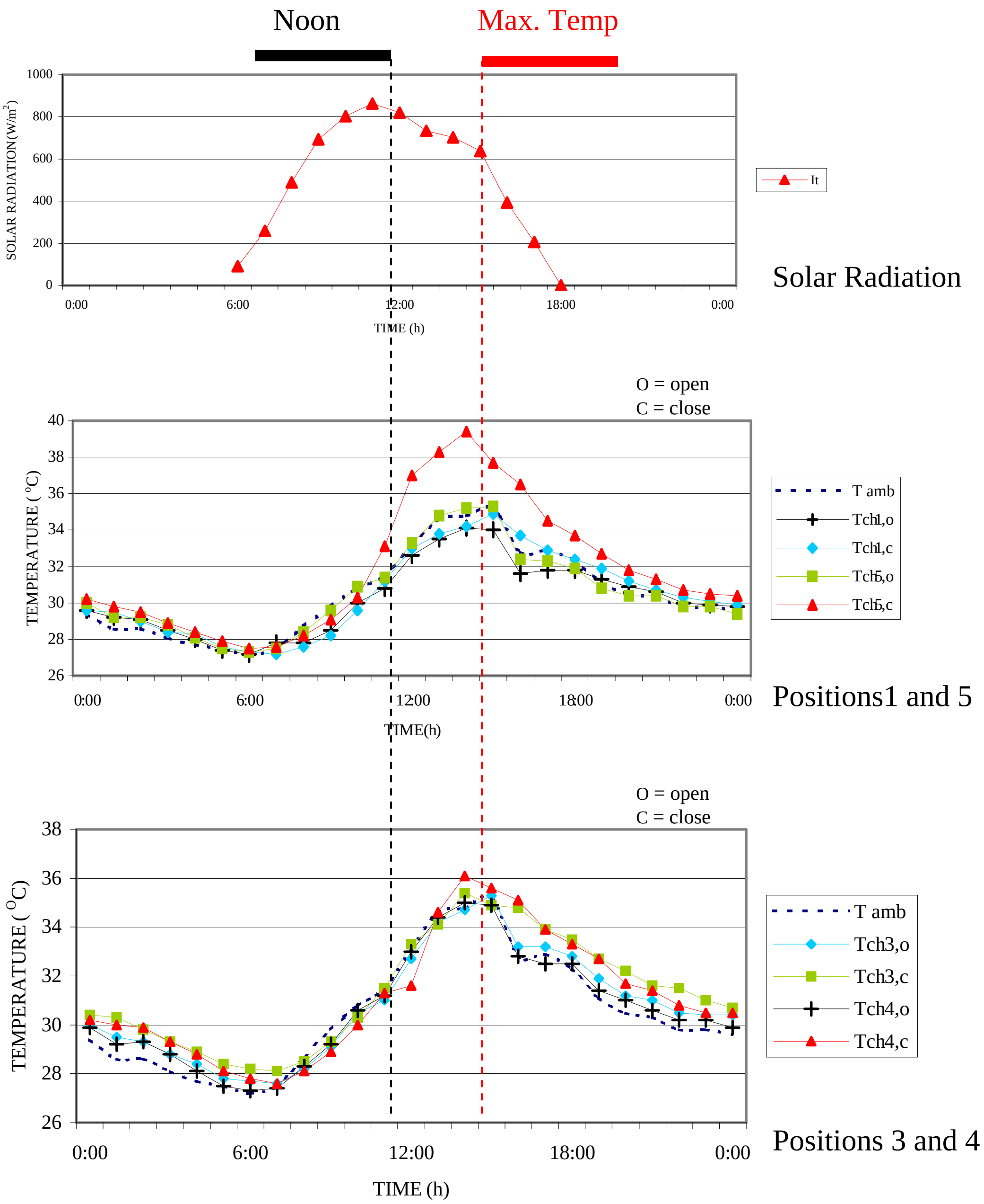
$\Delta T = T - T_{amb}$

3 °C	3 °C	0°C
3 °C	3 °C	2 °C
	3 °C	

Figure 4.5 Average day and night temperature distribution of the shophouse in hot and cool season.

4.2The results of study models test

4.2.1 The result of model test-1



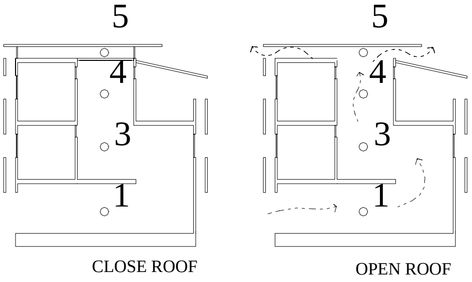


Figure 4.6 Comparison of air temperature between open flat roof and closed flat roof (Model Test-1 no cross ventilation) on May 24,2002

Figure 4.6 gives the daily variation of air temperature at the three floors for closed and open flat roof. Obviously, higher temperatures are observed when the roof was closed as no ventilation occurred. The heat gain is stored continuously. In the afternoon, the temperature difference between open and closed roofs in each floor is evidently, namely, at the third floor. The temperature difference between the floors varied between 0-2°C for the ground floor, 0-1.6°C for the second floor, 0-2.3 °C for the third and 0-4.2 °C at the ceiling, which is extremely clear. Therefore, it is evident that without using cross ventilation technique, which is admitted by designers as the most efficient technique for natural ventilation, open roof ability to reduce heat gain using the buoyant force or stack effect is very efficient and thus should be implemented. It should be pointed that even using a study model, temperature profile varies in a way similar to that of the real shophouse. Consequently, general application for the real house seems to be appropriate.

4.2.1 The result of model test-2

In this case, due to cross ventilation, temperature difference between the various positions is less than that observed from the previous case where no direct wind-based ventilation was permitted. However, the open roof study model experiences lower temperature level, namely, in the afternoon that confirms the benefit from opening the roof. The difference between closed and open roof are as follows: 0-1.6 °C, 0-1°C, 0-1.5°C and 0-2.1°C from the ground floor up to the ceiling respectively.

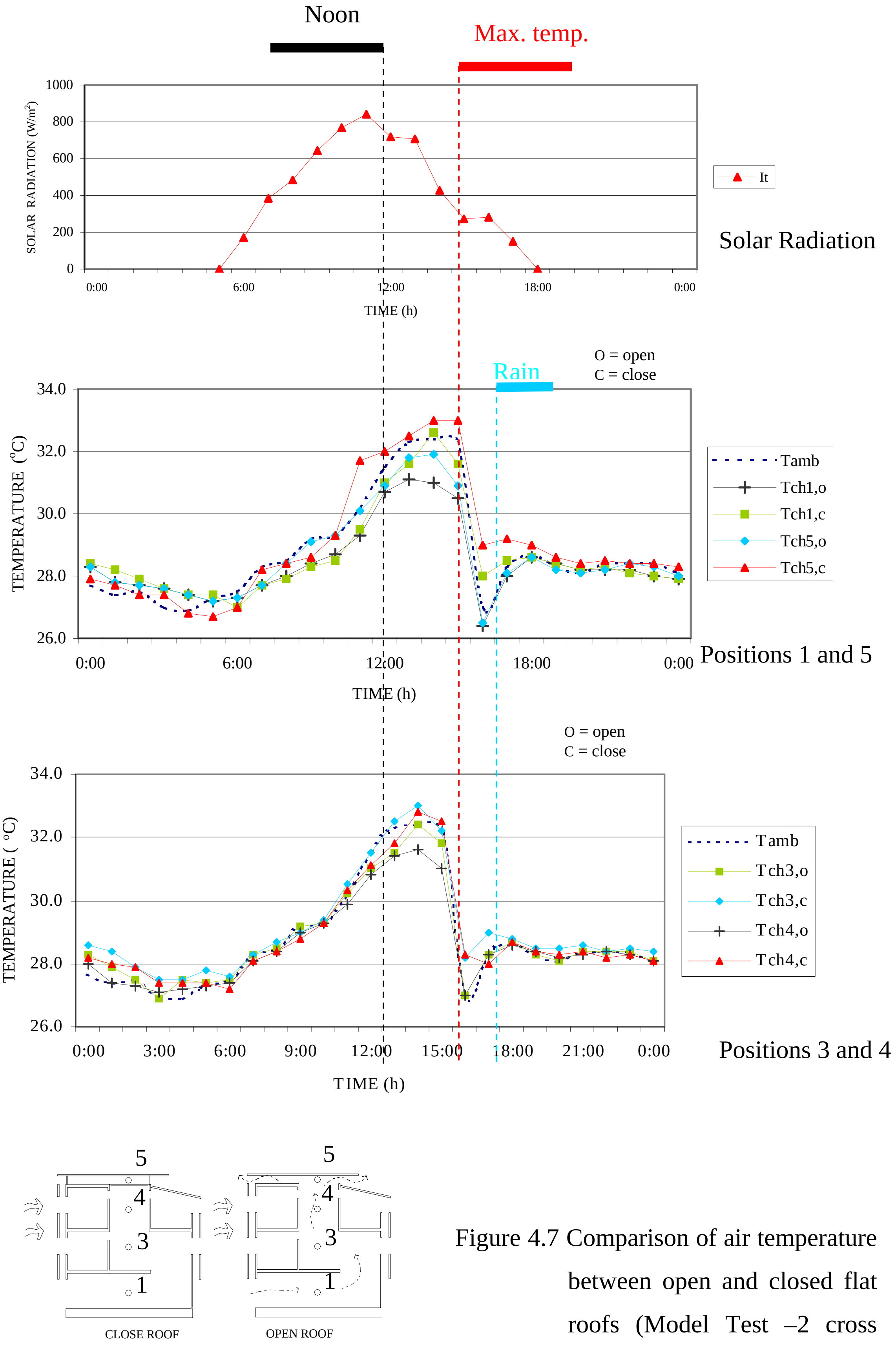
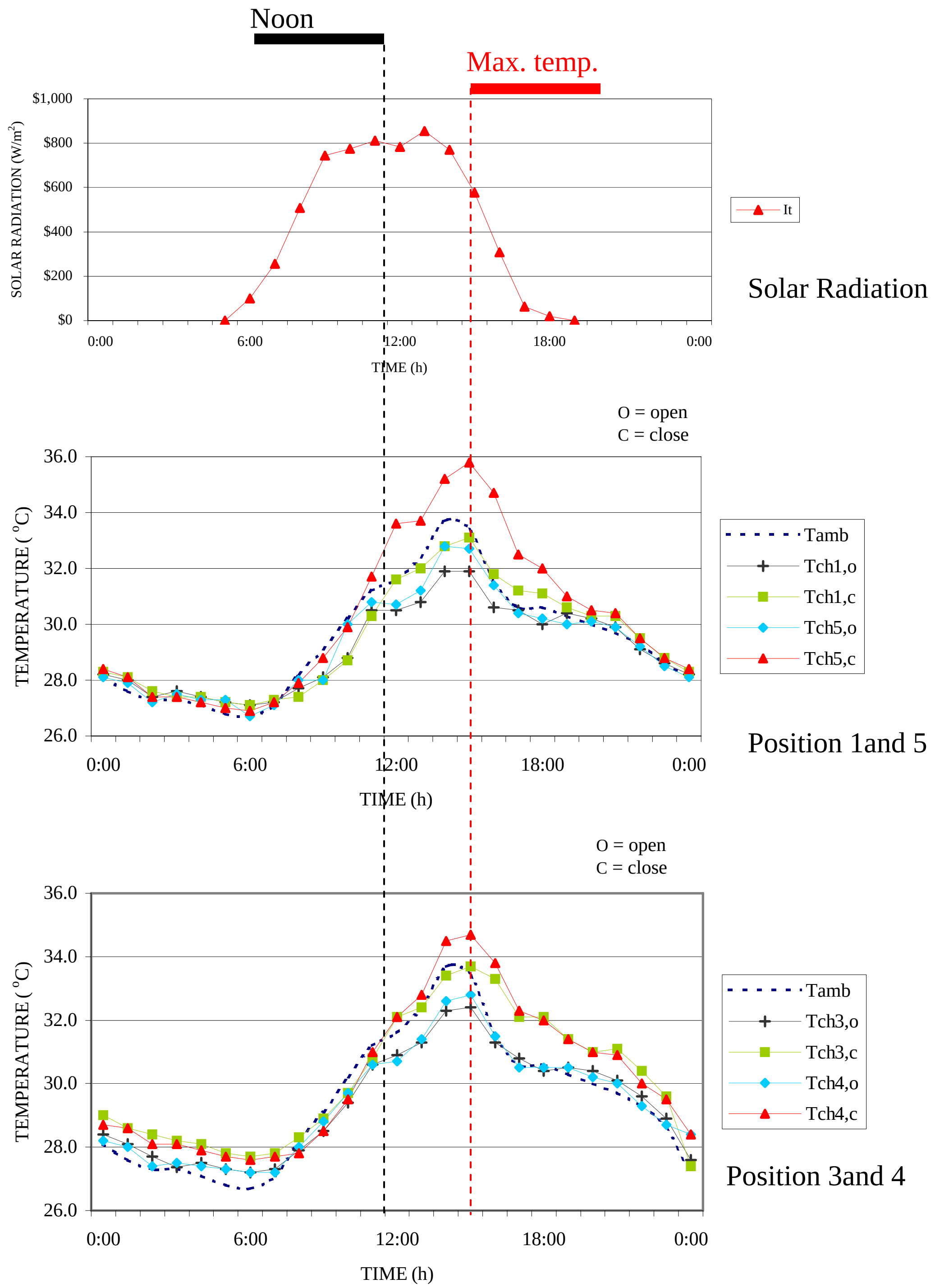


