DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND

Miss Chatsuda Phuapradit

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Architecture Program in Architectural Design
Department of Architecture
Faculty of Architecture
Chulalongkorn University
Academic Year 2013

การออกแบบโรงพยาบาลวัณโรคในประเทศไทย

นางสาวชัชสุดา พัวประดิษฐ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาสถาปัตยกรรมศาสตรมหาบัณฑิต
สาขาวิชาการออกแบบสถาปัตยกรรม ภาควิชาสถาปัตยกรรมศาสตร์
คณะสถาปัตยกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2556

Thesis Title	DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND
By	Miss Chatsuda Phuapradit
Field of Study	Architectural Design
Thesis Advisor	Assistant Professor Vorapat Inkarojrit, Ph.D.

Accepted by the Faculty of Architecture, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Architecture

(Assistant Professor Pongsak Vadhanasindhu, Ph.D.)

THESIS COMMITTEE

....Chairman

(Associate Professor Pinraj Khanjanusthiti, D.Phil)

....Thesis Advisor

(Assistant Professor Vorapat Inkarojrit, Ph.D.)

....Examiner

(Assistant Professor Rachaporn Choochuey, Ph.D.)

....Examiner

(M.l. Chittawadi Chitrabongs, Ph.D.)

....External Examiner

(Dr. Jayada Boonyakiat, Ph.D.)

ชัชสุดา พัวประดิษฐ์ : การออกแบบโรงพยาบาลวัณโรคในประเทศไทย. (DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. วรภัทร์ อิงคโรจน์ฤทธิ์, หน้า.

อัตราการติดเชื้อวัณโรคในประเทศไทยสูงจัดอยู่ใน22อันดับแรกของโลก การวิจัยครั้งนี้เป็นการออกแบบสถาปัตยกรรมโรงพยาบาลวัณโรคในประเทศไทยโดยการทบทวนวรรณกรรมการติดเชื้อวัณโรคในโรงพยาบาลในประเทศไทยตลอดจนการศึกษานำร่องทางสถาปัตยกรรมโรงพยาบาลวัณโรค3แห่งในกรุงเทพมหานครเพื่อหาปัจจัยที่เกี่ยวข้องและนำมาออกแบบโรงพยาบาลวัณโรคในประเทศไทย จากการทบทวนวรรณกรรมพบว่าบุคลากรทางการแพทย์ปฏิบัติงานในโรงพยาบาลในกรุงเทพฯและต่างจังหวัดมีความเสี่ยงสูงต่อการติดเชื้อวัณโรคโดยเฉพาะพยาบาลและบุคลากรที่ปฏิบัติงานในหน่วยฉุกเฉินและห้องตรวจรังสีวิทยา การระบายถ่ายเทอากาศภายในห้องปฏิบัติงานต่ำกว่าเกณฑ์มาตรฐานทั้งนี้เนื่องจากมีจำนวนหน้าต่างและช่องเปิดน้อยและขนาดเล็กทำให้การระบายถ่ายเทอากาศไม่เพียงพอ ตลอดจนการติดเครื่องปรับอากาศภายในสถานพยาบาลแทนการใช้การระบายถ่ายเทอากาศตามธรรมชาติ

ผลการศึกษานำร่องทางสถาปัตยกรรมโรงพยาบาลวัณโรค3แห่งในกรุงเทพมหานครพบว่าการออกแบบห้องตรวจผู้ป่วยนอกไม่เหมาะสม หน้าต่างและช่องเปิดมีขนาดเล็กทำให้การระบายถ่ายเทอากาศไม่เพียงพอ เสี่ยงต่อการติดเชื้อระหว่างผู้ป่วยวัณโรคและบุคลากรทางการแพทย์ ตลอดจนลักษณะการจัดการทำงานภายในห้องปฏิบัติงานไม่เหมาะสม ข้อมูลดังกล่าวนี้ได้นำไปใช้ในการออกแบบโรงพยาบาลวัณโรคในพื้นที่เขตโป่งตาลอง อำเภอปากช่อง จังหวัดนครราชสีมา โดยกำหนดให้มีขนาดและจำนวนหน้าต่างและช่องเปิดให้เพียงพอต่อแนวการรับลมและการระบายถ่ายเทอากาศตามธรรมชาติ จัดลักษณะการปฏิบัติงานภายในสถานที่ทำงานให้เอื้อต่อการรักษาพยาบาล โดยออกแบบทางสถาปัตยกรรมภายในและภายนอกอาคารเพื่อให้มีการระบายถ่ายเทอากาศให้เพียงพอในการควบคุมการติดเชื้อ ตลอดจนจัดสภาพแวดล้อมให้สวยงามและน่าอยู่สำหรับผู้ป่วย

ภาควิชา สถาปัตยกรรมศาสตร์ ลายมือชื่อนิสิต ....

สาขาวิชา การออกแบบสถาปัตยกรรม ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

ปีการศึกษา 2556

 # # 5374351125 : MAJOR ARCHITECTURAL DESIGN
KEYWORDS: TUBERCULOSIS/ NOSOCOMIAL/ HOSPITAL/DESIGN

CHATSUDA PHUAPRADIT: DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND. ADVISOR: ASST. PROF. VORAPAT INKAROJRIT, Ph.D., pp.

Thailand has been ranked as one of the top 22 highest Tuberculosis (TB) burden countries. The main purpose of this study is to conduct an architectural design for TB hospital in a setting with high prevalence of TB infection. Review studies from general and referral hospitals both in central Bangkok and provincial areas showed that health care workers (HCWs) in Thailand were at higher than average risk for TB infection; nurses and emergency department HCWs had the highest risk.

Findings from pilot study in three TB hospitals in Bangkok showed that current floor plans of the clinics prevent good airflow into the room which cross ventilation could occur between patients and HCWs. The size of the opened windows is too small and prevents good air ventilation and the function of spaces does not serve the sequence of the user behavior. An architectural design of a TB hospital in Pak Chong, Nakorn Ratchasima is conducted to foster infection control. The design comprises of the orientation to optimize wind exposure for building occupants, the development of appropriate opening size and location, the spread of function to create wind gap and courtyard, and the use of designed facade to provide ventilation and to create a sense of privacy and healing environment for the patients while controlling the airborne transmission.

Department:	Architecture	Student's Signature	....
Field of Study:	Architectural Design	Advisor's Signature	....
Academic Year:	2013		

ACKNOWLEDGEMENTS

This study project would not have been possible without the support of many people and institutes. I would like to thank my mentor and advisor-Assistant Professor Dr.Vorapat Inkarojrit who took care of my thesis revisions and gave me guidance and support.

I would like to extend my sincere gratitude to Associate Professor. Dr. Pinraj Khanjanusthiti, and committee members, M.L. Chittawadi Chitrabongs, Ph.D., and Assistant Professor. Rachaporn Choochuey, Ph.D., for their valuable comments, teachings and guidances throughout this study.

CONTENTS

Page

THAI ABSTRACT ... v

ENGLISH ABSTRACT ... vii

ACKNOWLEDGEMENTS ... viii

CONTENTS ... ix

DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND

Miss Chatsuda Phuapradit

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Architecture Program in Architectural Design
Department of Architecture
Faculty of Architecture
Chulalongkorn University
Academic Year 2013

การออกแบบโรงพยาบาลวัณโรคในประเทศไทย

นางสาวชัชสุดา พัวประดิษฐ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาสถาปัตยกรรมศาสตรมหาบัณฑิต
สาขาวิชาการออกแบบสถาปัตยกรรม ภาควิชาสถาปัตยกรรมศาสตร์
คณะสถาปัตยกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2556

Thesis Title	DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND
By	Miss Chatsuda Phuapradit
Field of Study	Architectural Design
Thesis Advisor	Assistant Professor Vorapat Inkarojrit, Ph.D.

Accepted by the Faculty of Architecture, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Architecture

(Assistant Professor Pongsak Vadhanasindhu, Ph.D.)

THESIS COMMITTEE

....Chairman

(Associate Professor Pinraj Khanjanusthiti, D.Phil)

....Thesis Advisor

(Assistant Professor Vorapat Inkarojrit, Ph.D.)

....Examiner

(Assistant Professor Rachaporn Choochuey, Ph.D.)

....Examiner

(Mom Luang Chittawadi Chitrabongs, Ph.D.)

....External Examiner

(Dr. Jayada Boonyakiat, Ph.D.)

ชัชสุดา พัวประดิษฐ์ : การออกแบบโรงพยาบาลวัณโรคในประเทศไทย. (DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. วรภัทร์ อิงคโรจน์ฤทธิ์, หน้า.

อัตราการติดเชื้อวัณโรคในประเทศไทยสูงจัดอยู่ใน22อันดับแรกของโลก การวิจัยครั้งนี้เป็นการออกแบบสถาปัตยกรรมโรงพยาบาลวัณโรคในประเทศไทยโดยการทบทวนวรรณกรรมการติดเชื้อวัณโรคในโรงพยาบาลในประเทศไทยตลอดจนการศึกษานำร่องทางสถาปัตยกรรมโรงพยาบาลวัณโรค3แห่งในกรุงเทพมหานครเพื่อหาปัจจัยที่เกี่ยวข้องและนำมาออกแบบโรงพยาบาลวัณโรคในประเทศไทย จากการทบทวนวรรณกรรมพบว่าบุคลากรทางการแพทย์ปฏิบัติงานในโรงพยาบาลในกรุงเทพฯและต่างจังหวัดมีความเสี่ยงสูงต่อการติดเชื้อวัณโรคโดยเฉพาะพยาบาลและบุคลากรที่ปฏิบัติงานในหน่วยฉุกเฉินและห้องตรวจรังสีวิทยา การระบายถ่ายเทอากาศภายในห้องปฏิบัติงานต่ำกว่าเกณฑ์มาตรฐานทั้งนี้เนื่องจากมีจำนวนหน้าต่างและช่องเปิดน้อยและขนาดเล็กทำให้การระบายถ่ายเทอากาศไม่เพียงพอ ตลอดจนการติดเครื่องปรับอากาศภายในสถานพยาบาลแทนการใช้การระบายถ่ายเทอากาศตามธรรมชาติ

ผลการศึกษานำร่องทางสถาปัตยกรรมโรงพยาบาลวัณโรค3แห่งในกรุงเทพมหานครพบว่าการออกแบบห้องตรวจผู้ป่วยนอกไม่เหมาะสม หน้าต่างและช่องเปิดมีขนาดเล็กทำให้การระบายถ่ายเทอากาศไม่เพียงพอ เสี่ยงต่อการติดเชื้อระหว่างผู้ป่วยวัณโรคและบุคลากรทางการแพทย์ ตลอดจนลักษณะการจัดการทำงานภายในห้องปฏิบัติงานไม่เหมาะสม ข้อมูลดังกล่าวนี้ได้นำไปใช้ในการออกแบบโรงพยาบาลวัณโรคในพื้นที่เขตโป่งตาลอง อำเภอปากช่อง จังหวัดนครราชสีมา โดยกำหนดให้มีขนาดและจำนวนหน้าต่างและช่องเปิดให้เพียงพอต่อแนวการรับลมและการระบายถ่ายเทอากาศตามธรรมชาติ จัดลักษณะการปฏิบัติงานภายในสถานที่ทำงานให้เอื้อต่อการรักษาพยาบาล โดยออกแบบทางสถาปัตยกรรมภายในและภายนอกอาคารเพื่อให้มีการระบายถ่ายเทอากาศให้เพียงพอในการควบคุมการติดเชื้อ ตลอดจนจัดสภาพแวดล้อมให้สวยงามและน่าอยู่สำหรับผู้ป่วย

ภาควิชา	สถาปัตยกรรมศาสตร์	ลายมือชื่อนิสิต	....
สาขาวิชา	การออกแบบสถาปัตยกรรม	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก	....
ปีการศึกษา	2556		

5374351125 : MAJOR ARCHITECTURAL DESIGN
KEYWORDS: TUBERCULOSIS/ NOSOCOMIAL/ HOSPITAL/DESIGN

CHATSUDA PHUAPRADIT: DESIGN OF TUBERCULOSIS HOSPITAL IN THAILAND. ADVISOR: ASST. PROF. VORAPAT INKAROJRIT, Ph.D., pp.

Thailand has been ranked as one of the top 22 highest Tuberculosis (TB) burden countries. The main purpose of this study is to conduct an architectural design for TB hospital in a setting with high prevalence of TB infection. Review studies from general and referral hospitals both in central Bangkok and provincial areas showed that health care workers (HCWs) in Thailand were at higher than average risk for TB infection; nurses and emergency department HCWs had the highest risk.

Findings from pilot study in three TB hospitals in Bangkok showed that current floor plans of the clinics prevent good airflow into the room which cross ventilation could occur between patients and HCWs. The size of the opened windows is too small and prevents good air ventilation and the function of spaces does not serve the sequence of the user behavior. An architectural design of a TB hospital in Pak Chong, Nakorn Ratchasima is conducted to foster infection control. The design comprises of the orientation to optimize wind exposure for building occupants, the development of appropriate opening size and location, the spread of function to create wind gap and courtyard, and the use of designed facade to provide ventilation and to create a sense of privacy and healing environment for the patients while controlling the airborne transmission.

Department:	Architecture	Student's Signature	....
Field of Study:	Architectural Design	Advisor's Signature	....
Academic Year:	2013		

ACKNOWLEDGEMENTS

This study project would not have been possible without the support of many people and institutes. I would like to thank my mentor and advisor-Assistant Professor Dr.Vorapat Inkarojrit who took care of my thesis revisions and gave me guidance and support.

I would like to extend my sincere gratitude to Associate Professor. Dr. Pinraj Khanjanusthiti, and committee members, M.L. Chittawadi Chitrabongs, Ph.D., and Assistant Professor. Rachaporn Choochuey, Ph.D., for their valuable comments, teachings and guidances throughout this study.

CONTENTS

Page

Page

Page

Page

Page

Page

Page

Page

CHAPTER I
INTRODUCTION

1.1 Problem Statement

The growing number of *Mycobacterium* Tuberculosis (TB) infected patients is a global threat. About 10% of infected people develop active infection in their lungs, which can develop into a fatal stage. TB carriers can spread the infection to others through airborne droplets by coughing and sneezing. With a population of approximately 70 million, Thailand has been ranked by the World Health Organization (WHO) as one of the top 22 highest TB burden countries with 13,000 deaths each year (WHO, 2012). Problems in TB control in Thailand derived from the spread of HIV and the increase of alien workers infected with or carriers of TB entering the country. In Thailand, TB Bureau, Ministry of Public Health is responsible for the multi-tiered National TB Program. There are 12 regional offices at the sub-country level, with each regional office covering 4-5 provinces (Jittimanee., 2012)

Due to the increasing prevalence of TB, Thailand has made considerable progress in expanding and enhancing TB diagnosis and care, particularly among vulnerable populations (i.e. migrants, people living with HIV and AIDS, and populations in closed shelters such as jail). Unfortunately, TB hospitals in Thailand still remain the place where the nosocomial (disease that originates in hospital) transmission occurs between the non-patients or the health care workers (HCWs) and the TB patients. In 2003 and 2007, WHO and Centers for Disease Control and Prevention (CDC) released a design guideline document on infection prevention and control of epidemic- and pandemic-prone acute respiratory diseases in healthcare setting. (CDC, 2003)

The WHO infection control guidelines are based on a 3 level of controls, including administrative, environmental control, and respiratory protection or personal control. In WHO guidelines, natural ventilation is one of the effective environmental control measures. In resource limited settings lacking negative-pressure respiratory isolation system, natural ventilation (also known as passive ventilation) by opening windows and doors provides high rates of air exchange and it is recommended for the control of nosocomial TB infection (Granich, 1999) Natural ventilation is inexpensive and can be applied to most health care settings.

Moreover, the airborne transmission of TB infection in hospital has been reviewed (Escombe, 2007) In Thailand, there are reported cases of TB transmission among HCWs in healthcare setting. However, there are only few studies that tackle the issue of healthcare design, operation, and management in a high risk healthcare setting like a TB hospital. By integrating the understanding of the mode of disease spread and proper control to the design of infrastructure, it is possible to reduce spread of infection in healthcare setting. In resource limited settings, such as the rural areas of Thailand that lack negative pressure respiratory isolation systems; natural ventilation can be used for the control of nosocomial TB. Escombe's study showed that natural ventilation offers high rates of air exchange for a cheaper cost as it is free of maintenance. According to American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) to prevent TB transmission, mechanical ventilation of high risk clinical areas at a rate of 6-12 air changes per hour (ACH) is recommended (Handbook, 2005; Jensen, 2005)However, mechanical ventilation can become costly and inadequate if it is maintain in the wrong way due to the technical usage. Therefore, to achieve TB hospital with adequate standard services especially in a rural area, the use of natural ventilation can become resourceful and effective.

By conducting the pilot study, it has validated the current status quo of TB healthcare setting in Thailand. The study reveals the disconnection between design guideline and the actual design. Thus, this thesis goal is to exercise the WHO design guideline and implementing with the configuration of the openings and natural ventilation theory in order to reducing the nosocomial and cross infection.

1.2 Research Objectives

There are strong and sufficient evidence of the disconnection between the design guideline and the actual design, the control of airflow direction in buildings, and the transmission of infectious diseases among patients in healthcare settings. However, the lack of sufficient data on the specification of the validated requirement in hospitals and other healthcare settings in relation to the transmission of airborne infectious diseases, suggest the existence of a knowledge gap. This reveals an important need for a study in investigating the origin of disease outbreaks. Thus, the main objective is to design a TB hospital for limited resource area in Thailand, and focuses the use of natural ventilation and planning of departments and functions that related to TB healthcare setting only. This study does not involve with any simulation test. Natural ventilation and planning are the keys for reducing nosocomial and cross infection in healthcare facility.

1.3 Scope and Limitations

1.3.1 TB hospital in a resource limited setting context of TB healthcare setting by implementing design experimentation with a variety of ventilation methods that could solve the problem of cross infection and minimize the airborne infection.

1.3.2 The transmission of airborne infection in healthcare setting. It will focus on the prime contamination area such as the Out-patient Department (OPD) and In-patient Ward (IPD) in hospital which excludes the other supporting facility such as dormitories.

1.3.3 This study will be based on the design and implementation of natural ventilation for TB infected patients and HCWs, the financial analysis is not conducted in detail.

Due to a limited frame, the design does not include the ventilation performance through simulation tool. However, it is accurately referred to the published design guidelines and basic natural ventilation methods. The design does not accommodate other factor such as energy usage. Due to this special type of hospital, the design will be a small scale resource limited with specific program of TB hospital.

1.4 Design Method and Analysis

Design method and analysis comprise of methods such as literature reviews, field study, and analysis on existing design of TB hospital to gain further knowledge in identifying the current status quo in airborne prevention design direction. Regarding literature reviews and case studies related to the issues that involved with TB and environmental design issue, the collected information is summarized and analyzed in order to find the ultimate solution to solve airborne infection issue in healthcare setting. Data analysis is based on the following methods;

1.4.1 Literature Review

TB infection control guidelines such as WHO- Natural Ventilation Design Guideline in Hospital, CDC- Guidelines for preventing the transmission of TB in healthcare settings, ASHRAE- Guideline in building consumption, Laws and Regulations in Building Control Act of Thailand which guides the implementation of required rules of ventilation in building, building control and general hospital design are reviewed.

4.2 Field Study

Prior to the design phase, case study of 3 naturally ventilated TB healthcare centers which locate in Bangkok was conducted to understand the planning and design of current status quo, including pros and cons of infection control measures.

1.4.3 Design

The design concept has 2 folds which are administrative control and environmental control. Planning of functions and implementing wind direction are keys of the design. It will foster the infection control aspect by various natural ventilation methods.

1.4.4 Beneficiary

This part will conclude the design concept of the building and the main focus areas such as the OPD, Sputum booth, and IPD.

CHAPTER II
LITERATURE REVIEW

This chapter reviews the current literature review of research and study of TB related topics.