Figure 4.7 Comparison of air temperature between open and closed flat roofs (Model Test –2 cross ventilation) on May 29,2002



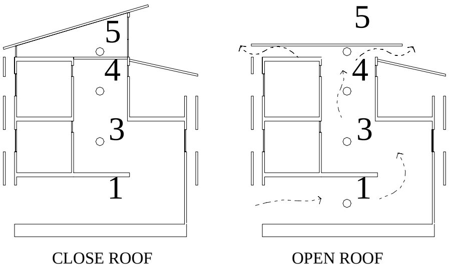


Figure 4.8 Comparison of air temperature between open flat and closed sloping roofs (Model Test-3 no cross ventilation) on June 7, 2002

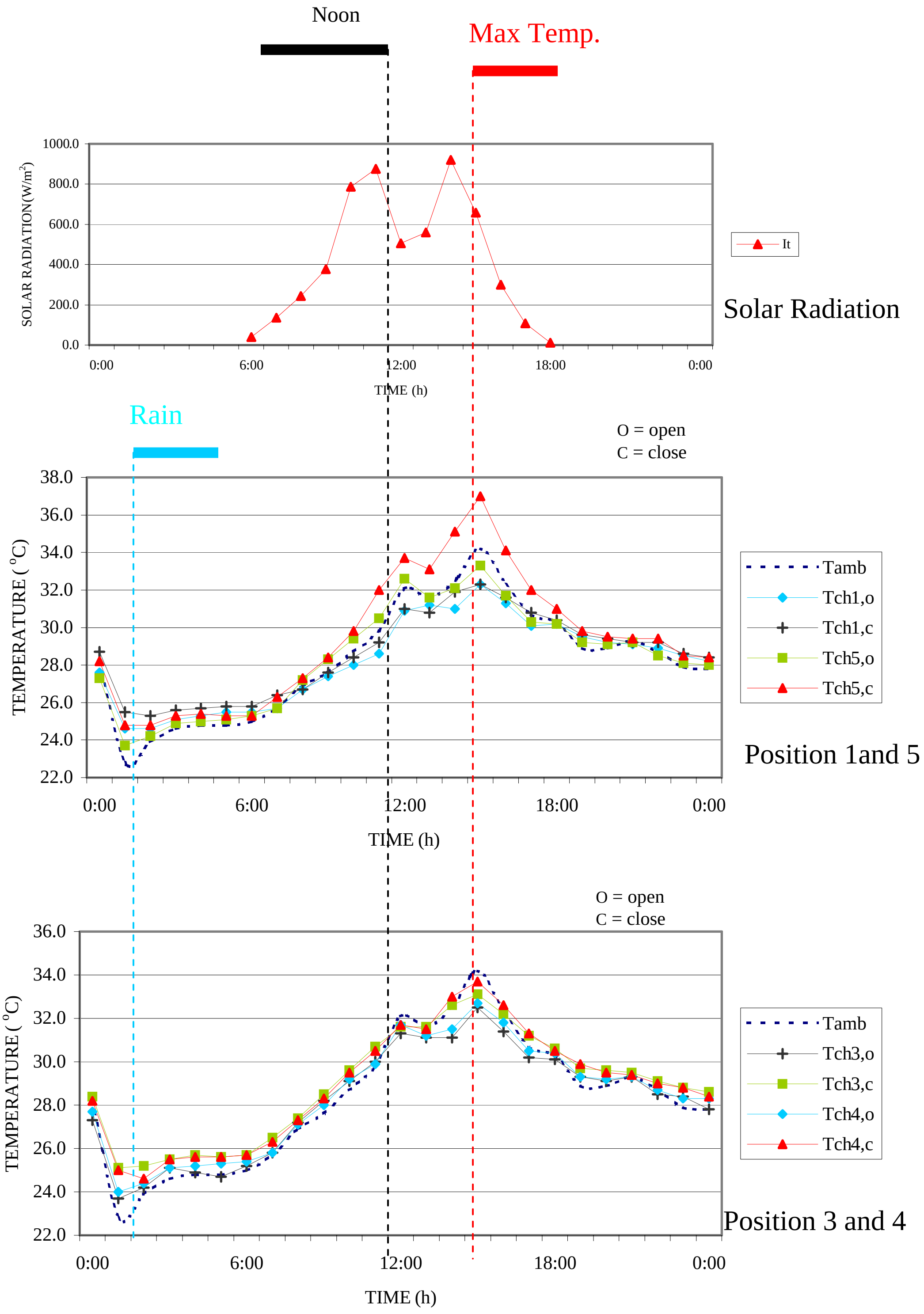
4.2.3 The result of model test-3

The testing results confirm that open flat roof is efficient for decreasing in the indoor air temperature, mainly in the afternoon until midnight, Figure 4.8. The temperature differences between open flat and closed lean-to roof is as flows: 0-1.2°C, 0-2 °C, 0-1.9 °C and 0-3.3 °C from ground floor up to the ceiling respectively.

Closed tilted roof tends to hotter than closed flat roof. Table 4.1 (on page 48) shows that test-3 is more reduced temperature than test-1 in each point excepted at the ceiling (position-5, not occupied space). This indicates that in this condition still air as an insulating tool in tilted roof has lowered efficient than open flat roof.

4.2.4 The result of model test-4

With slope roof and open windows, indoor air temperatures was observed close to ambient, and open flat roof was slightly lower than closed slope roof model. The temperature difference between the two models at the second and third levels is as follows: 0-1.5 °C and 0-1.5 °C respectively. At the ceiling (point 5) the difference is considerably by 0-2.4 °C approximately. Therefore, insulating still air gap of closed lean-to roof in condition of cross ventilation also has lowered efficient than open flat roof.



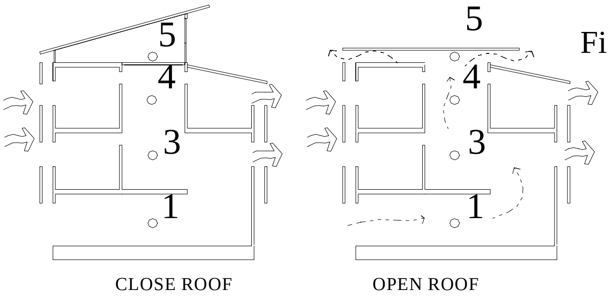
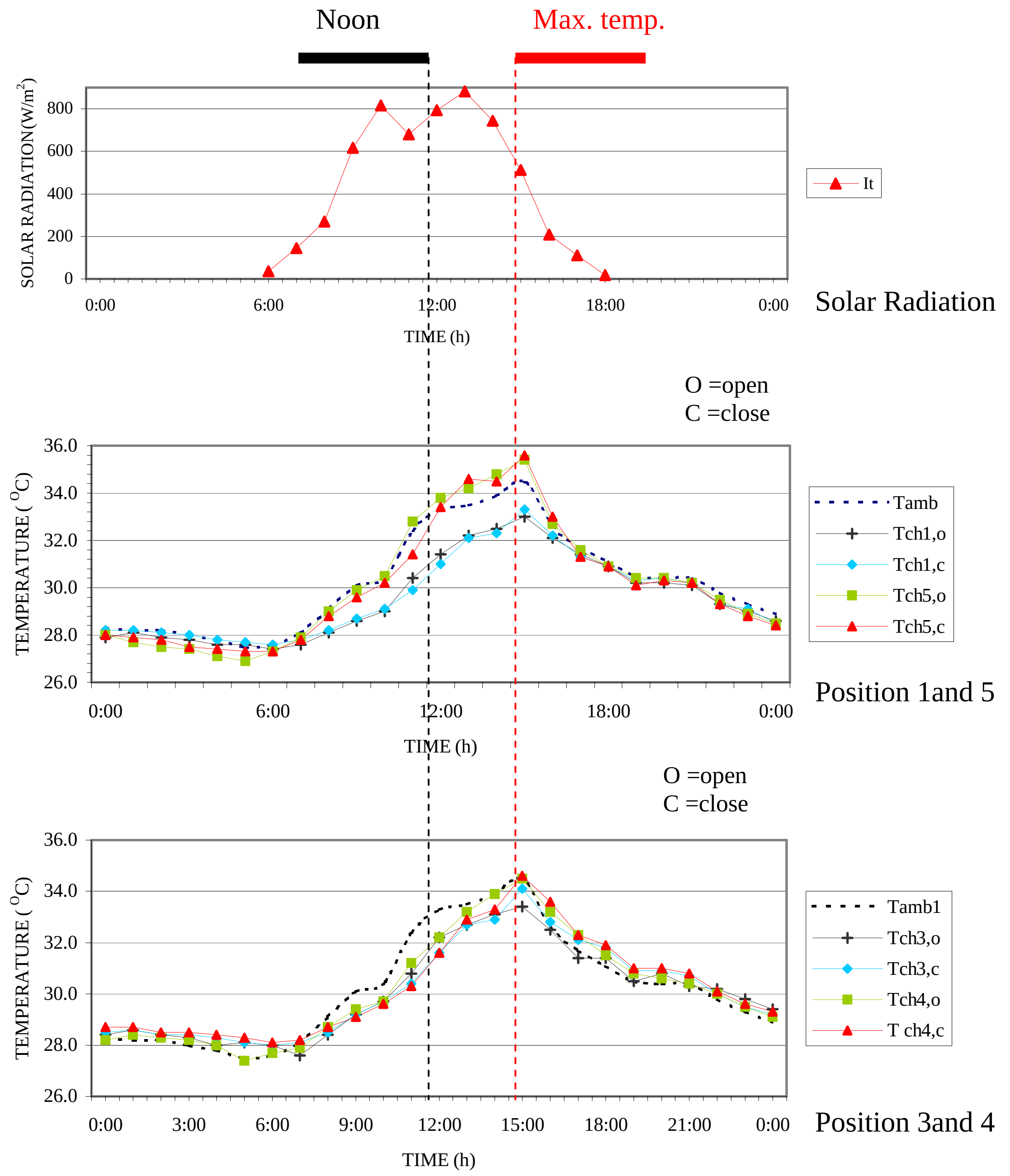


Figure 4.9 Comparison air temperature between open flat and closed sloping roofs (Model Test-4 cross ventilation) on June 11,2002



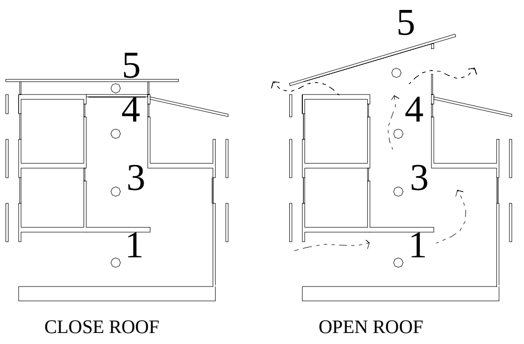


Figure 4.10 Comparison air temperature between closed flat and open sloping roofs (Model Test-5 no cross ventilation) on June 16, 2002.