1. WHO- Natural Ventilation Design Guideline in Hospital
2. CDC- Guidelines for preventing the transmission of TB in healthcare settings
3. ASHRAE- Guideline in building consumption
4. Moore, F. Environmental Control System: Heating, Cooling, and Lighting
5. Laws and Regulations in Building Control Act of Thailand

It consists of 5 sections as followings;

1. Historical Review of Architecture of TB Hospital
2. Study of Ventilation and Airborne Transmission among HCWs in Hospital
3. Study of Ventilation and Airflow
4. Study of Natural Ventilation
5. Laws and Regulations in Hospital Design

2.1. Historical Review of Architecture of TB Hospital

The influence of hospital design on patient well-being has been a debate for the last 150 years. Florence Nightingale, in her publication “Notes on Nursing” and “Notes on Hospitals” which were published in 1860, states the important factors that affect patient safety in the hospital at that time. Through her many years of experience working in a military hospital during World War, she identified the main problems which was caused by inadequate ventilation, poor sanitation, and insufficient room for the patient bed and lack of natural light or sunlight. Nightingale states, “To keep the air he breathes as pure as the external air, without chilling.” Nightingale proposed improvements in the design of hospital buildings based largely around the *Pavilion* principle" .The state of well-being definition is both subjective and objective. It can be described in two different forms, which are health and security. In order to achieve the state of well-being, there has to be a balance. The old Thai traditional beliefs about the causes of sicknesses and epidemics derived from folklore, religion, observation, test, and feeling of fear. The results and methods of human existence had been changing while social formation was developing. The result of fear forced people to unite to fight dangers together rather than fight alone. However, fear is a double edged sword, it can make people unite and fight or it can make people go against each other especially when there's a fear of death. This is when the beginning of social classification and social issue will soon emerge in our society. Social classification and social issues have been affecting the lives of patients with Tuberculosis (Nightingale, 2013)

Tuberculosis is perceived as "stigma". It has been linked to negative patient experiences in different social settings (Sengupta, 2006) It refers to a cluster of negative attitudes and beliefs that motivate the general public to fear, reject, avoid, and discriminate against people with mental illness (Corrigan, 1999) Social support is essentially the opposite of stigma, with trust and openness forming the basis of interaction between patients and their environment. For patients with TB, their experience and relationship with their social network may prevent them from seeking treatment. Tuberculosis is associated with the rapid growth of industrialization and low class working people who have poor life quality. In this case, it is important to be concerned about the hospital care and treatment which can be implemented in the hospital friendly environment and design.

During the mid-nineteenth to the mid-twentieth century, buildings known as sanatoria and asylums were built to cure TB infected patients. The spatial separation was used to symbolize the use of natural light, air and sun. In this case, the spatial was the reflection of development of modern hygienic design solution (Campbell, 2005) A typical hospital typology during that time was the pavilion form with its narrow wings and large openings in the façade to force natural ventilation and the penetration of daylight. Tuberculosis patients were treated with light therapy called Heliotherapy. Ultraviolet light was thought to kill the infection, which influenced the design method and architecture of clinics and sanatoriums. To maximize the sun light, it required architectural design features such as balconies, garden and terraces.

Paimo Sanatorium in Finland was built between 1929 and 1933. It was designed by Alvar Aalto (see figure 2.1). It located in a rural setting, where the building is surrounded by forest. The building is separated into different wards; each wing of the building has the functions within it form a unit of its own. A-wing is the main element of the design that reflects TB treatment. It is facing the south, best daylight allowing TB patient to sun bathe during the day (see figure 2.2).

The entire building is done in concrete frame structure. The program of function is well organized in each wing. The B-wing consists of the common spaces such as treatment rooms, dining hall, library and common rooms. C-wing holds the service department such as the laundry, kitchens and staff accommodation. The single-storey D-wing contains the boiler room and heating plant. The main circulation is on the main entrance hall between A-wing and B-wing and the stairwell linked to the other wings of the building. The asymmetric concrete frame structural contains all six floors of terraces. The symmetrical and asymmetrical quality combining with the organic of this building reflects the innovation of the modernity, as Alvar Aalto stated, “Form follows function” (see figure 2.3 and 2.4) (Paimio Sanatorium, 2013: Online).

Figure 2.1 Exterior of the Paimo Sanatorium in Finland

Figure 2.2 Sculptural shape of terrace for the patients to lie in the sun

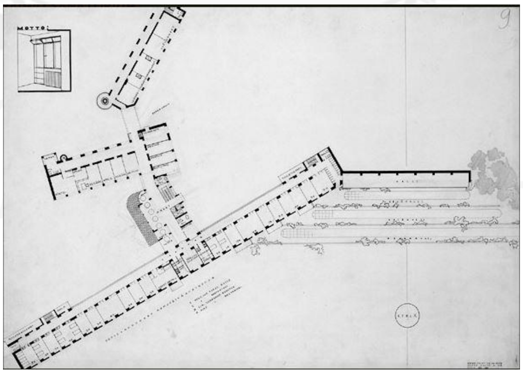


Figure 2.3 Floor plan of the Sanatorium which reflects both asymmetrical and symmetrical. The single load corridor was applied in gaining the direct wind into the ward area.

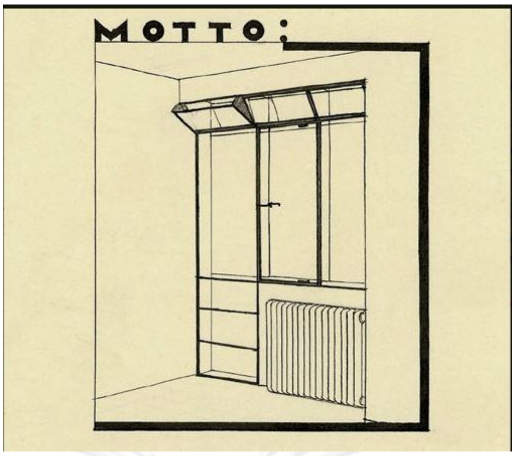


Figure 2.4 Light shelf was applied in the design to achieve better ventilation and day light

Source: http://www.alvaraalto.fi/net/paimio/paimio.html

In addition, an example of a small scale naturally ventilated healthcare center is Tuberculosis control unit, Tan Tock Seng Hospital, Singapore. The Tuberculosis Control Unit (TBCU) outpatient service serves as the Diagnostic clinic where TB infected patients are evaluated and treated. This healthcare center has 20 beds included separated men's and women's ward. Patients tend to stay for a long period. They are mostly poor with no family support. The total of staff for each ward is 2-4 nurses and one health care attendant (see figure 2.5).

Figure 2.5 Single story Tuberculosis inpatient ward with windows on all sides allow for maximum natural ventilation

Infection control aspects: The single story building allows multiple axes for wind driven airflow, which creates perfect cross ventilation thorough out the ward. The building is a long and rectangular shape with sloping roof that overhangs the windows on each side. The windows are kept open all day. The spacing between each bed is 1.35 m. and patients are able to walk around the ward and sit outside (see figure 2.6). The staff area is located at the end of the ward, opposite the main entrance. It is separated from the main ward by incomplete partitions so it is moveable. In order to achieve the maximum cross-airflow, the back door can be opened (WHO, 2007).

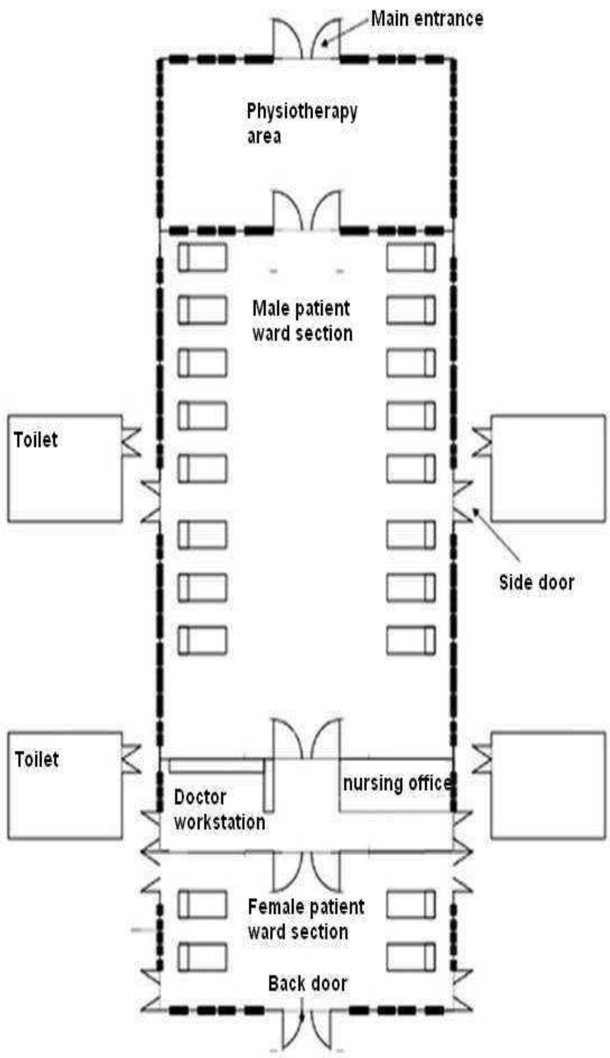


Figure 2.6 Floor plan of Tuberculosis unit inpatient ward (WHO, 2007)

Another humanistic case study of a small scale is the TB hospital called Butaro. It is located in the Burera District of Rwanda, where poor healthcare and poverty are apparent. The hospital was built in 2011, designed by Mass Design Group. This TB center holds about 140 beds. The design concept is based on the holistic model of architecture that educates and empowers within the local community. Construction materials were harvested locally in the region.

Infection control aspects: nosocomial infection is the main issue that architects prioritize in the design process. The design tackles the problems several aspects such as the reorganizing of the hospital layout by eliminating the interior corridors and installing a large fan throughout the corridors or waiting areas. Achieving better ventilation is the key strategy in reducing the spread of TB and cross infection. Germs and TB microbes are tending to rise up in the air. The use of germicidal UV lights is applied to inactivate the rising of germs and TB microbes in the most active area such as the waiting area, OPD and IPD. Circulation of patients and staff was taken into the study. Utilizing the advantage of opened pocket of courtyard maximizes natural ventilation in the design (see figure 2.7-2.10). This could be used as the model that can be duplicated in other hospitals especially in the resource limited settings.

Figure 2.7 Aerial view of Butaro hospital exterior

Figure 2.8 An interior of Butaro IPD ward. Tall ceiling with windows allows micro bacteria to rise up and diffuses through the top opening

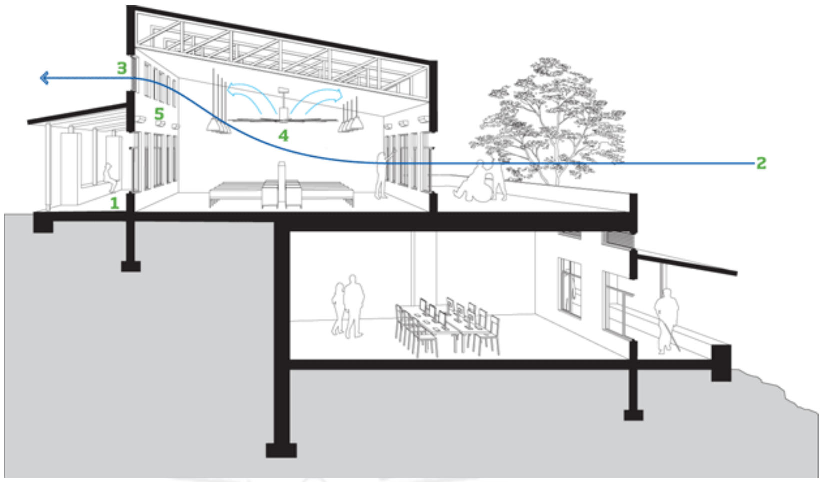


Figure 2.9 A cross sectional diagram displays a cross natural ventilation in IPD ward of Butaro hospital

1. Intensive care unit
2. Post operative ward
3. Operating room
4. Reception check-in area
5. ICU
6. Delivery
7. Pre-delivery
8. Pediatric ward
9. Post delivery ward
10. TB infected men's and women's ward Laundry

Figure 2.10 Site layout and floor plan of Butaro hospital Source: http://www.archdaily.com/165892/butaro-hospital-mass-design-group

Moreover, Mass Design Group, who believes in improving the social health and strengthening the local communities, is also well known for their expertise in designing airborne infection control hospital. One of their healthcare center is Gheskio hospital in Haiti. The facility also features exam room, radiology department, offices, nurse stations, pharmacies, and 29 patient isolation suites.