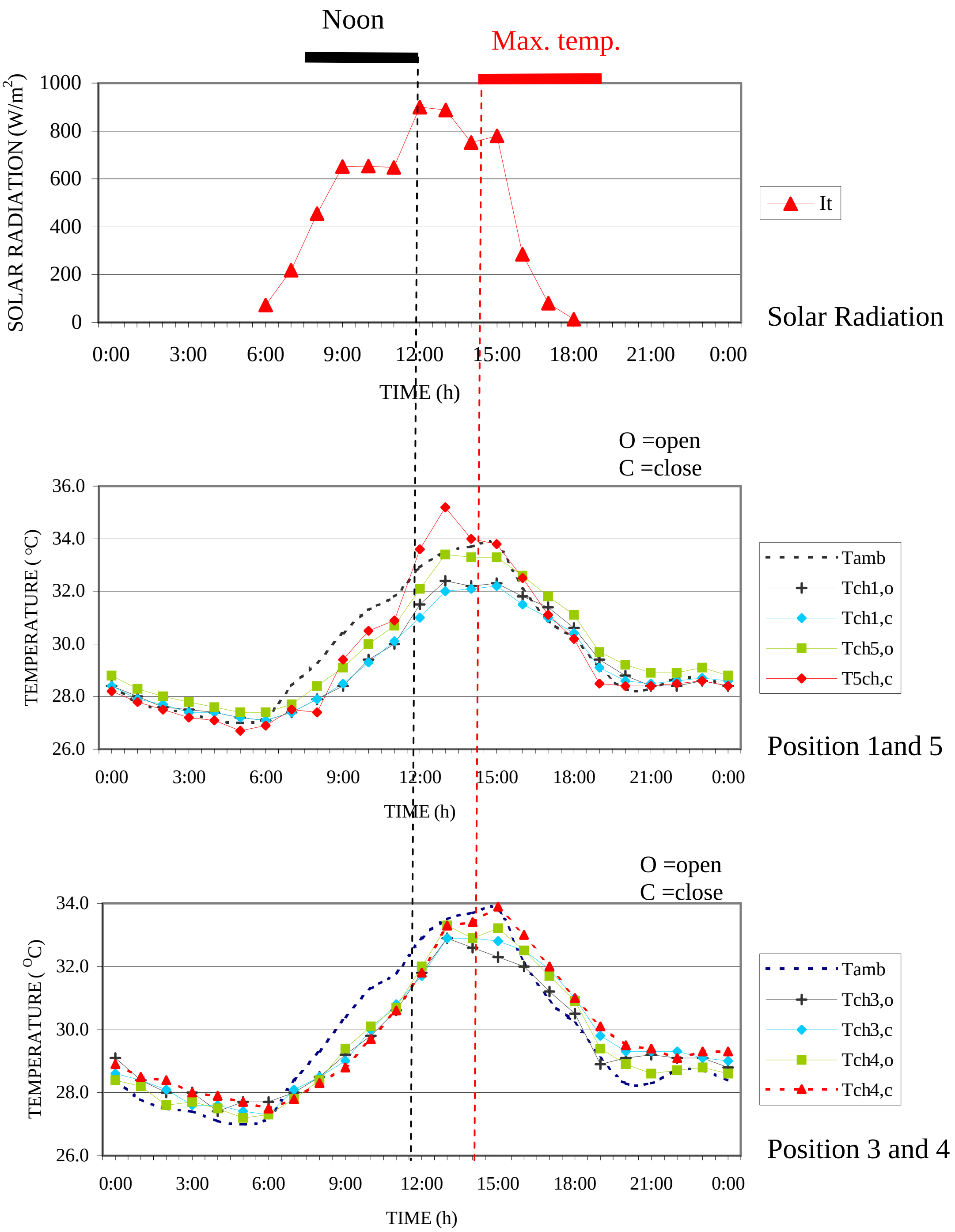
4.2.5 The result of model test-5

The results of this test condition are quite surprising, air temperature of open slope roof is almost the same as closed flat roof, as shown in Figure 4.10. In addition, the roof (attic) temperature is higher than the ambient in the afternoon, the peak was observed at 15:00. And the other positions temperatures are slightly lower than ambient temperature in the morning, contrary higher than ambient temperature after the peak temperature.

Moreover, we observed that in the morning closed roof tends to be lower than open roof. Because in the morning closed roof air was cooled from night time and no air change, while open roof air was mixed with higher temperature ambient air.

4.2.6 The result of model test-6

Figure 4.11 shows that air temperature of opened roof model is slightly lower than closed roof mode. The temperature difference at the position 3 (middle) is lower than that of the close by 0-0.7 °C approximately and by 0-0.7 °C at the position 4. On the ceiling, the temperature is lower by about 0-1.8 °C. Then this test condition provides better performance than the model test-5. Because the size of openings was bigger (0.4x0.4 m^2), so there are more induced air flow by the small chimney between ground level and the second level.



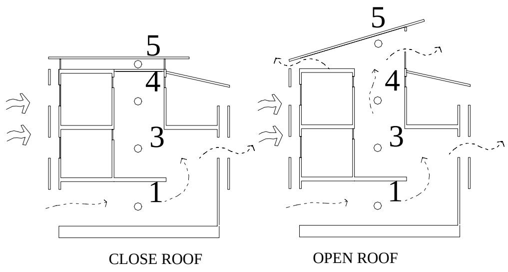
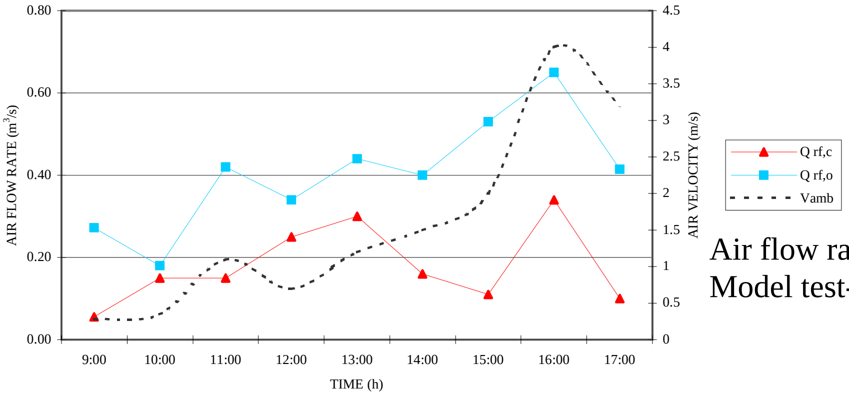


Figure 4.11 Comparison air temperature between closed flat and open sloping roofs (Model Test-6 cross ventilation)on June 18, 2002

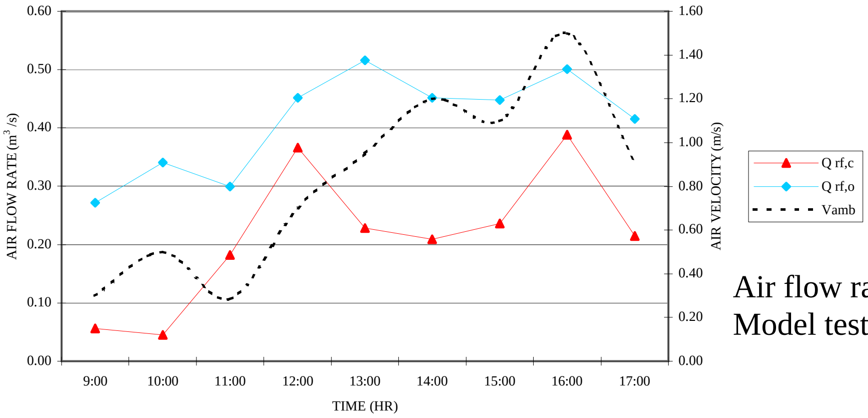
4.3 Measured air flow rate and day lighting

4.3.1 The result of air flow rate

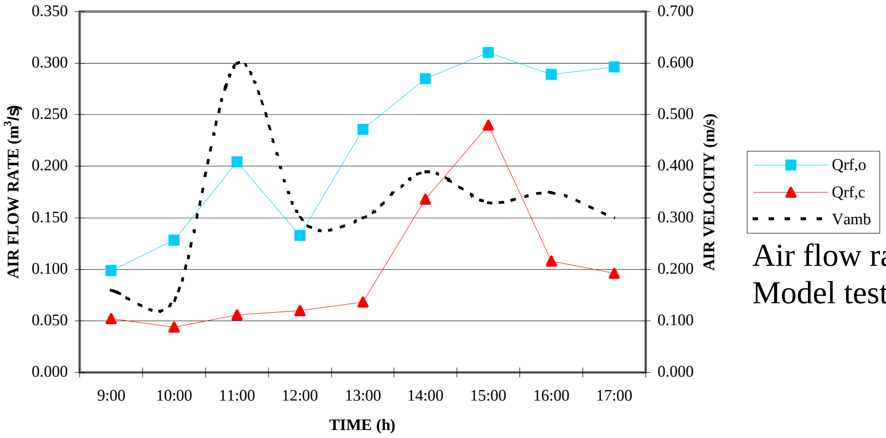
Air velocity was measured in the middle outlet opening by collecting data ten times and average in test-2, 4 and 6. Then, to find air flow rate, the velocity will be multiplied with cross section area.



Air flow rate of
Model test-2



Air flow rate of
Model test-4



Air flow rate of
Model test-6

Figure 4.12 Air flow rates of model test 2, 4 and 6

The measured data are presented in Figure 4.12. It is obvious that the difference between the closed and opened varies between 0.03and 0.31 m^3/s depending on the test configuration.

Opening the roof enhances the air flow rate. In each test, air flow rate opened roof is higher than closed roof approximately in range of 0.03-0.31 m^3/s, for test-2, 0.08-0.29 m^3/s, for test-4 and 0.05-0.181 m^3/s, for test-6.

The air flow rate in the test-6 condition is lower than the other two tests, because the opening area is reduced. In this test it shows that the air flow rate depends on wind speed.

4.3.2 The result of Daylighting in Test-6

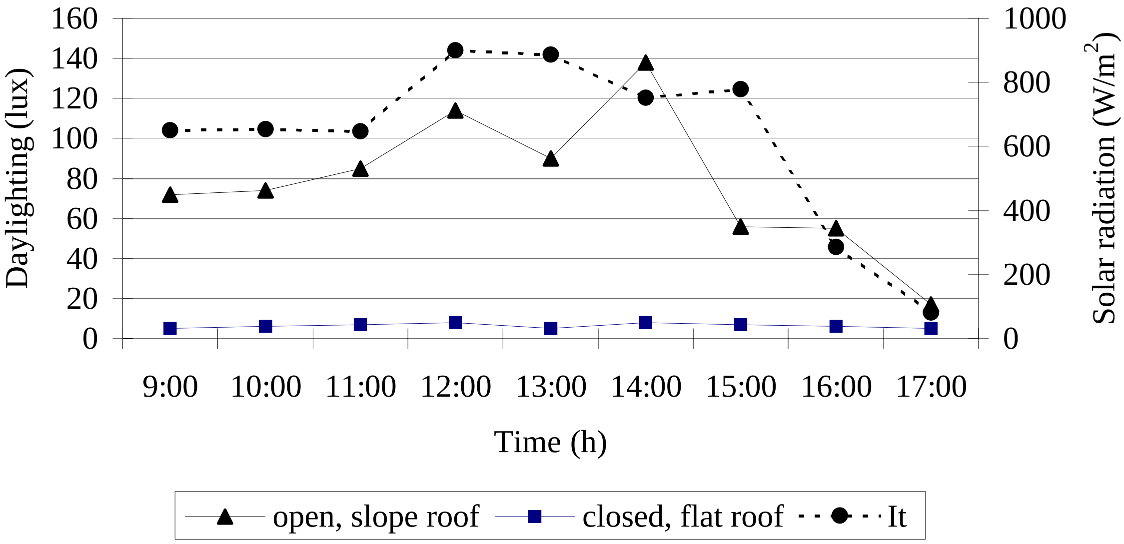


Figure 4.13 Comparison of day lighting between closed flat roof and open sloping roof.

Indoor daylighting was recorded in one test condition (Test-6). Figure 4.13 shows that the indoor with open roof, the indoor is brighter than that with closed flat roof. As no overheating is observed, it can be used to reduce artificial lighting during the day time. We remind that this should be done with some care as improper design will increase the rate of heat transfer from the aperture.

4.4 Conclusion of Testing Results

Based on above discussion of each test condition, simple and accurate conclusion should be formulated in order to derive a set of design recommendations for improving the Thai shophouses. To do this, we calculated average data for the roof of six study model tests which are presented in Table 4.1 to 4.3

Table 4.1 Test conclusion of without cross ventilation (no wind effect)

Parameters	Test-1					Test-3					Test-5				
Average Solar Radiation (W/m^2)	514.8					505.2					448.3				
Average RH (%)	68.6					71.6					70.2				
Average T_{amb}(^{o}C)	30.5					29.5					30.2				
Position	1	3	4	5	7	1	3	4	5	7	1	3	4	5	7
Average $T_{avg,Closed\ Roof}$ (^{o}C)	30.5	31.3	31.1	31.8	31.1	29.4	30.1	30.2	30.2	30.1	29.6	30.1	30.3	30.1	30.3
Average $T_{avg,Open\ Roof}$ (^{o}C)	30.2	30.8	30.6	30.5	30.6	29.1	29.4	29.4	29.2	29.3	29.6	30	30.2	30.1	29.9
Mean Temperature Difference or Reduced T (^{o}C)	**0.3**	**0.5**	**0.5**	**1.3**	**0.5**	**0.3**	**0.8**	**0.8**	**0.9**	**0.7**	**0.1**	**0.1**	**0.1**	**-0.1**	**-0.1**

(Mean Temperature difference is lower than zero, it means that temperature of the open roof is higher than closed roof.)

Opening of closed roof - Ground level size 0.7x1.0 m^2
Opening of opened roof - Ground level size 0.7x1.0 m^2
- Roof opening size south 0.2x1.0 m^2
north 0.2x1.0 m^2

When cross ventilation is not permitted, Table 4.1 indicates that opened roof can reduce temperature in each position of the study models 0.1 to 1.3 °C, which depends on roof condition. The higher level, the more reduced temperature.

Table 4.2 Test conclusions with cross ventilation (wind effect)

Parameters	**Test-2**					**Test-4**				
Average Solar Radiation (W/m^2)	487.3					487.3				
Average RH (%)	75.8					77.5				
Average T_{amb}(^{o}C)	28.8					28.3				
Position	1	3	4	5	7	1	3	4	5	7
Average $T_{avg,Closed\ Roof}$ (^{o}C)	28.7	29.1	28.9	29	28.9	28.6	28.9	28.9	29.4	29
Average $T_{avg,Open\ Roof}$ (^{o}C)	28.4	28.8	28.6	28.6	28.4	28.2	28.2	284	28.4	28.3
Mean Temperature Difference or Reduced T (^{o}C)	**0.2**	**0.3**	**0.3**	**0.4**	**0.5**	**0.4**	**0.7**	**0.5**	**0.9**	**0.7**

Size of opening closed roof - Ground level 0.7x1.0 m^2
- 2nd Floor 0.4x1.0 m^2 on the south
0.4x1.0 m^2 on the north
- 3rd Floor 0.4x1.0 m^2 on the south
0.4x1.0 m^2 on the north

opened roof - Ground level 0.7x1.0 m^2
- 2nd Floor 0.4x1.0 m^2 on the south
0.4x1.0 m^2 on the north
- 3rd Floor 0.4x1.0 m^2 on the south
0.4x1.0 m^2 on the north
- Roof opening south 0.2x1.0 m^2
north 0.2x1.0 m^2

It is obvious that wind effect (wind force) is much more influential than stack effect (thermal force), that is why the average mean temperature difference or reduced temperature between the closed and the open roof is les than the previous case. However, open roof still reduce indoor air temperature.

Table 4.3 Test summary of study models 6 (Simulate existing condition)

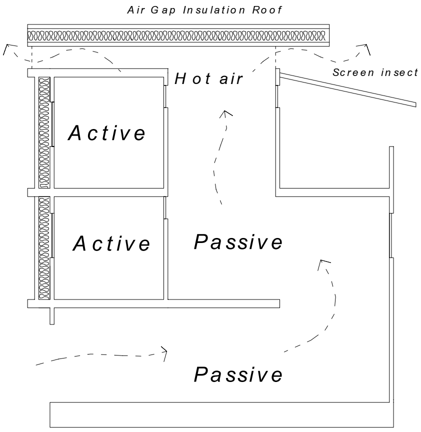
Parameters	**Test-6**				
Average Solar Radiation (W/m^2)	532.1				
Average RH (%)	6938				
Average T_{amb}(^{O}C)	29.7				
Position	1	3	4	5	7
Average $T_{avg,Closed\ Roof}$ (^{O}C)	29.1	29.7	29.9	29.5	28.9
Average $T_{avg,Opened\ Roof}$ (^{O}C)	29.2	29.6	29.6	29.7	28.4
Mean Temperature Difference or Reduced T (^{O}C)	**-0.1**	**0.1**	**0.3**	**-0.2**	**-0.2**

(Mean Temperature difference is lower than zero, it means that temperature of opened roof is higher than closed roof.)

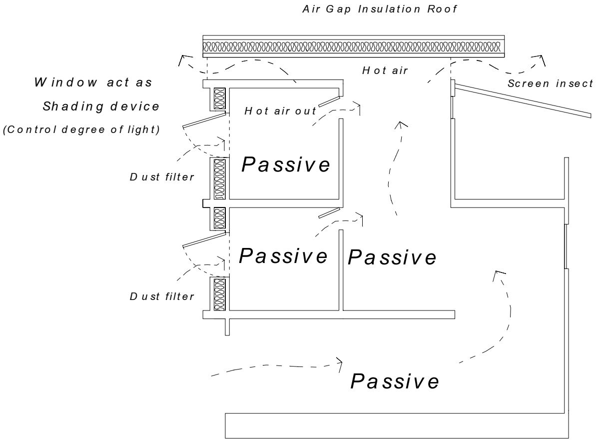
Although Table 4.3 shows that indoor air temperature of the open lean-to roof is slightly higher than closed flat roof. Air in open roof is heated by both ambient air and solar radiation This means that heat flow by convection can not overcome heat transfer by radiation, because the opening are at a roof, the higher heat gain.

CHAPTER 5 CONCLUSION

This research work aims to improve the design of Thailand shophouses in order to reduce energy use and to improve the indoor conditions without inducing any significant change to the function of the building. A preliminary study conducted using a three-storey real shophouse showed that there is an ascendant hot air flows from the ground floor to 3rd floor level. And the heat is collected at the top floor, where there is no opening. In the second study, approach to solve the problem by mainly opening the roof was explored and tested using small scale simulated models. Various design conditions were considered including flat and tilted roof, with and without wind –based cross ventilation. It was concluded that opening the roof of shophouse can greatly enhance air flow rate and reduce indoor temperature up to 2-3°C (Appendix C) depending on floor position and time. The maximum reduction is obviously at the higher floor level.



Hot Season Approach



Cool Season Approach

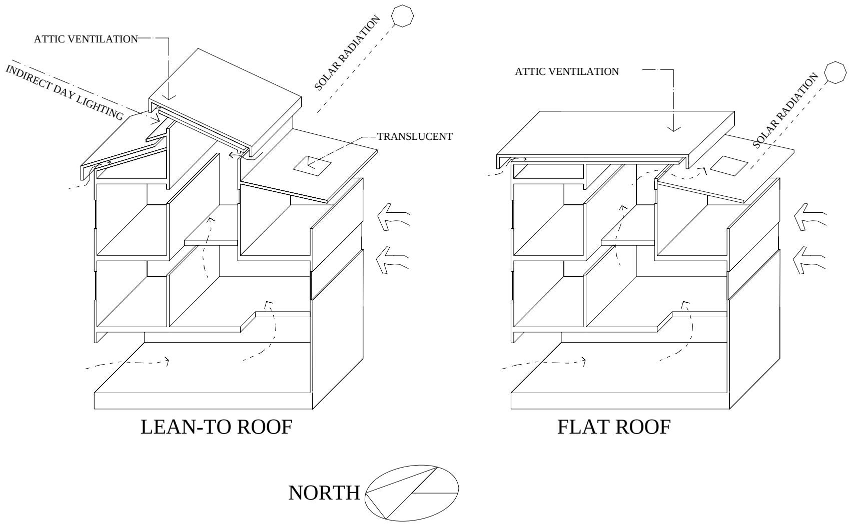
Figure 5.1 Design Approach with Passive and Active Zones

As a result, conventional shophouses would experience longer period of human comfort in the cool season. This takes a significant part in reducing period of using air conditioning.

Therefore, from our design approach (opening roof), two scenarios might be envisaged for the shophouse, which are illustrated in figure 5.1. In this case, the shophouse is initially divided into passive and active. During monsoon and cool season, the passive approach (Figure 5.1 bottom) is fully employed while for the hot season, a combination of the two modes could be used which is resident's dependent. In this case, when the air conditioning is used, the cooling load is considerably reduced due to the attic stack-based ventilation. Figures 5.2 to 5.5 give sketch of design solution for different shophouse orientation.

The set of design recommendations could be summarized as follows;

1. There must be an opening under the roof top level in order to lower the indoor air temperature, induce the airflow rate and allow the adequate daylighting. However, the opening should be in the north-south direction due to the wind direction which normally come from the south-west.
2. For daylighting, the opening must be carefully designed to allow only the adequate natural lighting. There are various design techniques that can be applied.
3. To cope with dust and flies, dust filter and insect screen have to be installed. It is noted that the air flow should not be reduced.



LEAN-TO ROOF

FLAT ROOF

Figure 5.2 Design recommendation for the north façade.

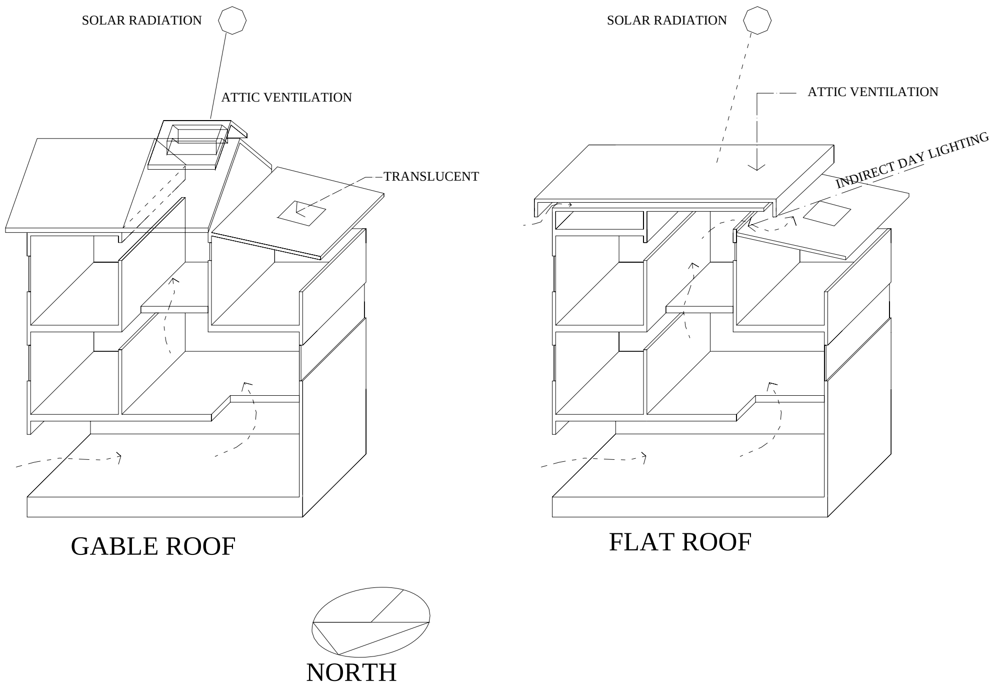


Figure 5.3 Design recommendation for the east façade.

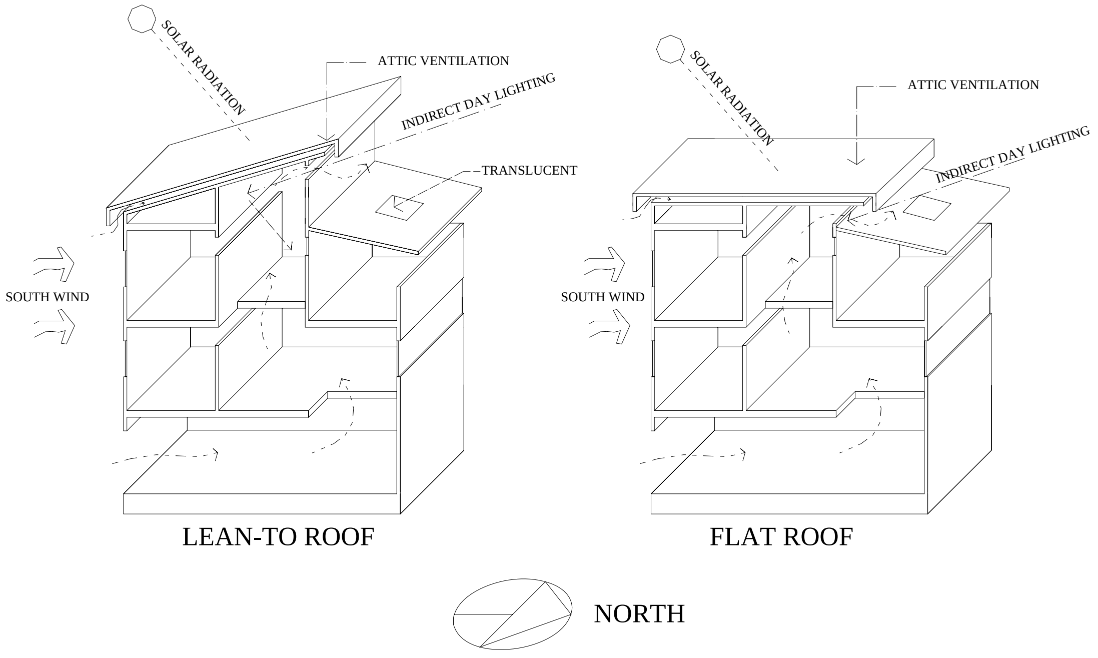


Figure 5.4 Design recommendation for the south façade.