Infection Control Aspects: the design team has worked with the Medical College of Cornell University to develop and apply the use of passive natural ventilation and infection control to reduce the transmission of TB in the design (see figure 2.11 and 2.12).

Figure 2.11 The exterior rendering of the 2 story tall Gheskio hospital TB hospital

Figure 2.12 The layout of Gheskio hospital emphasizes on the courtyard in maximizing the natural ventilation

Source:http://www.archinect.com/firms/project/106488/gheskio-tb hospital/1391910

Table 2.1 Case Studies

	Case 1: Paimo Sanatorium	Case 2 : Tan Tock Seng Hospital	Case 3 : Butaro hospital	Case 4 : Gheskio hospital
Location	Rural setting in Finland	Singapore	the Burera District of Rwanda	Haiti
No. of Bed	n/a	20 beds	140 beds	29 patient isolation suites.
Physical aspect	7 stories tall building with separated function in each wing.	1 story	2 stories building scattered with an opened courtyard in the center	2 stories building with an opened courtyard in the center
Infection Control Aspects	Passive Natural ventilation ● single load	Passive Natural ventilation ● 1 storey to	Passive Natural ventilation ● Open pocket of	Passive Natural ventilation ● Emphasize on the

	corridor to gain the direct wind into the ward area ● light shelf was applied to achieve better ventilation and day light	multiply axes for wind driven airflow ● Long and rectangular building shape complete with rows of windows to promote maximum natural ventilation ● Separate staff area from patient area ● Use movable partition to maximizing cross ventilation	courtyard ● High ceiling and windows to control the micro bacterial path and natural ventilation ● Use natural slope to promote cross ventilation cross ventilation of IPD	courtyard in maximizing the natural ventilation

The analysis of the case studies:

1. All four TB hospitals is located in the rural area closer to nature

2. They are small to medium scale size hospital

3. Utilize mainly natural ventilation

3.1 The scattering of building layout

3.2 Utilize the Single Load Corridor

3.3 The use of architectural details to promote natural ventilation such as windows, light shelf design and movable partitions.

2.2. Study of Ventilation and Airborne Transmission among HCWs in Hospital

The probability of developing TB is much higher among people infected with HIV, when they are more prone to acquire new infections due to weaker immune system. According to the statistical report, it shows that TB is more common among men than women and affects mostly adults in the economically productive age groups. Without a proper treatment, mortality rates are high. In studies of natural history of the disease among HIV positive and HIV negative cases with pulmonary TB, approximately 70% of HIV positive cases died within 10 years. The most common method for diagnosing TB worldwide is sputum smear for acid-fast bacilli under microscopy (WHO, 2012).

Following recent developments in TB diagnosis, rapid molecular tests are now used for the diagnosis of TB as well as culture methods. Treatment of new cases of drug-susceptible TB consists of a 6 months regimen of four first line drugs. Treatment for case which does not respond to first line treatment or multidrug-resistant TB (MDR-TB) is longer, more dangerous and expensive (WHO, 2012). Transmission risks are associated with specific types of healthcare settings, numerous factors influence differences in transmission risks among the various healthcare settings. These include the population characteristics (e.g. increased susceptibility to infections, type and prevalence of indwelling devices), intensity of care, exposure to environment sources, length of stay, and nosocomial infection. It is a frequency of interaction between patients and residents with each other and also HCWs (Wongsaheam, 1999)

The risk of nosocomial transmission of TB to HCWs from studies in industrialized and resource limited countries shown that HCWs and medical and nurse students with patient contact are at increased risk for acquisition of TB infection and disease development. The greatest risk of transmission occurs when patients remain undiagnosed and untreated (Baussano, 2011; Beggs, 2003; Granich, 1999; Joshi,

2008) A cross-sectional tuberculin skin test (TST) including a risk assessment questionnaire was conducted with 911 HCWs in Chiang Rai hospital. HCWs had an increased risk for TB infection, which was significantly associated with occupational exposure (Do, 1999) A prospective study among HCWs working in a provincial referral hospital in Chiang Rai included annual TST screening and active TB surveillance. Following a comprehensive risk assessment, preventive interventions were implemented for HCWs, patients, and the hospital environment. During 1995-1996, it showed that HCWs were exposed to active TB patients and were at risk for TB infection, particularly during the first 12 months of employment.(Yanai, 2003)

In addition, there was also another cross-sectional study conducted to assess the risk of TB infection among HCWs of government hospital in Bangkok. It was applied by hospital TB control strategies, including administrative control, risk exposure, use of protective barriers when in contact with TB patients, and microbial air quality in the studied ward. These findings show that HCWs in the studies wards, except ICU, were at risk for TB infection. The hospital infection control committee should validate the importance of the use of TB standard precautions to hospital personnel and provide a ventilation system for reducing the microbial counts in the air of the studies wards (Pipat Luksamijarulkul, 2004) Moreover, a cohort of 3,959 HCWs at Chulalongkorn Memorial hospital was observed from 1988-2002 for the risk of TB infection. The results of the study support the premise that certain groups of HCWs in developing countries are occupationally at increased risk of TB. The occupation of highest risk was nurse and the emergency room was at the highest risk for the transmission area (N. H. Wiroj Jiamjarasrangsi, and Pirom Kamolratanakul. , 2005)

A study of nosocomial TB infection and recommended appropriate risk management procedure for the trauma ward of the emergency department at a university hospital in Bangkok was conducted during 2004-2005. The results of the study showed that the trauma ward of the emergency department has a high risk for nosocomial TB infection (S. U. Wiroj Jiamjarasrangsi, and Wisaruth Srisintorn, 2006). A cross sectional study of HCWs in high risk out-patient department in Paholpolpayuasana hospital, Kanchanaburi province revealed that knowledge, perception, and accessibility of TB information were low. This may be the consequence of high the incidence of HCWs nosocomial TB infection in Thailand (In Sokhanya, 2008)

The study of inadequacy of ventilation in healthcare setting was surveyed and conducted among 323 patient care and ancillary areas in 42 community and general hospitals in central Thailand. Data on indoor ventilation rate were collected by the tracer gas method and reported as air change per hour (ACH). The adequacy of the measured ventilation rates was determined by comparison with the international recommended standard values. The results proved that indoor ventilation were inadequate in almost half of the studied areas. The inadequacy was particularly serious in the emergency rooms and radiological areas. Detailed analysis showed that most of the rooms with natural ventilation had air exchange rates that exceeded the recommended standards, while the opposite was the case for rooms with air conditioning, particularly the window or wall-mount type. This study concluded that indoor ventilation in high risk nosocomial TB areas in public hospitals in Thailand was inadequate due to the installation of air-conditioning systems in modern buildings.(Wiroj Jamjarasrangsi, 2009)

Recently, a case control study at Srinagarind hospital, Khon Kaen to ascertain the association of job types and TST conversion or recent onset latent TB in HCWs in an endemic area of TB was conducted and the result of the study showed the certain job types do increase risks of recent onset of latent TB in HCWs, particularly nurses, nurse assistants, ward workers, male HCWs (Kittisak Sawanyawisuth, 2012)

In summary, studies from general and referral hospitals both in central Bangkok and provincial areas show HCWs in Thailand are at higher than average risk for TB infection and of developing TB disease and for the TB hospital, the risk of nosocomial TB transmission among HCWs is critical. Natural ventilation should be emphasized as a key and priority of environment control measures in building design, construction, and renovation which in turn must be customized to local climate and socioeconomic status.

2.2.1. Tuberculosis Infection Control Strategies

There are 3 levels of infection control. Each level has different role in operating at different point in the transmission process:

1. First level is administrative control. It is used to reduce HCWs and patient risk exposure. This supervisory measure is consisted of nurse triage system. It is established to monitor the sustainable infection control by providing policies for infection control measure. The health-care facility management is required to monitor the ratio between patients and staffs. It should promote staff training and provide staff health program such as vaccination.(WHO, 2007)

2. The second level is environmental control. This is where the architect and HCWs provide a linkage between the infection control and the actual usage for infection control. It is used to prevent the spread and reduce the concentration of infectious droplet nuclei in the air. The standard primary environmental controls consist of controlling the source of infection by using local exhaust ventilation (e.g., hoods, tents, or booths) and diluting and removing contaminated air by using general ventilation. Secondary environmental controls consist of controlling the airflow to prevent contamination of air in areas adjacent to the

source (A II rooms) and cleaning the air by using high efficiency particulate air (HEPA) filtration or ultraviolet germicidal irradiation (UVGI).(CDC, 2003) However, this study will explore on the natural ventilation side of environmental control features.

3. The third level is the use of respiratory protective equipment known as PPE. The first two control levels minimize the number of areas in which exposure to Tuberculosis might occur and, therefore, minimize the number of persons exposed. These control levels also reduce, but do not eliminate the risk for exposure in the limited areas in which exposure can still occur, because persons entering these areas might be exposed to Tuberculosis, The following measures can be taken to reduce the risk for exposure: implementing a respiratory-protection program, training HCWs on respiratory protection, and training patients on respiratory hygiene and cough safety procedure.

2.2.2. Main Focus: Environmental Control

2.2.2.1 The Standard Guidelines for Environmental Control

In 2007, WHO released a new guideline. The purpose of this guideline is first to promote natural ventilation for infection control in healthcare setting design, and second is to present the basic principles of how to design, construct, operate and maintain an effective natural ventilation system for infection control.

Eliminating the infectious droplet nuclei can be hard and risky. Environmental control by utilizing natural ventilation and controlling the direction of airflow can help reduce the concentration of the infection droplet in the air. According to the standard guideline, environmental control can be done with an expensive technology which requires high maintenance and complex. This can become the downside, when applying this type of environmental control in a limited resource setting such as the rural area where people are less educated with low quality of life and also financial burden. Thus, the certified WHO and CDC requirement for environmental control measure may not be suitable for the resource limited healthcare setting.

2.2.2.2 Appropriate Environmental Control Measure

According to WHO standard environmental control guidelines that can be applied with limited resource healthcare setting, maximizing natural ventilation through open windows is the basic and cost free technique. To remove and dilute the air from TB patient areas away from non TB patient and HCWs can be done as followings (see figure 2.13);

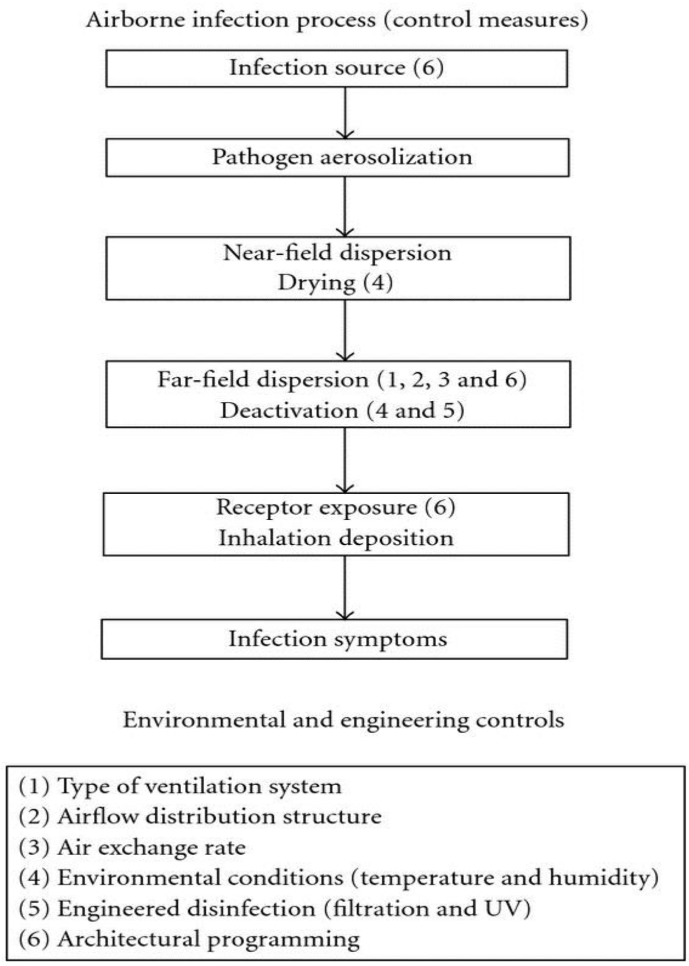


Figure 2.13 Environmental and engineering controls measure (CDC, 2005)

2.3. Study of Ventilation and Airflow

Ventilation refers to the movement of air that flows from outside to inside of the building (ASHRAE, 1998). Design of the building, form of the window openings and location have a significant impact on the quality of the indoor climate. With maximum ventilation, it can decrease the indoor air pollution, chronic respiratory diseases and malignancies. The basic rules of ventilation are as followings;

1. Ventilation provides airflow filtration of good air into the space and moves the polluted and infected air out of space. Occupants are able to breathe clean air (see figure 2.14).

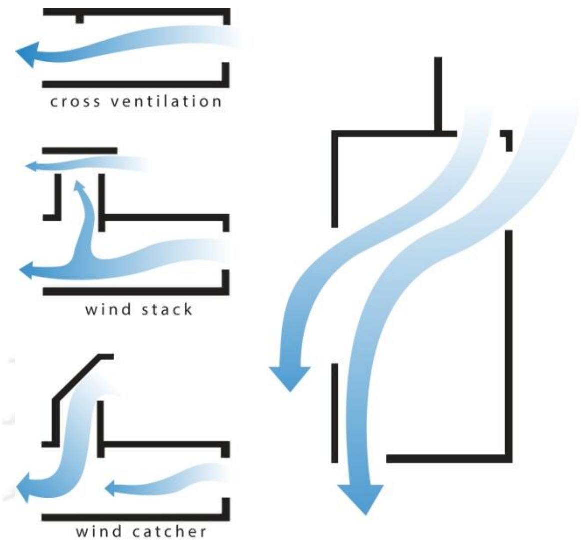


Figure 2.14 Diagram of airflow of basic natural ventilation (Qaiser, 2009)

2. Ventilation provides cooling and allows a psychological connection between the indoor and outdoor realm (Ventilation, 2008: Online). The main task of building ventilation is not only to provide occupants with better Indoor Air Quality (IAQ), but also increasing thermal comfort (Boonyakiat., 2003). Besides patients, visitors and workers who spend their daily lives in hospital are also affected by the thermal comfort. The proper thermal condition can increase productivity of occupants, nurses, and other workers and improve their wellbeing. Infection transmission risks are present in all hospital settings. However, certain hospital settings and patient populations have unique conditions that predispose patients to infection and merit special mention. These are often sentinel sites for the emergence of new transmission risks that may be unique to that setting or present opportunities for transmission to other settings in the hospital. Hospital is one of the most critical building types that deal with thermal comfort issue. The

studies show thermal comfort can affect patient healing and also their length of stay. Thus, maximum natural ventilation has to be regulated throughout the space to balance the thermal comfort. In achieving the natural ventilation, the study of location of opening and directional wind is significant. Table 2.1 and 2.2 demonstrate that wind speed may have an effect on the thermal comfort. Human thermal comfort is a combination of a subjective sensation of how we feel and several objective interactions with the environment (heat and mass transfer rates).

3. The general ventilation rule states that direction of air will flow from the less contaminated areas to more contaminated areas. In certain rooms where surgical procedures are performed, infection control can be done by personal protection environment control. Direction of airflow should flow from corridors into the A II rooms, where it is less clean area to stop the spreading of contaminants. For example, air should flow from the room into the hallway so the air flushes out the contaminants into the hallway. Cough-inducing or aerosol-generating procedures should not be performed in the airy space where maximum airflow is ventilated throughout the space.

Table 2.2 Wind speed and temperature range of thermal comfort (Khedari et al., 2000)

Velocity (m/s)	Temperature of Thermal Comfort
0.2	27.0 -29.5
0.5	28.5 – 30.8
1.0	29.5 – 32.5
1.5	31.0 – 33.8
2.0	31.2 – 36.0
3.0	31.6 – 36.3

Table 2.3 Wind speed and subjective sensation (Olgyay, 1963)

Velocity (m/s)	Sensation
0.00 – 0.25	Serene and no wind in contact
0.25 – 0.50	No wind in contact but nice and cool
0.50 - 1.00	Wind in contact, nice and cool
1.00 – 1.50	More wind contact, little disturbing
> 1.50	Disturbing

2.4 Study of Natural Ventilation

With tropical climate condition, natural ventilation can be simply applied in healthcare ventilation design method. One of the advantages is that windows can be left opened throughout the year. To maximize the natural ventilation, it can be done by designing an open construction ward with free flow air in and out through open windows as recommended in CDC 2005 as followings;

1. Waiting areas, sputum collection areas, examination rooms, and wards should be opened to environment in order to receive the moderate air flow. Windows and openings should be placed on outer walls such that air moves to the outdoor, not reverse into the wards and waiting areas.
2. Windows should be left open since diluting and exchanging rather than just mixing the air is the objective of applying ceiling fans.

"Radial ventilation corridors of streets or open space can take advantage of cool air drainage and night thermal currents" as stated by Brown and DeKay in Sun, Wind, and Light, Architectural Design Strategies. There are several ways to gain a passive cooling and ventilation in tropical climate. However, this study mainly depicts the use of dispersed buildings strategies. For taller buildings, the scattering of buildings with continuous and wide open space allows each building to gain direct access of cool ventilation. It is recommended that buildings where cross ventilation happens should be separated by a distance of five to seven times the building height to assure adequate airflow, if the buildings are located directly behind each other. As for the low rise or one story buildings, create less wind shadow. Thus, the buildings can be located closer (Brown, 2011; O. H. Koenigsberger, 2001) (see figure 2.15).

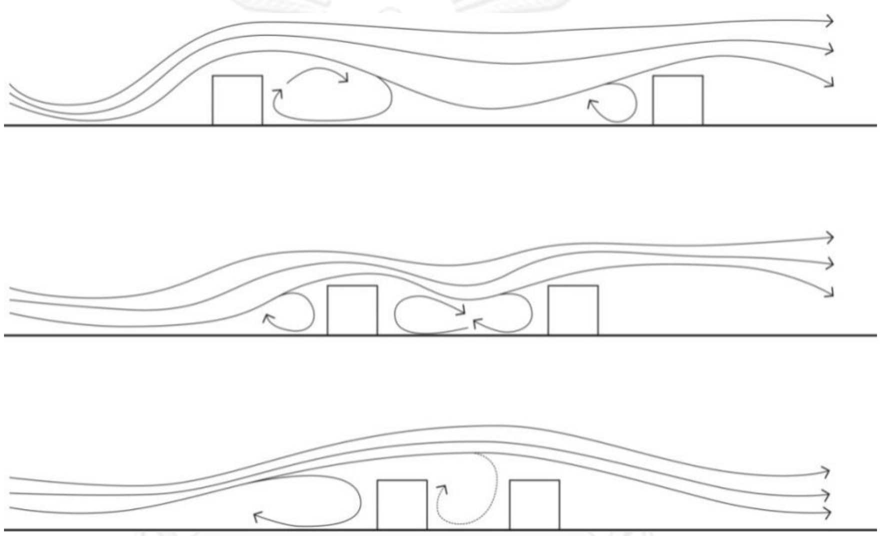


Figure 2.15 Three flow regimes between buildings 1. Isolated roughness of downwind eddy and upwind eddy 2. Wake Interference of the width and height of the building 3. Skimming Flow; Stable vortex (the space between two buildings) is when buildings space

2.4.1. Location and Orientation of Rooms and Courtyard

Location and orientation of rooms and courtyard is one of the significant parts of design. Building itself can block and direct sun and wind by creating a series of different microclimates. Wind and sun have a major impact on dictating where to locate rooms especially in the naturally ventilated facility in tropical climate condition. Cooling is very important in tropical climate condition because it can affect on the occupants thermal comfort. Therefore, each area or room should be designed to work with hot and humid weather condition.