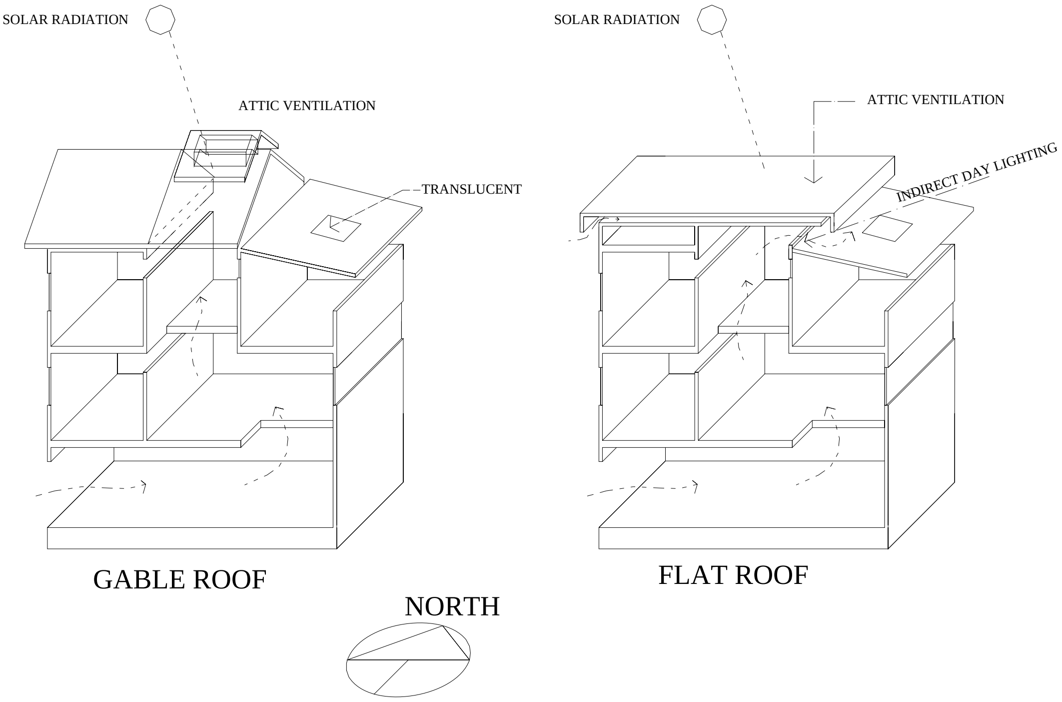


Figure 5.5 Design recommendation for the west façade.

Further analysis is still needed to improve the thermal performance of Thailand shophouses. For example the combination of the building thermal mass and night ventilative cooling, evaporative cooling and properties of materials used in shophouse in order to offer residents a longer period of reasonable thermal comfort. These topics are undergoing by researchers from the Building Scientific Research Center.

REFERENCES

1. Sucha, C.,1981, **Shophouse and Urban Design**, Master of Architecture Thesis, Department of Urban Design and Planning, Silpakorn University, pp. 4-7.
2. Jayanetra, K., 1998, **Natural Ventilation in the Thai shop-house: A Study of the Effect of Building Physical Parameters on the Ventilation of Shop-houses in Bangkok**, Master of Science Built Environment, Environmental Design and Engineering, University of London, pp.
3. Chantawarang, P., 1986, **Shop-house: The Transition of Mixed-used Buildings in Bangkok Metropolis**, Master of Architecture Thesis, Department of Architecture, Chulalongkorn University, pp.58-87.
4. **Ministerial Building Regulation** B.E. 2522 Chapter 4 Section 8(11)
5. Seehawong R., 1998, **Electricity Use in Residential Housing**, Master of Engineering Thesis, Energy Technology Program, King Mongkut's Institute of Technology Thonburi, pp. 48, 105.
6. Givoni, B., 1994, **Passive and Low energy Cooling of buildings**, Van Nostrand Reinhold, New York USA, pp. 1, 50
7. Awbi, H.B., 1994, "Design Considerations for naturally Ventilated Buildings", **Renewable Energy**, Vol.5, part II, pp.1081-1090.
8. Awbi, H.B., 1991, **Ventilation of Buildings**, Chapman&Hall, London, UK, p.65.
9. Allard, F. and Santamouris, M., 1998, **Natural Ventilation in Buildings**, James&James Ltd, UK, pp.203-210.
10. Fathy, H., 1985, "The Malqaf: A traditional cooling and ventilation system," **Sun World**, Vol.9, No.2, pp. 48-50.
11. Bunnag, T., 1995, **A Study of a Roof Solar Collector Towards the Natural Ventilation of New Habitation**, Master of Engineer Thesis, Thermal Technology Program, King Mongkut's University of Technology Thonburi, 85p.
12. Khedari, J., Boonsri, B., Hirunlabh, J., 1999, "Ventilation Impact of Solar Chimney on Indoor Temperature Fluctuation and Air change in a School Building," **Energy and Buildings**, Vol. 3, pp 89-93.

13. Khedari, J., Mansirisub, W., Chaima, S., Prathintong and Hirunlabh, J., 2000, “Field Measurement of Performance of Roof Solar Collector”, **Energy and Buildings**, Vol.31, pp.171-178.
14. Waewsak, J., Hirunlabh, J. and Khedari, J., 2000, “ Designing of a Thai Bio-Climatic Roof”, **World Renewable Energy Congress VI**, 1-7 July 2000, Bringhton, UK, pp.1830-1833.
15. Khedari, J., Lertsatitthanakorn, C., Pratinthong, N. and Hirunlabh, J., 1998, “The Modified Thrombe Wall: A simple Ventilation Means and an Efficient Insulating Materials”, **The Int. J. of Ambient Energy**, Vol.19, No.2, pp.104-110.
16. Wachirapuwadon, S., 1996, **An Adapted Model of Passive Roof Solar Collector for New Houses with Respect to Traditional Thai Style**, Master of Science Thesis, Energy Technology Program, King Mongkut’s University of Technology Thonburi, 68p.
17. Waewsak, J., 1998, **Feasibility Study of Night Radiation Cooling in Thailand**, Master of Science Thesis, Energy Technology Program, King Mongkut’s University of Technology Thonburi, 85p.
18. Bansal, N.K., 1993, “Solar Chimney for Enhanced Stack Ventilation,” **Building and Environment**, Vol.28, No.3, pp. 373-377.
19. Bansal, N.K.,Mathur,R. and Bhandari,M.S., 1994, “A Study of Solar Chimney Assisted Wind Tower System for Natural Ventilation in Buildings,” **Building and Environment**, Vol.29, No.4 pp. 495-500.
20. Peppes, A.A., Santamouris, M. and Asimakopoulos, D.N., 2002, “ Experimental and numerical study of buoyancy-driven stairwell flow in a three storey building”, **Building and Environment**, 37, pp.497-506.
21. Parker, D.S, 1995, “Measured Air-Conditioning and Thermal Performance of A Thai Residential Building”, **Energy**, Vol.20, No.9 pp.907-914.
22. Tantasavasdi, C., Srebric, J. and Chen, Q., 2001, “Natural Ventilation Design for houses in Thailand”, **Energy and Buildings**, Vol. 33, pp. 815-824.
23. Ajibola, K., 1997, “Ventilation of Spaces in a Warm Humid Climate-Case Study of Some Housing Types”, **Renewable Energy**, Vol.10, No.1, pp.61-70.

APPENDIX

APPENDIX A Procedure of Thermocouple Wires Calibration

Thermal couple type K Error Analysis

Thermal couple is calibrated with temperature standard to check error. Range of calibration is 24-40° C

Data logger Model 308721 SN 4RA0772 0346-360-050(1)				
Calibration	Error (^{o}C)			
Temperature (^{o}C)	24	28	32	36
Channel-1	23.7	27.7	31.6	35.4
Channel-2	23.5	27.7	31.6	35.5
Channel-3	23.5	27.7	31.6	35.5
Channel-4	23.6	27.6	31.6	35.4
Channel-5	23.5	27.7	31.6	35.5
Channel-6	23.5	27.6	31.6	35.5
Channel-7	23.5	27.7	31.7	35.5
Channel-8	23.6	27.7	31.7	35.5
Data logger Model 308721 SN 4RA0772 0346-360-050(2)				
Calibration	Error (^{o}C)			
Temperature (^{o}C)	24	28	32	36
Channel-1	24.8	28.8	32.9	36.8
Channel-2	24.7	28.8	32.7	36.6
Channel-3	24.9	28.8	32.8	36.7
Channel-4	24.6	28.6	32.6	36.5
Channel-5	24.7	28.6	32.6	36.6
Channel-6	24.7	28.7	32.7	36.6
Channel-7	24.7	28.7	32.7	36.6
Channel-8	24.7	28.8	32.8	36.7

APPENDIX B The results of six model test (Model Test 1)

Date	Time	It	RH%	T amb	Tch1,o	Tch1,c	Tch3,o	Tch3,c	Tch4,o	Tch4,c	Tch5,o	Tch5,c	Tch7,o	Tch7,c	Tch1,c-Tch1,o	Tch3,c-Tch3,o	Tch4,c-Tch4,o	Tch5,c-Tch5,o	Tch7,c-Tch7,o
MAY 24 2002	0:00		71.2	29.4	29.6	29.6	30.0	30.4	29.9	30.2	30.0	30.2	29.9	30.2	0.0	0.4	0.3	0.2	0.3
			70.8	28.6	29.2	29.5	29.5	30.3	29.2	30.0	29.2	29.8	29.2	30	0.3	0.8	0.8	0.6	0.8
			71.6	28.6	29.1	29.0	29.3	29.8	29.3	29.9	29.2	29.5	29.3	29.9	-0.1	0.5	0.6	0.3	0.6
	3:00		74.6	28.1	28.5	28.4	28.8	29.3	28.8	29.3	28.8	28.9	28.8	29.3	-0.1	0.5	0.5	0.1	0.5
			75.4	27.7	28.0	28.3	28.4	28.9	28.1	28.8	28.1	28.4	28.1	28.8	0.3	0.5	0.7	0.3	0.7
			76.3	27.5	27.4	27.6	27.8	28.4	27.5	28.1	27.5	27.9	27.5	28.1	0.2	0.6	0.6	0.4	0.6
	6:00	91.386	77.0	27.2	27.2	27.3	27.7	28.2	27.3	27.8	27.3	27.5	27.3	27.8	0.1	0.5	0.5	0.2	0.5
		258.61	75.0	27.5	27.8	27.2	27.6	28.1	27.4	27.6	27.5	27.6	27.4	27.6	-0.6	0.5	0.2	0.1	0.2
		489.17	75.3	28.7	27.8	27.6	28.2	28.5	28.3	28.1	28.4	28.2	28.3	28.1	-0.2	0.3	-0.2	-0.2	-0.2
	9:00	692.78	75.1	29.8	28.5	28.2	29.1	29.3	29.2	28.9	29.6	29.1	29.2	28.9	-0.3	0.2	-0.3	-0.5	-0.3
		804.17	74.3	30.8	30.0	29.6	30.5	30.3	30.6	30.0	30.9	30.3	30.6	30	-0.4	-0.2	-0.6	-0.6	-0.6
		862.5	68.3	31.5	30.8	31.2	31.0	31.5	31.2	31.3	31.4	33.1	31.2	31.3	0.4	0.5	0.1	1.7	0.1
	12:00	820.28	62.5	33.1	32.6	33.0	32.7	33.3	33.0	31.6	33.3	37.0	33	31.6	0.4	0.6	-1.4	3.7	-1.4
		733.89	58.6	34.6	33.5	33.8	34.2	34.1	34.4	34.6	34.8	38.3	34.4	34.6	0.3	-0.1	0.2	3.5	0.2
		703.06	50.5	34.8	34.1	34.2	34.7	35.4	35.0	36.1	35.2	39.4	35	36.1	0.1	0.7	1.1	4.2	1.1
	15:00	637.5	50.8	35.2	34.0	34.9	35.3	34.9	34.9	35.6	35.3	37.7	34.9	35.6	0.9	-0.4	0.7	2.4	0.7
		393.33	52.1	32.8	31.6	33.7	33.2	34.8	32.8	35.1	32.4	36.5	32.8	35.1	2.1	1.6	2.3	4.1	2.3
		206.11	62.9	32.9	31.8	32.9	33.2	33.9	32.5	33.9	32.3	34.5	32.5	33.9	1.1	0.7	1.4	2.2	1.4
	18:00	0	63.5	32.3	31.8	32.4	32.8	33.5	32.5	33.3	31.9	33.7	32.5	33.3	0.6	0.7	0.8	1.8	0.8
			66.4	31.1	31.3	31.9	31.9	32.7	31.4	32.7	30.8	32.7	31.4	32.7	0.6	0.8	1.3	1.9	1.3
			69.1	30.5	30.9	31.2	31.2	32.2	31.0	31.7	30.4	31.8	31	31.7	0.3	1.0	0.7	1.4	0.7
	21:00		71.8	30.3	30.6	30.7	31.0	31.6	30.6	31.4	30.4	31.3	30.6	31.4	0.1	0.6	0.8	0.9	0.8
			72.1	29.8	30.0	30.3	30.5	31.5	30.2	30.8	29.8	30.7	30.2	30.8	0.3	1.0	0.6	0.9	0.6
			73.5	29.8	29.9	30.1	30.4	31.0	30.2	30.5	29.8	30.5	30.2	30.5	0.2	0.6	0.3	0.7	0.3
MAY 25 2002	0:00		75.2	29.6	29.8	29.9	30.4	30.7	29.9	30.5	29.4	30.4	29.9	30.5	0.1	0.3	0.6	1.0	0.6
Average		**514.8**	**68.6**	**30.5**	**30.2**	**30.5**	**30.8**	**31.3**	**30.6**	**31.1**	**30.5**	**31.8**	**30.6**	**31.1**	**0.3**	**0.5**	**0.5**	**1.3**	**0.5**
Total		**6693**																	