2.4.2. Combined Organization of Programs or Rooms

The concept of permeable buildings can be done through a design of open plans and sections in order to achieve fully cross ventilation as well as stack ventilation effect. Cross ventilation relies on the windward side and upper level room while stack ventilation uses mainly wind in lee side and lower rooms (Brown, 2011)Cross ventilation and stack ventilation can work intertwiningly well in enhancing the maximum of ventilation in the infectious area.

2.4.3. Zoning of Program

Zoning of program is also related to combined organization of programs or rooms. The perfect module for design in gaining the maximum cross ventilation is the elongated shape of building. Thus, the function of programs in the building must be organized onto one side of the building so that circulation of occupants is opened and there should be no walls obstructing the ventilation entering from outside to the interior of the building into the rooms. This recommendation can be well applied with a new small scale building.

2.4.4. Orientation of Building

The orientation of building dictates where the wind direction will react towards the building. When wind is perpendicular to the larger opening, the more airflow enters the building. Cross ventilation also takes place when inlets are placed in higher areas and outlets in lower pressure zones (Melaragno, 1982). The effective ventilation may be achieved when the wind does not come from a direction perpendicular to the window. It does not require that building has to be perpendicular to the wind in order to achieve great ventilation rate. For instance, the range of angle can be up to 40°angle perpendicular to the prevailing wind (Givoni, 1994). With the implementation of wing wall, openings do not have to be oriented to the prevailing breeze. Wing wall can be used to alter the positive and negative pressure zones around the building and induce wind flow through windows parallel to the prevailing wind directions (Brown and Dekay, 2011) (see figure 2.16).

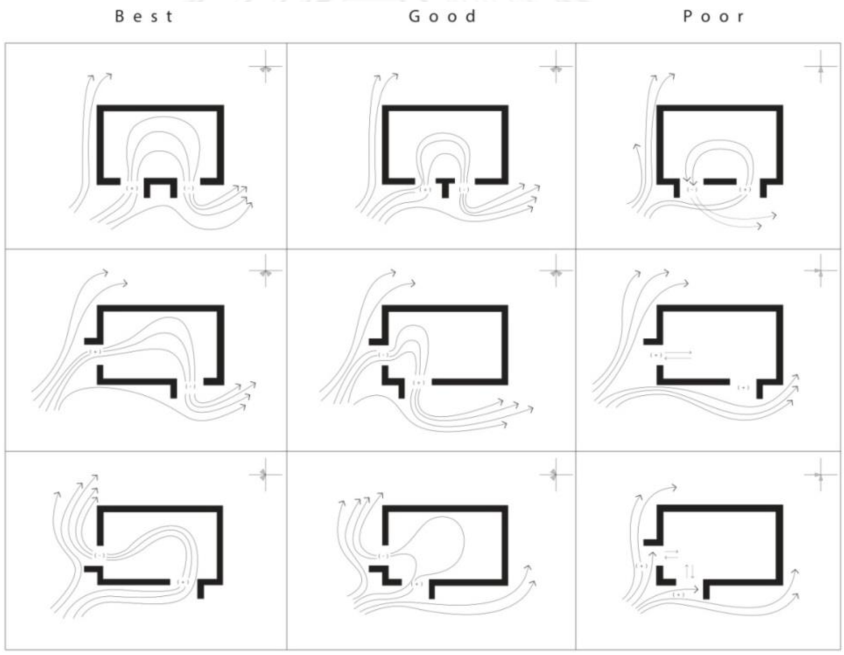


Figure 2.16 Diagrams of wing wall design strategies show different location of apertures on adjacent walls or on the same wall (Brown and Dekay, 2011)

2.4.5. Shape and Enclosure

Shape and enclosure is another component that has an impact on building cooling. When air flow moves across the room, it reduces heat in the room. Cross ventilation can be increased by placing the inlets in the higher pressure zones and outlets in the lower pressure zones. The airflow speed is dependent on the difference of temperature between the outside and inside of the building and pressure difference between the inlets and outlets; it also removes the amount of heat around the building skin as well. The maximum rate occurs when the area of inlets and outlets is large and perpendicular to the opening.

Applying stack ventilation into the design, the maximum airflow depends on the horizontal and vertical axis of the height between inlets and outlets of tall room. In an effective cooling method, cross ventilation can happen when the wind is circulating while the outside temperature is lower than the inside temperature condition. However, cross ventilation does not serve the ventilation throughout the night. When the wind becomes scarce, the use of stack ventilation comes into play. Stack ventilation relies solely on the temperature difference between inside and outside, where pressure is created across the envelop which then drives the airflow out of the upper part of the building and continue to drive the airflow through the lower part of the building. Thus, it does not require wind to drive the airflow throughout the building.

2.4.6. Understanding Wind

"Wind is simply the air in motion". Wind is caused when air moves from the higher to the lower pressure area, creating a difference in atmospheric pressure and different range of wind speed. The effects of differential heating between the equator and the poles and the rotation of the planet have impacted on the driving force of the wind ("Wind," 2012)

Velocity defines wind speed and the rate of change of the position of an object, equivalent to a specification of its speed and direction of motion. Speed describes only how fast an object is moving; whereas velocity gives both how fast and in what direction the object is moving (Gibbs, 2012) Wind direction is reported by the direction from which it originates. It can be measured by various types of tools. Compass is a conservative and accurate media to use since old time. Wind direction can be called after the compass. The main 4 main directions are north, south, east, and west. These directions can be divided in 8 different segments which are northeastern, southeastern, northwestern, and southwestern respectively. In addition to the 8 directions, it can be divided into 16 directions and 32 directions. However, it is more common to use 8 or 16 directions only (Saucier, 2003.)(see Figure 2.17).

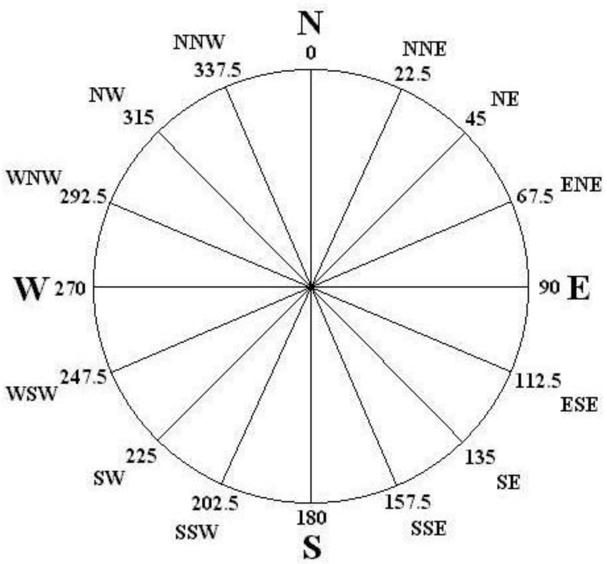


Figure 2.17 Wind directions on compass

2.4.7. Understanding Airflow

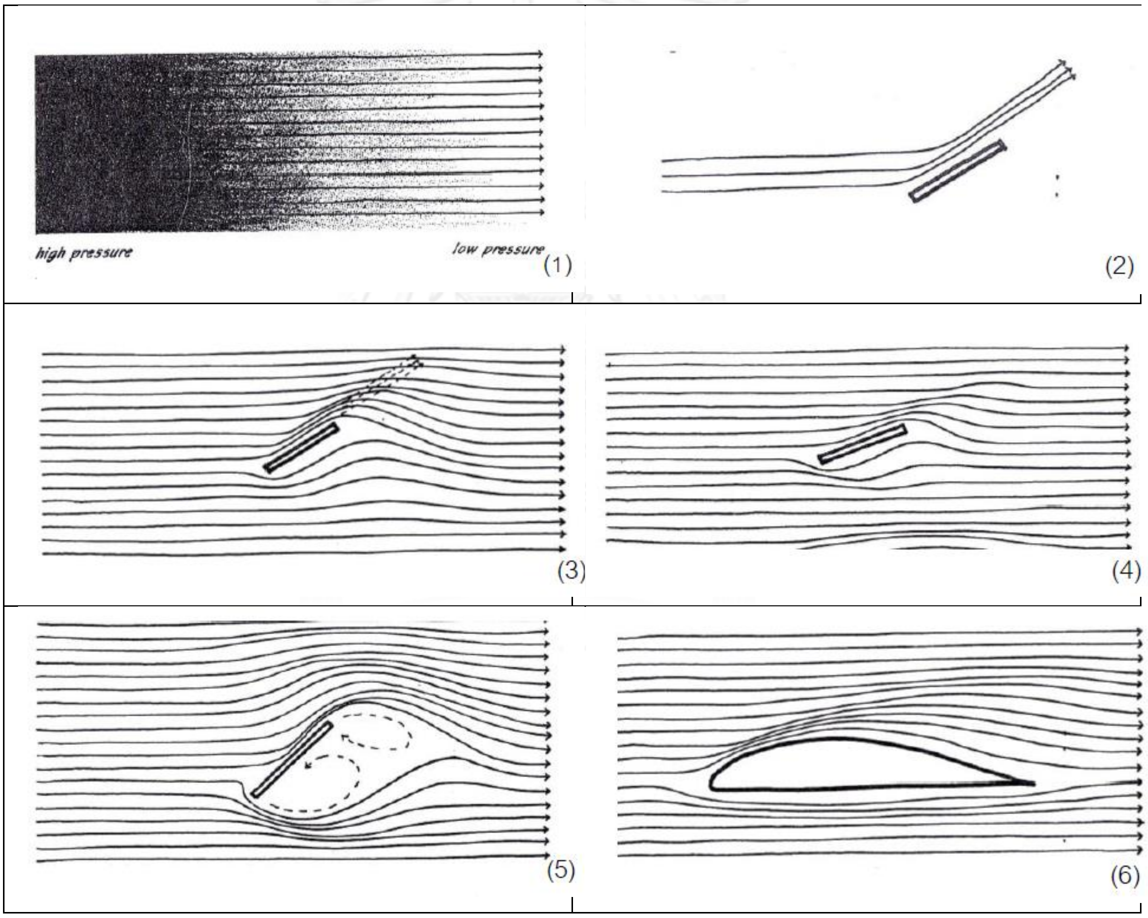
There are 4 major types of air flow as followings;

1. Laminar airflow is a fluid flows moving in similar slow speed and direction without any disruption between layers.
2. Separated occurs when the boundary layers travels far enough against an adverse pressure gradient that the speed of the boundary layer relative to the object falls.
3. Turbulent occurs when air currents separate abruptly into swirling with unpredictable direction.
4. Eddy happens when two currents of air are moving in opposite directions, they will always be separated.