Model Test 2

Date	Time	It	RH%	Tamb	Tch1,o	Tch1,c	Tch3,o	Tch3,c	Tch4,o	Tch4,c	Tch5,o	Tch5,c	Tch7,o	Tch7,c	Tch1,c-Tch1,o	Tch3,c-Tch3,o	Tch4,c-Tch4,o	Tch5,c-Tch5,o	Tch7,c-Tch7,o
MAY 29 2002	0:00		80.4	27.7	28.3	28.4	28.3	28.6	28.0	28.2	28.3	27.9	27.8	28.1	0.1	0.3	0.2	-0.4	0.3
			82.5	27.4	27.8	28.2	27.9	28.4	27.4	28.0	27.8	27.7	27.3	27.8	0.4	0.5	0.6	-0.1	0.5
			83.2	27.5	27.7	27.9	27.5	27.9	27.3	27.9	27.7	27.4	27.1	27.8	0.2	0.4	0.6	-0.3	0.7
	3:00		85.8	27.0	27.6	27.6	26.9	27.5	27.1	27.4	27.6	27.4	27.3	27.6	0.0	0.6	0.3	-0.2	0.3
			81.8	26.9	27.4	27.4	27.5	27.5	27.2	27.4	27.4	26.8	27.0	27.3	0.0	0.0	0.2	-0.6	0.3
			81.8	27.3	27.2	27.4	27.4	27.8	27.3	27.4	27.2	26.7	27.0	27.4	0.2	0.4	0.1	-0.5	0.4
	6:00	169.4	80.2	27.5	27.3	27.0	27.5	27.6	27.4	27.2	27.3	27.0	27.2	27.2	-0.3	0.1	-0.2	-0.3	0.0
		384.7	81.0	28.3	27.7	27.7	28.3	28.3	28.1	28.1	27.7	28.2	28.1	28.2	0.0	0.0	0.0	0.5	0.1
		484.7	75.8	28.5	28.0	27.9	28.5	28.7	28.4	28.4	28.4	28.4	28.4	28.5	-0.1	0.2	0.0	0.0	0.1
	9:00	643.3	73.0	29.2	28.4	28.3	29.2	29.0	29.0	28.8	29.1	28.6	29.0	28.9	-0.1	-0.2	-0.2	-0.5	-0.1
		767.8	70.3	29.3	28.7	28.5	29.3	29.4	29.3	29.3	29.3	29.3	29.2	29.4	-0.2	0.1	0.0	0.0	0.2
		840.0	69.2	30.2	29.3	29.5	30.2	30.5	29.9	30.3	30.1	31.7	30.0	30.5	0.2	0.3	0.4	1.6	0.5
	12:00	718.3	65.6	31.5	30.7	31.0	31.0	31.5	30.8	31.1	30.9	32.0	30.6	31.4	0.3	0.5	0.3	1.1	0.8
		705.8	63.6	32.3	31.1	31.6	31.5	32.5	31.4	31.8	31.8	32.5	31.1	32.1	0.5	1.0	0.4	0.7	1.0
		428.3	61.8	32.4	31.0	32.6	32.4	33.0	31.6	32.8	31.9	33.0	31.2	33.0	1.6	0.6	1.2	1.1	1.8
	15:00	273.6	62.3	32.3	30.5	31.6	31.8	32.2	31.0	32.5	30.9	33.0	30.6	32.5	1.1	0.4	1.5	2.1	1.9
		281.4	74.0	27.0	26.4	28.0	27.0	28.2	27.0	28.3	26.5	29.0	26.3	28.3	1.6	1.2	1.3	2.5	2.0
		150.6	81.7	28.3	28.0	28.5	28.3	29.0	28.3	28.0	28.1	29.2	28.2	28.7	0.5	0.7	-0.3	1.1	0.5
	18:00		77.9	28.7	28.6	28.6	28.7	28.8	28.6	28.7	28.6	29.0	28.0	28.8	0.0	0.1	0.1	0.4	0.8
			78.5	28.3	28.4	28.4	28.3	28.5	28.4	28.4	28.2	28.6	28.2	28.4	0.0	0.2	0.0	0.4	0.2
			79.8	28.1	28.2	28.2	28.1	28.5	28.2	28.3	28.1	28.4	28.0	28.2	0.0	0.4	0.1	0.3	0.2
	21:00		77.4	28.4	28.2	28.3	28.4	28.6	28.3	28.4	28.2	28.5	28.3	28.4	0.1	0.2	0.1	0.3	0.1
			76.5	28.4	28.2	28.1	28.4	28.4	28.4	28.2	28.4	28.4	28.3	28.3	-0.1	0.0	-0.2	0.0	0.0
			75.7	28.4	28.0	28.0	28.4	28.5	28.3	28.3	28.3	28.4	28.2	28.3	0.0	0.1	0.0	0.1	0.1
MAY 30 2002	0:00		75.1	28.1	27.9	27.9	28.1	28.4	28.1	28.1	28.0	28.3	28.0	28.2	0.0	0.3	0.0	0.3	0.2
Average		**487.3**	**75.8**	**28.8**	**28.4**	**28.7**	**28.8**	**29.1**	**28.6**	**28.9**	**28.6**	**29.0**	**28.4**	**28.9**	**0.2**	**0.3**	**0.3**	**0.4**	**0.5**
Total		**5848**																	

Model Test 3

Date	Time	It	RH%	Tamb	Tch1,o	Tch1,c	Tch3,o	Tch3,c	Tch4,o	Tch4,c	Tch5,o	Tch5,c	Tch7,o	Tch7,c	Tch1,c-Tch1,o	Tch3,c-Tch3,o	Tch4,c-Tch4,o	Tch5,c-Tch5,o	Tch7,c-Tch7,o
JUNE 07 2002	0:00		69.7	28.1	28.2	28.3	28.4	29.0	28.2	28.7	28.1	28.4	28.2	28.5	0.1	0.6	0.5	0.3	0.3
			71.1	27.6	28.0	28.1	28.1	28.6	28.0	28.6	27.9	28.1	28.1	28.4	0.1	0.5	0.6	0.2	0.3
			74.6	27.3	27.4	27.6	27.7	28.4	27.4	28.1	27.2	27.4	27.5	27.9	0.2	0.7	0.7	0.2	0.4
	3:00		74.9	27.3	27.6	27.4	27.4	28.2	27.5	28.1	27.5	27.4	27.7	27.7	-0.2	0.8	0.6	-0.1	0.0
			75.2	27.1	27.4	27.4	27.5	28.1	27.4	27.9	27.3	27.2	27.5	27.5	0.0	0.6	0.5	-0.1	0.0
			76.2	26.8	27.2	27.2	27.3	27.8	27.3	27.7	27.3	27	27.3	27.4	0.0	0.5	0.4	-0.3	0.1
	6:00	99.4	76.4	26.7	27.1	27.1	27.2	27.7	27.2	27.6	26.7	26.9	27.2	27.3	0.0	0.5	0.4	0.2	0.1
		255.6	77.1	27.1	27.2	27.3	27.3	27.8	27.2	27.7	27.1	27.2	27.2	27.4	0.1	0.5	0.5	0.1	0.2
		508.6	77.0	28.2	27.7	27.4	27.9	28.3	28.0	27.8	28.0	27.9	27.9	27.8	-0.3	0.4	-0.2	-0.1	-0.1
	9:00	745.0	74.7	29.1	28.1	28.0	28.5	28.9	28.8	28.5	28.0	28.8	28.3	28.4	-0.1	0.4	-0.3	0.8	0.1
		773.3	71.1	30.2	28.8	28.7	29.4	29.7	29.7	29.5	30.0	29.9	29.0	29.4	-0.1	0.3	-0.2	-0.1	0.4
		811.7	69.6	31.2	30.5	30.3	30.6	30.8	30.6	31.0	30.8	31.7	30.4	30.9	-0.2	0.2	0.4	0.9	0.5
	12:00	783.3	67.4	31.6	30.5	31.6	30.9	32.1	30.7	32.1	30.7	33.6	30.8	32.2	1.1	1.2	1.4	2.9	1.4
		855.0	63.8	32.4	30.8	32.0	31.3	32.4	31.4	32.8	31.2	33.7	31.5	32.9	1.2	1.1	1.4	2.5	1.4
		769.4	62.7	33.7	31.9	32.8	32.3	33.4	32.6	34.5	32.8	35.2	32.2	33.9	0.9	1.1	1.9	2.4	1.7
	15:00	577.2	60.8	33.4	31.9	33.1	32.4	33.7	32.8	34.7	32.7	35.8	32.7	34.6	1.2	1.3	1.9	3.1	1.9
		307.2	62.2	31.5	30.6	31.8	31.3	33.3	31.5	33.8	31.4	34.7	31.6	33.8	1.2	2.0	2.3	3.3	2.2
		62.5	67.0	30.6	30.5	31.2	30.8	32.1	30.5	32.3	30.4	32.5	31.0	32.6	0.7	1.3	1.8	2.1	1.6
	18:00	18.9	70.1	30.6	30.0	31.1	30.4	32.1	30.5	32.0	30.2	32	30.5	32.3	1.1	1.7	1.5	1.8	1.8
			72.5	30.3	30.4	30.6	30.5	31.4	30.5	31.4	30.0	31	30.4	31.4	0.2	0.9	0.9	1.0	1.0
			76.5	30.0	30.2	30.3	30.4	31.0	30.2	31.0	30.1	30.5	30.4	31.0	0.1	0.6	0.8	0.4	0.6
	21:00		76.6	29.7	29.9	30.3	30.1	31.1	30.0	30.9	29.9	30.4	30.2	31.0	0.4	1.0	0.9	0.5	0.8
			77.7	29.3	29.1	29.5	29.6	30.4	29.3	30.0	29.2	29.5	29.1	29.9	0.4	0.8	0.7	0.3	0.8
			72.9	28.6	28.6	28.8	28.9	29.6	28.7	29.5	28.5	28.8	28.7	29.2	0.2	0.7	0.8	0.3	0.5
JUNE 08 2002	0:00		71	28.1	28.2	28.3	27.6	27.4	28.4	28.4	28.1	28.4	28.2	28.5	0.1	-0.2	0.0	0.3	0.3
Average		**505.2**	**71.6**	**29.5**	**29.1**	**29.4**	**29.4**	**30.1**	**29.4**	**30.2**	**29.2**	**30.2**	**29.3**	**30.1**	**0.3**	**0.8**	**0.8**	**0.9**	**0.7**
Total		**6567.1**																	