2.4.7.1 Understanding Airflow (Moore, 1992) (see figure 2.18)

1. Air will always flow from a region of high pressure to a region of lower pressure.
2. Air has mass and momentum and it will tend to continue in its direction until altered by an obstruction or adjacent airflow.
3. The overall effect of wind at a site is so large that locally deflected airflow by tree and building etc. will tend to return to the direction and speed of the site wind.
4. "Laminar" air flow is smooth with adjacent air moving in similar direction and speed.
5. "Turbulent flow" is an alteration where adjacent air currents separate abruptly into swirling, unpredictable directions.
6. "Bernoulli effect" causes a decrease in pressure when air is accelerated in order to cover a greater distance than adjacent airflow.
7. "Venturi effect" causes acceleration when laminar airflow is constricted in order to pass through a smaller opening and area which creates turbulence.

8. “The stack effect” results when air in the building warms, becomes more buoyant than outside air, and rises to escape out of openings high in the building
9. Cross ventilation requires an outlet as well as an inlet. The configuration of buildings, rooms, and especially the locations of inlet and outlet openings within rooms have a major effect on ventilation rates in buildings.
10. Low pressure zones occur along the sides parallel to the wind and on the leeward side of the building.



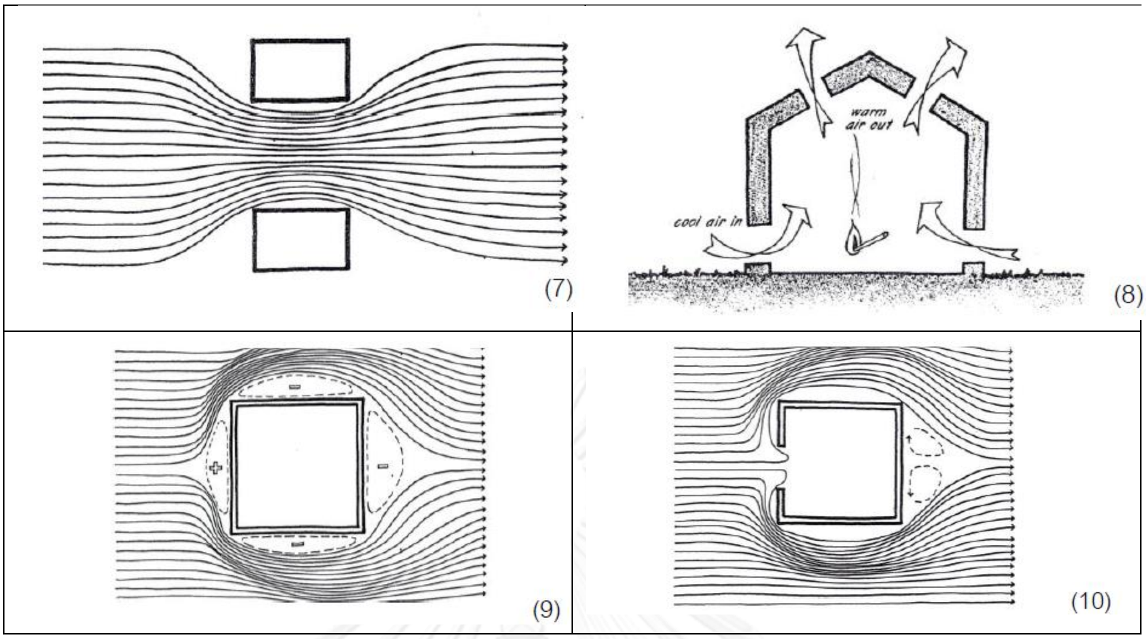


Figure 2.18 Illustration of airflow (Moore, 1992)

2.4.8. Natural Ventilation

Natural ventilation works the opposite way of mechanical ventilation. It is a process of supplying and removing air through an indoor space without relying on mechanical systems. It refers to the flow of external air to an indoor space as a result of pressure or temperature differences. There are two types of natural ventilation occurring in buildings: wind driven ventilation and buoyancy-driven ventilation. While wind is the main mechanism of wind driven ventilation, buoyancy-driven ventilation occurs as a result of the directional buoyancy force that results from temperature differences between the interior and exterior (see figure 2.19). Ventilation is essentially the flow of air between the inside and outside of a building. This flow occurs through vents, traditionally windows, but increasingly through purposely designed, controlled openings not necessarily used for introducing light (Linden, 1999). Ventilation rate in public space like hospital is required to have an opening no less than 20% of the room area. Bringing in a large amount of outdoor air can be very helpful in creating a pleasant indoor environment. The role of natural ventilation is emphasized and necessitates the integration into the design and operations of the indoor building control systems .(Boonyakiat., 2003)

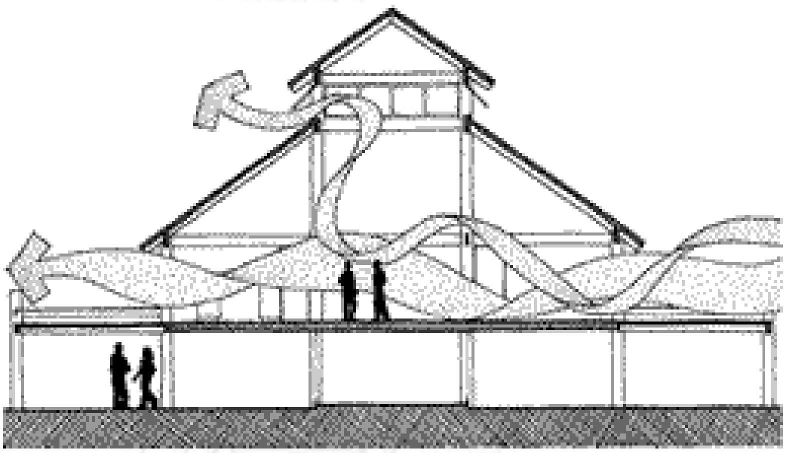


Figure 2.19 Displays stack ventilation of air moving through the building under the force of buoyancy (Brown and Dekay, 2011).

2.4.8.1. Natural Ventilation Principles

2.4.8.1.1. Single-side Ventilation

Single-sided ventilation is one of the more common forms of natural ventilation and occurs when there is a single opening into a space. It may take the form of either mixing or displacement ventilation depending on the position of the opening. The windows can only be opened on one side of the room. The amount of fresh air coming into the room is limited by single-sided ventilation. It is recommended that the depth of the room should not exceed 2.5 times the clear height of the room and that the space is not used for meeting rooms, classrooms or similar (CIB BSG Seminar, 2001: Online).

2.4.8.1.2. Cross-Ventilation

Windows in two or more facades can create cross-ventilation of the room. The ventilation is powered primarily by the wind, which creates differences in wind pressure on the facades in which the window openings are located (see figure 2.20-2.25). As a principle rule cross-ventilation can be used effectively when the depth of the room is up to 5 times the clear height of the room (CIB BSG Seminar, 2001: Online).

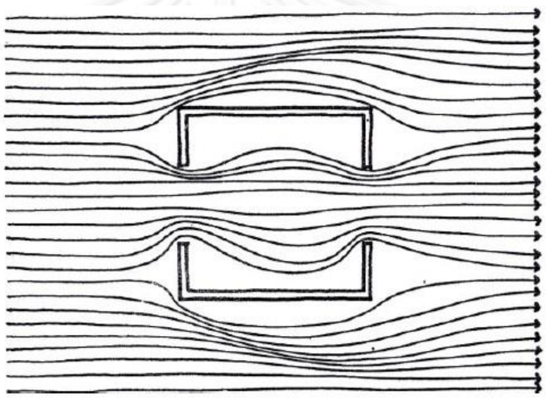


Figure 2.20 Displays the example "cross-ventilation". Opening of opposite walls relieve high pressure on the windward side, creating good cross-ventilation through the interior. Thus, maximum air change is created when the inlet and outlet area are equal

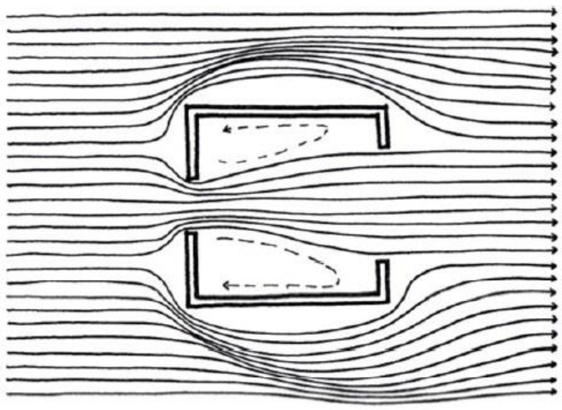


Figure 2.21 Shows the maximum interior airspeed is created when the inlet is smaller than the outlet, making this the optimum configuration when people cooling is the goal (Moore, 1992).

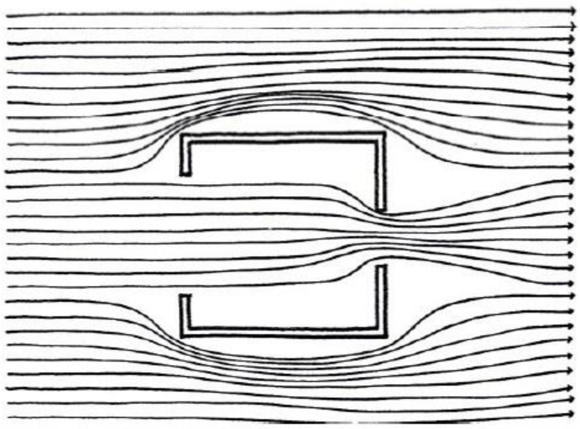


Figure 2.22 Informs that if the inlet is larger than the outlet, then velocity in the room is reduced. Although velocity outside just to leeward of the outlet is increased, this helps for cooling exterior part such as a patio (Moore, 1992).

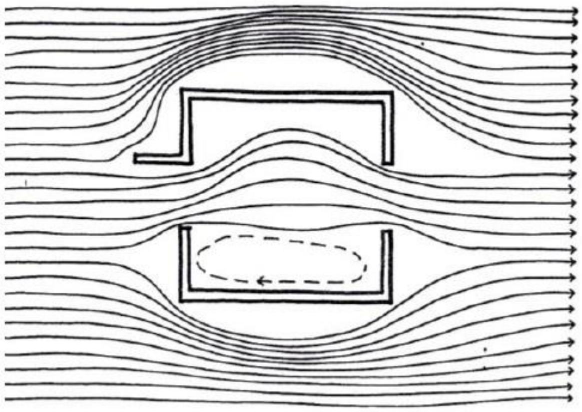


Figure 2.23 An opening of wing wall, door, or window places perpendicular to the opening changes the direction of airflow through the space with only a small reduction in velocity (Moore, 1992).