Model Test 4

Date	Time	It	RH%	Tamb	Tch1,o	Tch1,c	Tch3,o	Tch3,c	Tch4,o	Tch4,c	Tch5,o	Tch5,c	Tch7,o	Tch7,c	Tch1,c-Tch1,o	Tch3,c-Tch3,o	Tch4,c-Tch4,o	Tch5,c-Tch5,o	Tch7,c-Tch7,o
JUNE 11 2002	0:00		73.5	28.2	27.6	28.7	27.3	28.4	27.7	28.2	27.3	28.2	27.7	27.8	1.1	1.1	0.5	0.9	0.10
			81.7	22.8	24.6	25.5	23.7	25.1	24.0	25.0	23.7	24.8	23.6	24.7	0.9	1.4	1.0	1.1	1.10
			83.1	23.9	24.6	25.3	24.2	25.2	24.4	24.6	24.2	24.8	24.2	25.0	0.7	1.0	0.2	0.6	0.80
	3:00		87.7	24.6	25.1	25.6	25.1	25.5	25.1	25.5	24.9	25.3	24.9	25.2	0.5	0.4	0.4	0.4	0.30
			89.2	24.8	25.3	25.7	24.9	25.7	25.2	25.6	25.0	25.4	25.0	25.5	0.4	0.8	0.4	0.4	0.50
			88.7	24.8	25.5	25.8	24.7	25.6	25.3	25.6	25.1	25.3	25.0	25.5	0.3	0.9	0.3	0.2	0.50
	6:00	40.6	88	25.0	25.5	25.8	25.2	25.7	25.4	25.7	25.3	25.3	25.1	25.7	0.3	0.5	0.3	0.0	0.60
		135.0	88.5	25.7	25.7	26.4	25.8	26.5	25.8	26.3	25.7	26.3	25.7	26.3	0.7	0.7	0.5	0.6	0.60
		243.1	90.5	26.9	26.7	26.7	27.2	27.4	27.1	27.3	27.2	27.3	27.2	27.4	0.0	0.2	0.2	0.1	0.20
	9:00	376.9	90.6	27.6	27.4	27.6	28.2	28.5	28.0	28.3	28.3	28.4	28.0	28.5	0.2	0.3	0.3	0.1	0.50
		787.5	86.9	28.7	28.0	28.4	29.1	29.6	29.2	29.5	29.4	29.8	29.1	29.8	0.4	0.5	0.3	0.4	0.70
		876.4	83.1	29.8	28.6	29.2	30.0	30.7	29.9	30.5	30.5	32.0	30.1	31.1	0.6	0.7	0.6	1.5	1.00
	12:00	506.1	76.2	32.1	30.9	31.0	31.3	31.6	31.7	31.7	32.6	33.7	31.8	32.1	0.1	0.3	0.0	1.1	0.30
		560.6	72.3	31.6	31.2	30.8	31.1	31.6	31.2	31.5	31.6	33.1	31.2	32.2	-0.4	0.5	0.3	1.5	1.00
		919.7	44	32.5	31.0	31.9	31.1	32.6	31.5	33.0	32.1	35.1	31.4	33.5	0.9	1.5	1.5	3.0	2.10
	15:00	685.9	65.9	34.2	32.3	32.3	32.5	33.1	32.7	33.7	33.3	37.0	32.8	34.1	0.0	0.6	1.0	3.7	1.30
		298.9	59.2	32.3	31.3	31.6	31.4	32.2	31.8	32.6	31.7	34.1	31.5	32.9	0.3	0.8	0.8	2.4	1.40
		106.7	63.7	30.7	30.1	30.8	30.2	31.2	30.5	31.3	30.3	32.0	30.3	31.5	0.7	1.0	0.8	1.7	1.20
	18:00	12.8	69.1	30.3	30.2	30.4	30.1	30.6	30.4	30.5	30.2	31.0	30.2	30.7	0.2	0.5	0.1	0.8	0.50
			72	28.9	29.5	29.6	29.3	29.7	29.3	29.9	29.2	29.8	29.4	29.8	0.1	0.4	0.6	0.6	0.40
			72.7	28.9	29.2	29.4	29.1	29.6	29.2	29.5	29.1	29.5	29.0	29.5	0.2	0.5	0.3	0.4	0.50
	21:00		77.5	29.3	29.1	29.2	29.3	29.5	29.3	29.4	29.2	29.4	29.2	29.5	0.1	0.2	0.1	0.2	0.30
			76.3	28.7	28.9	29.2	28.5	29.1	28.7	29.0	28.5	29.4	28.7	28.9	0.3	0.6	0.3	0.9	0.20
			77.8	27.9	28.5	28.6	28.4	28.8	28.3	28.8	28.1	28.5	28.4	28.5	0.1	0.4	0.5	0.4	0.10
JUNE 12 2002	0:00		78.6	27.8	28.2	28.4	27.8	28.6	28.3	28.4	28.0	28.4	28.1	28.2	0.2	0.8	0.1	0.4	0.10
Average		**426.9**	**77.5**	**28.3**	**28.2**	**28.6**	**28.2**	**28.9**	**28.4**	**28.9**	**28.4**	**29.4**	**28.3**	**29.0**	**0.4**	**0.7**	**0.5**	**0.9**	**0.7**
Total		**5550**																	

Model Test-5

Date	Time	It	RH%	Tamb	Tch1,o	Tch1,c	Tch3,o	Tch3,c	Tch4,o	T ch4,c	Tch5,o	Tch5,c	Tch7,o	Tch7,c	Tch1,c-Tch1,o	Tch3,c-Tch3,o	Tch4,c-Tch4,o	Tch5,c-Tch5,o	Tch7,c-Tch7,o
JUNE 16 2002	0:00		69.3	28.3	27.9	28.2	28.4	28.5	28.2	28.7	28.0	28.0	28.3	28.2	0.3	0.1	0.5	0.0	-0.1
			73.1	28.2	28.1	28.2	28.6	28.6	28.4	28.7	27.7	27.9	28.4	28.3	0.1	0.0	0.3	0.2	-0.1
			76.3	28.2	27.9	28.1	28.4	28.4	28.3	28.5	27.5	27.8	28.3	28.2	0.2	0.0	0.2	0.3	-0.1
	3:00		77.5	28.0	27.8	28	28.3	28.4	28.2	28.5	27.4	27.5	28.2	28.0	0.2	0.1	0.3	0.1	-0.2
			77.1	27.8	27.6	27.8	28.0	28.3	28.0	28.4	27.1	27.4	27.9	27.8	0.2	0.3	0.4	0.3	-0.1
			78.0	27.5	27.6	27.7	28.1	28.1	27.4	28.3	26.9	27.3	27.8	27.7	0.1	0.0	0.9	0.4	-0.1
	6:00	35.6	80.9	27.6	27.4	27.6	28.0	28.0	27.7	28.1	27.3	27.3	27.7	27.5	0.2	0.0	0.4	0.0	-0.2
		144.4	79.3	28.1	27.6	27.8	27.6	28.1	27.9	28.2	27.9	27.8	28.0	27.8	0.2	0.5	0.3	-0.1	-0.2
		268.9	78.6	29.1	28.1	28.2	28.4	28.5	28.7	28.7	29.0	28.8	28.5	28.6	0.1	0.1	0.0	-0.2	0.1
	9:00	615.6	77.1	30.1	28.6	28.7	29.2	29.2	29.4	29.1	29.9	29.6	29.0	29.6	0.1	0.0	-0.3	-0.3	0.6
		815.3	75.2	30.4	29	29.1	29.7	29.7	29.7	29.6	30.5	30.2	29.5	30.0	0.1	0.0	-0.1	-0.3	0.5
		679.7	70.8	32.4	30.4	29.9	30.8	30.4	31.2	30.3	32.8	31.4	30.4	31.8	-0.5	-0.4	-0.9	-1.4	1.4
	12:00	793.6	67.6	33.3	31.4	31	32.2	31.6	32.2	31.6	33.8	33.4	31.5	32.8	-0.4	-0.6	-0.6	-0.4	1.3
		882.2	65.5	33.5	32.2	32.1	32.7	32.7	33.2	32.9	34.2	34.6	32.7	34.0	-0.1	0.0	-0.3	0.4	1.3
		743.6	59.3	33.9	32.5	32.3	33.1	32.9	33.9	33.3	34.8	34.5	33.0	34.5	-0.2	-0.2	-0.6	-0.3	1.5
	15:00	512.5	58.0	34.5	33	33.3	33.4	34.1	34.5	34.6	35.4	35.6	34.0	35.4	0.3	0.7	0.1	0.2	1.4
		208.9	56.8	32.6	32.1	32.2	32.5	32.8	33.2	33.6	32.7	33.0	33.0	33.5	0.1	0.3	0.4	0.3	0.5
		110	58.4	31.7	31.4	31.3	31.4	32.1	32.3	32.3	31.6	31.3	31.7	32.3	-0.1	0.7	0.0	-0.3	0.6
	18:00	18.1	63.3	31.1	30.9	30.9	31.4	31.8	31.5	31.9	30.9	30.9	31.2	31.5	0.0	0.4	0.4	0.0	0.3
			66.5	30.5	30.2	30.3	30.5	30.9	30.8	31.0	30.4	30.1	30.4	30.7	0.1	0.4	0.2	-0.3	0.3
			68.4	30.4	30.2	30.4	30.8	30.9	30.6	31.0	30.4	30.3	30.5	30.7	0.2	0.1	0.4	-0.1	0.2
	21:00		71.0	30.4	30.1	30.2	30.3	30.7	30.4	30.8	30.2	30.2	30.4	30.4	0.1	0.4	0.4	0.0	0.0
			70.5	29.8	29.3	29.3	30.2	30.0	30.0	30.1	29.5	29.3	29.6	29.6	0.0	-0.2	0.1	-0.2	0.0
			68.5	29.3	29	29.1	29.8	29.5	29.5	29.6	28.9	28.8	29.2	29.3	0.1	-0.3	0.1	-0.1	0.1
JUNE 17 2002	0:00		69.1	28.9	28.6	28.5	29.4	29.2	29.1	29.3	28.5	28.4	28.8	28.9	-0.1	-0.2	0.2	-0.1	0.1
Average		**448.3**	**70.2**	**30.2**	**29.6**	**29.6**	**30.0**	**30.1**	**30.2**	**30.3**	**30.1**	**30.1**	**29.9**	**30.3**	**0.1**	**0.1**	**0.1**	**-0.1**	**-0.1**
Total		**5828**																	

Model Test-6

Date	Time	It	RH%	Tamb	Tch1,o	Tch1,c	Tch3,o	Tch3,c	Tch4,o	Tch4,c	Tch5,o	T5ch,c	Tch7,o	Tch7,c	Tch1,c-Tch1,o	Tch3,c-Tch3,o	Tch4,c-Tch4,o	Tch5,c-Tch5,o	Tch7,c-Tch7,o
JUNE 18 2002	0:00		72.4	28.4	28.4	28.4	29.1	28.6	28.4	28.9	28.8	28.2	28.6	28.6	0.0	-0.5	0.5	-0.6	0.0
			71.3	27.8	28.0	27.9	28.4	28.4	28.2	28.5	28.3	27.8	28.2	28.2	-0.1	0.0	0.3	-0.5	0.0
			72.8	27.5	27.6	27.7	28.0	28.1	27.6	28.4	28.0	27.5	27.9	27.9	0.1	0.1	0.8	-0.5	0.0
	3:00		72.8	27.4	27.5	27.4	28.0	27.6	27.7	28.0	27.8	27.2	27.6	27.7	-0.1	-0.4	0.3	-0.6	0.1
			73.8	27.1	27.4	27.4	27.4	27.6	27.5	27.9	27.6	27.1	27.5	27.5	0.0	0.2	0.4	-0.5	0.0
			74.7	27.0	27.2	27.2	27.7	27.4	27.2	27.7	27.4	26.7	27.3	27.3	0.0	-0.3	0.5	-0.7	0.0
	6:00	73.1	75.1	27.2	27.1	27.1	27.7	27.3	27.3	27.5	27.4	26.9	27.3	27.2	0.0	-0.4	0.2	-0.5	-0.1
		219.2	77.5	28.4	27.4	27.4	28.0	28.1	27.8	27.8	27.7	27.5	27.6	27.6	0.0	0.1	0.0	-0.2	0.0
		455	75.1	29.3	27.9	27.9	28.5	28.5	28.4	28.3	28.4	27.4	28.1	28.4	0.0	0.0	-0.1	-1.0	0.3
	9:00	651.4	74.2	30.4	28.4	28.5	29.2	29.0	29.4	28.8	29.1	29.4	28.8	29.2	0.1	-0.2	-0.6	0.3	0.4
		653.9	71.4	31.3	29.4	29.3	29.8	30.0	30.1	29.7	30.0	30.5	29.6	30.4	-0.1	0.2	-0.4	0.5	0.8
		647.2	69.2	31.8	30.0	30.1	30.6	30.8	30.7	30.6	30.7	30.9	30.4	31.1	0.1	0.2	-0.1	0.2	0.7
	12:00	900.3	67.7	32.9	31.5	31.0	31.8	31.7	32.0	31.8	32.1	33.6	31.6	32.5	-0.5	-0.1	-0.2	1.5	0.9
		887.2	64.9	33.5	32.4	32.0	32.9	32.9	33.3	33.3	33.4	35.2	32.7	33.9	-0.4	0.0	0.0	1.8	1.2
		751.4	60.5	33.7	32.2	32.1	32.6	32.9	32.9	33.4	33.3	34.0	32.6	34.1	-0.1	0.3	0.5	0.7	1.5
	15:00	778.9	58.8	33.8	32.3	32.2	32.3	32.8	33.2	33.9	33.3	33.8	32.8	34.2	-0.1	0.5	0.7	0.5	1.4
		286.4	58.8	32.1	31.8	31.5	32.0	32.5	32.5	33.0	32.6	32.5	32.1	33.2	-0.3	0.5	0.5	-0.1	1.1
		81.1	60.7	30.9	31.4	31.0	31.2	31.9	31.7	32.0	31.8	31.1	31.3	32.0	-0.4	0.7	0.3	-0.7	0.7
	18:00		64.3	30.2	30.6	30.4	30.5	31.0	30.9	31.0	31.1	30.2	30.4	31.2	-0.2	0.5	0.1	-0.9	0.8
			69.6	29.1	29.4	29.1	28.9	29.8	29.4	30.1	29.7	28.5	29.2	29.7	-0.3	0.9	0.7	-1.2	0.5
			70.0	28.3	28.8	28.6	29.1	29.3	28.9	29.5	29.2	28.4	28.9	29.2	-0.2	0.2	0.6	-0.8	0.3
	21:00		70.2	28.3	28.4	28.5	29.2	29.3	28.6	29.4	28.9	28.4	28.9	28.8	0.1	0.1	0.8	-0.5	-0.1
			71.7	28.7	28.4	28.6	29.1	29.3	28.7	29.1	28.9	28.5	28.8	28.7	0.2	0.2	0.4	-0.4	-0.1
			73.0	28.7	28.6	28.7	29.1	29.1	28.8	29.3	29.1	28.6	29.0	29.0	0.1	0.0	0.5	-0.5	0.0
JUNE 19 2002	0:00		73.4	28.4	28.4	28.6	28.8	29.0	28.6	29.3	28.8	28.4	28.9	28.7	0.2	0.2	0.7	-0.4	-0.2
Average		**532.1**	**69.8**	**29.7**	**29.2**	**29.1**	**29.6**	**29.7**	**29.6**	**29.9**	**29.7**	**29.5**	**29.4**	**29.9**	**-0.1**	**0.1**	**0.3**	**-0.2**	**-0.2**
Total		**6385**																	

Appendix C Results of Air flow rate in Test -2, Test-4 and Test-6

Test -2 (May 29,2002)

Time	Q flat roof,c (m^3/s)	Q flat roof,o (m^3/s)	Vamb (m/s)
9:00	0.06	0.27	0.28
10:00	0.15	0.18	0.35
11:00	0.15	0.42	1.10
12:00	0.25	0.34	0.70
13:00	0.30	0.44	1.20
14:00	0.16	0.40	1.50
15:00	0.11	0.53	2.00
16:00	0.34	0.65	4.00
17:00	0.10	0.42	3.20

Test-3 (June 07,2002)

Time	Qopen (m^3/s)	Vamb (m/s)
9:00	0.25	0.28
10:00	0.32	0.35
11:00	0.44	0.48
12:00	0.19	0.70
13:00	0.41	0.60
14:00	0.35	1.10
15:00	0.28	0.84
16:00	0.46	1.29
17:00	0.29	0.99

Test-4 (June 12,2002)

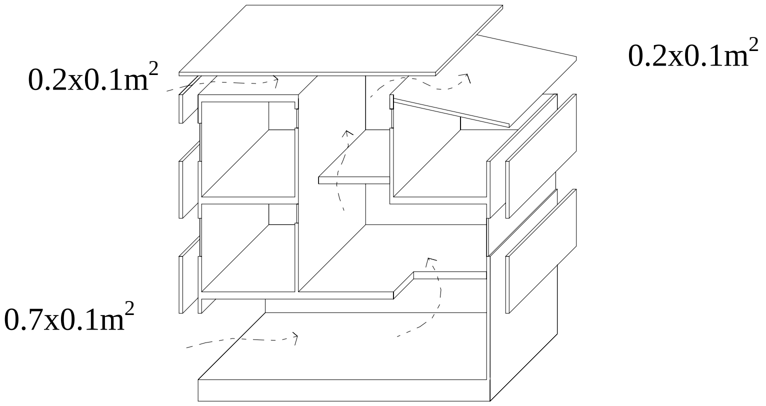
Time	Q sloping rf,c	Q flat rf,o	Vamb
	(m^3/s)	(m^3/s)	(m/s)
9:00	0.06	0.27	0.30
10:00	0.05	0.34	0.50
11:00	0.18	0.30	0.29
12:00	0.37	0.45	0.70
13:00	0.23	0.52	0.95
14:00	0.21	0.45	1.20
15:00	0.24	0.45	1.10
16:00	0.39	0.50	1.50
17:00	0.22	0.42	0.90
	0.21	0.41	0.83

Test-6 (June 20,2002)

Time	Q flat rf,c	Q sloping rf,o	Vamb
	(m^3/s)	(m^3/s)	(m/s)
9:00	0.05	0.10	0.16
10:00	0.04	0.13	0.14
11:00	0.06	0.20	0.60
12:00	0.06	0.13	0.30
13:00	0.07	0.24	0.30
14:00	0.17	0.29	0.39
15:00	0.24	0.31	0.33
16:00	0.11	0.29	0.35
17:00	0.10	0.30	0.30

APPENDIX D Prediction of Air Flow Rate and Reduced Temperature

Comparison the result of Test-3 with Mathematic Model



Method-1

Q = KAV

Q = Volumetric flow rate wind force (m^3/s)

K = Coefficient of effectiveness = 0.5

A = Area of smaller opening (m^2) 0.2x1 =0.2 m^2

V = Outdoor wind speed (m/s)

Time	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Air velocity(m/s)	0.2	0.35	0.48	0.7	0.6	1.1	0.84	1.29	0.99
Q (m3/s)	0.02	0.035	0.048	0.07	0.06	1.1	0.084	0.129	0.099

$Q= C_d A_o \{2(\Delta T/T_o) g H \sin\beta\}^{1/2} \{(1+A_r^2)\}^{1/2}$

Q = Volumetric flow rate thermal force(m^3/s)

H = Height (m) =3 m

C_d = Coefficient of Discharge = 0.5

A_o = Outlet cross section Area of flow (m^2) = 0.2+0.2 m^2

A_i = Inlet cross section Area of flow (m^2) = 0.7

ΔT = Temperature difference (°C) =Tch5-Tch1

T_o = Outlet temperature (°C) = Tch5

β = Slope (degree) = 0

A_r == A_o/A_i = 0.4/0.7 = 0.5714

Time	T outlet	T inlet	Qstack	Vamb	Qwind	Qtotal
9:00	28.1	28.0	0.0471	0.20	0.02	0.0100
10:00	30.0	28.8	0.0353	0.35	0.04	0.3549
11:00	30.8	30.5	0.1743	0.48	0.05	0.1808
12:00	30.7	30.5	0.1425	0.70	0.07	0.1588
13:00	31.2	30.8	0.2000	0.60	0.06	0.0880
14:00	32.8	31.9	0.2925	1.10	0.11	0.3125
15:00	32.7	3.9	0.2762	0.80	0.08	0.2887
16:00	31.4	30.6	0.2819	1.29	0.13	0.3100
17:00	30.4	30.4	0.0453	0.99	0.10	0.1089

Method-2

$Q = 0.1469\ A\ (gH)^{1/2}\ (\Delta T/T)^{0.3}$

Q = Volumetric flow rate (m^3/s)

0.1469 = Constant

A = Effective cross-sectional area of the opening connection the floors (m^2)=0.3

H = Height (m) = 3 m

g = Acceleration due to gravity (m/s^2)

ΔT = Average air temperature difference between two adjacent floors (°C)

T = Mean absolute air temperature of two adjacent floors (K)

Time	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Toutlet	28.1	30.0	30.8	30.7	31.2	32.8	32.7	31.4	30.4
Tinlet	28.0	28.8	30.5	30.5	30.8	31.9	31.9	30.6	30.4
Tout-Tin	0.1	1.2	0.3	0.2	0.4	0.9	0.8	0.8	0.0
Tmean	28.1	29.4	30.7	30.6	31.0	32.4	32.3	31.0	30.4
Q	0.044	0.093	0.060	0.054	0.066	0.083	0.080	0.081	0.027

Comparison Method-1and 2 with the result of test

Time	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Qmethod-1	0.512	0.3549	0.1808	0.1588	0.2088	0.3125	0.2887	0.31	0.1089
Qmethod-2	0.045	0.093	0.06	0.54	0.66	0.083	0.08	0.081	0.027
Q measure	0.22	0.32	0.44	0.19	0.41	0.35	0.28	0.46	0.29

The value of Q method-1 is more closely to Qmeasure; therefore, use Qmethod-1 for prediction. (Calculate only Qstack, not including Q wind)

$Q = C_d A_o \{2(\Delta T/T_o)\ g\ H \sin\beta\}^{1/2} \{(1+A_r^2)\}^{1/2}$

Q = Volumetric flow rate thermal force(m^3/s)

H = Height of real shophouse(m) =8 m

C_d = Coefficient of Discharge = 0.5

A_o = Outlet cross section Area of flow (m^2) 3.5x2 = 7 m^2

A_i = Inlet cross section Area of flow (m^2) 3.5x3.2= 11.2 m^2

ΔT = Temperature difference (°C) =Tst,top-Tst,bottom

T_o = Outlet temperature (°C) = Tst,top

β = Slope (degree) = 0

A_r == A_o/A_i =7/11.2 = .625

	To-Ti	Tst,top	Q (m^3/s)
Hot season	36-32	36	17.2276
Cool Season	32-30	32	12.9207

Find Reduced Temperature

$Q \quad = m\ Cp\ \Delta T \qquad (W/m^2)$

$Q \quad = \rho\ V\ Cp\ (T_{st,top} - T_{st,bottom})$

$T_{st,top} = T_{st,bottom} + (Q/\rho\ V\ Cp)$

ρ air ,305K (32 °C)	Cp air,305K	Season	V (m^3/s)	Q heat (W/m^2)	T out (°C)	$T_{measured}$ Tst, top (°C)	T_{reduce} (°C)
1.16	1005.5	Hot	17.227	100	32.005	36	4.00
				200	32.010		3.99
		Cool	12.92	100	30.007	32	1.99
				200	30.013		1.99

CURRICULUM VITAE

NAME	Mr. Wattanavit Nilaphanpitak
DATE OF BIRTH	2 April 1975
EDUCATIONAL RECORD	
HIGH SCHOOL	High School Graduation Assumption College, 1994
BACHELOR’S DEGREE	Bachelor of Architecture (Architecture) King Mongkut’s University of Technology Thonburi, 1999
SCHOLARSHIP/ RESEARCH GRANT	Research Grant for Graduate Student The Ministry of University Affairs, 2000
EMPLOYMENT RECORD	Architect Design Poiesis Inc. 2001-2002

มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี
ข้อตกลงว่าด้วยการโอนลิขสิทธิ์ในวิทยานิพนธ์

วันที่ 30 ตุลาคม พ.ศ. 2545

ข้าพเจ้า ([✓ นาย]/นาง/นางสาว) วรรธนวิชญ์ นิลพันธ์พิทักษ์ รหัสประจำตัว 44401104 เป็นนักศึกษาของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี ระดับปริญญา ☑ โท ☐ เอก ☐ ปร.ด หลักสูตร วิทยาศาสตรมหาบัณฑิต สาขาวิชาเทคโนโลยีการจัดการพลังงาน คณะพลังงานและวัสดุ

อยู่บ้านเลขที่ 22/11 ตรอก/ซอย – ถนน เจริญกรุง

ตำบล/แขวง วังบูรพา อำเภอ/เขต พระนคร จังหวัด กทม.

รหัสไปรษณีย์ 10200 ขอโอนลิขสิทธิ์ในวิทยานิพนธ์ให้ไว้กับมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี โดยมี รศ.ดร. **อภิชิต เทอดโยธิน** ตำแหน่ง คณบดีคณะพลังงานและวัสดุ เป็นผู้รับโอนลิขสิทธิ์และมีข้อตกลง ดังนี้

1. ข้าพเจ้าได้จัดทำวิทยานิพนธ์ เรื่อง "แนวทางการออกแบบอาคารตึกแถวประหยัดพลังงานในประเทศไทย" ซึ่งอยู่ในความควบคุมของ รศ.ดร.โจเซฟ เคดารี ตามมาตรา 14 แห่ง พ.ร.บ. ลิขสิทธิ์ พ.ศ. 2537 และถือว่าเป็นส่วนหนึ่งของการศึกษาตามหลักสูตรของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

2. ข้าพเจ้าตกลงโอนลิขสิทธิ์จากผลงานทั้งหมดที่เกิดขึ้นจากการสร้างสรรค์ของข้าพเจ้าในวิทยานิพนธ์ให้กับมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี ตลอดอายุแห่งการคุ้มครองลิขสิทธิ์ตามมาตรา 23 แห่งพระราชบัญญัติลิขสิทธิ์ พ.ศ. 2537 ตั้งแต่วันที่ได้รับอนุมัติโครงร่างวิทยานิพนธ์จากมหาวิทยาลัย

3. ในกรณีที่ข้าพเจ้าประสงค์จะนำวิทยานิพนธ์ไปใช้ในการเผยแพร่ในสื่อใด ๆ ก็ตาม ข้าพเจ้าจะต้องระบุว่าวิทยานิพนธ์เป็นผลงานของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรีทุก ๆ ครั้งที่มีการเผยแพร่

4. ในกรณีที่ข้าพเจ้าประสงค์จะนำวิทยานิพนธ์ไปเผยแพร่หรืออนุญาตให้ผู้อื่นทำซ้ำหรือดัดแปลงหรือเผยแพร่ต่อสาธารณชนหรือกระทำการอื่นใด ตามมาตรา 27, มาตรา 28 และมาตรา 29 และมาตรา 30 แห่งพระราชบัญญัติลิขสิทธิ์ พ.ศ. 2537 โดยมีค่าตอบแทนในเชิงธุรกิจ ข้าพเจ้าจะกระทำได้เมื่อได้รับความยินยอมเป็นลายลักษณ์อักษรจากมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

ลงชื่อ วรรธนวิชญ์ นิลพันธ์พิทักษ์ ผู้โอนลิขสิทธิ์
(นายวรรธนวิชญ์ นิลพันธ์พิทักษ์)

ลงชื่อ ______________________ ผู้รับโอนลิขสิทธิ์
(รศ.ดร. **อภิชิต เทอดโยธิน**)

ลงชื่อ ______________________ พยาน
(รศ.ดร.โจเซฟ เคดารี)

ลงชื่อ ______________________ พยาน
(................................)