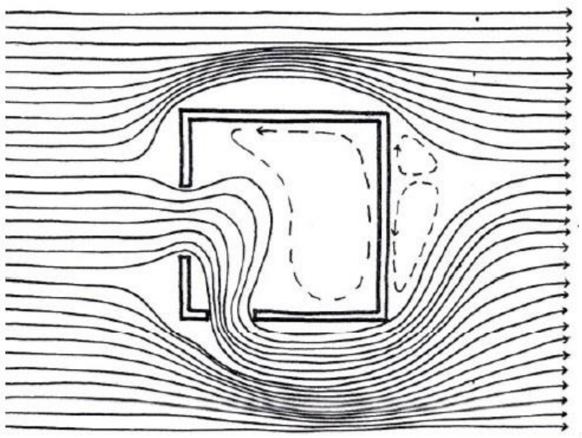


Figure 2.24 Shows an inlet centered in the wall restricts airflow to a side outlet due to an abrupt change in direction where flow is increased by repositioning the inlet to a more diagonal location and by adding a baffle directs entering air diagonally

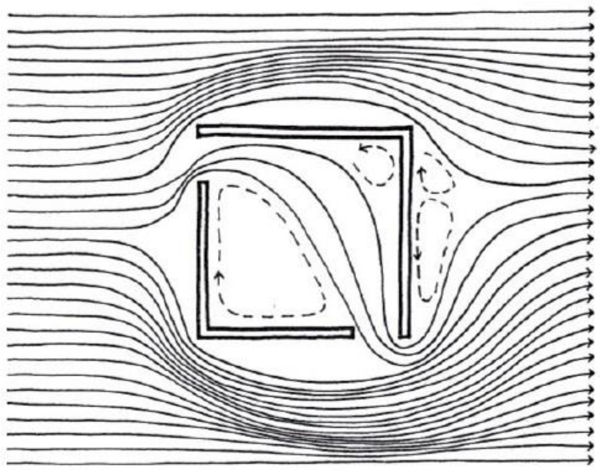


Figure 2.25 Displays openings located at the corners of the building as shown allow the inertia to continue the motion in the same direction in a smooth curve the outlet is reached (Moore, 1992).

2.4.8.1.3. Stack Driven Ventilation

Temperature differences between the inside and outside of a building and between different spaces within a building produce buoyancy forces that drive flow. In contrast to the purely wind-driven case, the presence of these buoyancy forces leads to temperature variations within the space. This stratification may lead to quite different flow configurations. The natural tendency for hot air to rise up and accumulate toward the upper part of the space leads to a stable stratification, and this has a large influence on the flow patterns within the space.

2.4.8.1.4. Wind Direction Ventilation

The effect of wind on a building is dominated by the shape of the building and the proximity of other buildings. It occurs when pressures are higher on the windward side of the building and lower on the leeward side and on the roof and so will tend to drive a flow within the building from the windward vents to the leeward vents. Thus, the configuration of buildings, rooms, and especially the locations of inlet and outlet openings within rooms have a major effect on the ventilation rate in buildings (Moore, 1992). Because separation is a major factor in determining the wind flow around the building, particularly downstream of the windward face, and most buildings have sharp corners, wind speed plays only a minor part in determining the air flow pattern around the building. Figure 2.26 shows when airflow hit the building surface directly and form 90 degree angle, the increasing of air pressure will become apparent in this area. However, when the airflow changed its direction and hit the wall surface of the interior and form 45 degree angle. As the air pressure will start to decrease to 50%. This will increase the airflow into the building throughout the building (O. H. Koenigsberger, Ingersoll, T., Mayhew, A., and Szokolay, S., 1973)

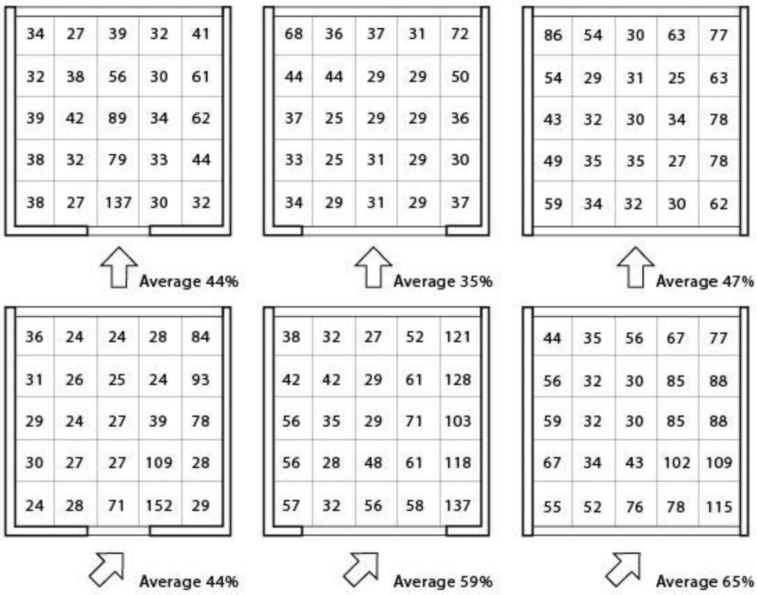


Figure 2.26 Displays airflow direction that effect by the opening (Givoni, 1998)

2.4.9. Important Factors for Maximizing Ventilation into the Building

Factors that have been applied in the design criteria in chapter 4 are as followings;

2.4.9.1. Building Layout and Shape

Building layout and shape can affect the airflow direction. Airflow can cause by a difference of air pressure. Thus, wind is formed by the difference of pressure gradient. In hot regions that rely on natural ventilation, whether or not ventilation can provide indoor comfort has an impact on the building shape and orientation (see figure 2.27). In a hot-humid climate, ventilation is the most effective way to minimize the physiological effect of the high humidity. Hence, a spread out building is suggested. It allows better natural cross ventilation than a compact one by providing more wall areas, and more directions for catching the winds into the building. Once the building is cross ventilated during the daytime hours its indoor temperature tends to follow the outdoor pattern. The heat flow through envelope that is small and larger surface areas does not significantly affect the daytime indoor temperature. Whereas, during the evening and night hours, when winds usually subside, the envelope's larger area permits faster cooling (Givoni, 1994).

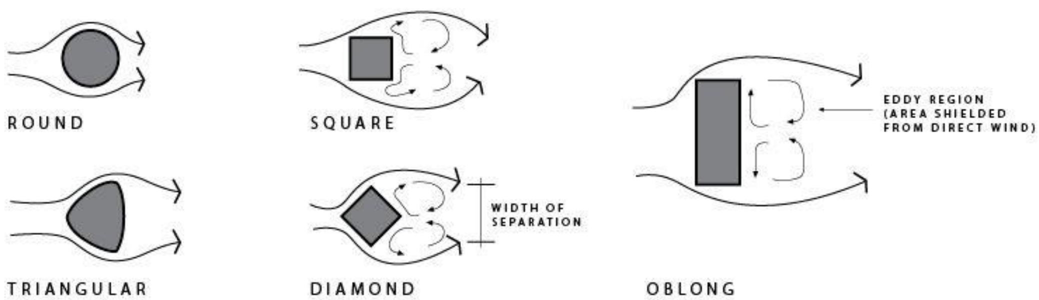


Figure 2.27 Displays the relation between airflow direction and different shapes of building (Egan, 1975)

2.4.9.2. Size and Windows

Openings in a hot humid climate plays a major role in determining the thermal comfort of the occupants as their location and size determine the ventilation conditions of the building. Large openings in all the walls can provide the design solution for effective cross ventilation (Givoni, 1994).

.

2.4.9.2.1. Location of the Openings

According to Givoni's study on the location of the openings, it was found that airflow that forms 45 degrees perpendicular to the building will increase the velocity of the airflow. This is due to the fact 45 degree angle has larger area of inlet airflow, which then creates greater low-pressure suction at the outlet. It will give a higher air velocity within the building (Koenigsberger, 2001; Online). Nevertheless, the 45 degree airflow will only result in a higher air velocity if the inlet is positioned opposite the outlet.

2.4.9.2.2. Size of the Openings

The effect of window size depends greatly on whether or not the room is cross ventilated. In rooms with a single window, the size of the window will have only a small effect on internal airflow, especially if the wind is perpendicular to the wall. When the window faces an oblique wind, increasing its width provides a larger pressure gradient and increases indoor air speed. To create cross ventilation in the building, one can simply design and enlarge windows. It will increase the airflow rate and interior air speed (Givoni, 1994).

2.4.9.2.3. Height of the Openings

The vertical position of the inlet window is important in maximizing the airflow through the lower, occupied portion of the room. The low inlet is best for cooling. The outlet location has little effect on flow within the room.

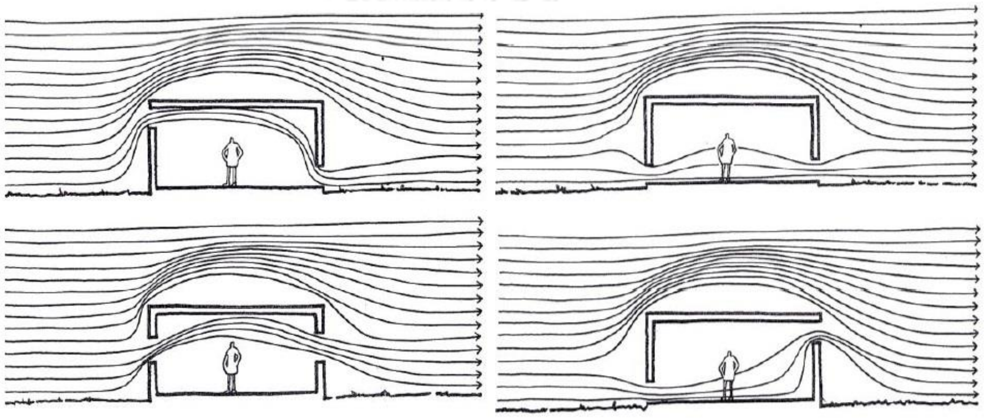


Figure 2.28 Illustration of height of the openings and airflow (Moore, 1992)

An overhang above the inlet window directs the interior airflow along the ceiling out of the occupied zone; the addition of a slot separating the overhang from the building directs the flow down into the room, increasing the useful cooling effect. Wind direction is more stable in vertical plan than in the horizontal plan because the vertical components are more constant (Moore, 1992) (see figure 2.28 and 2.29).

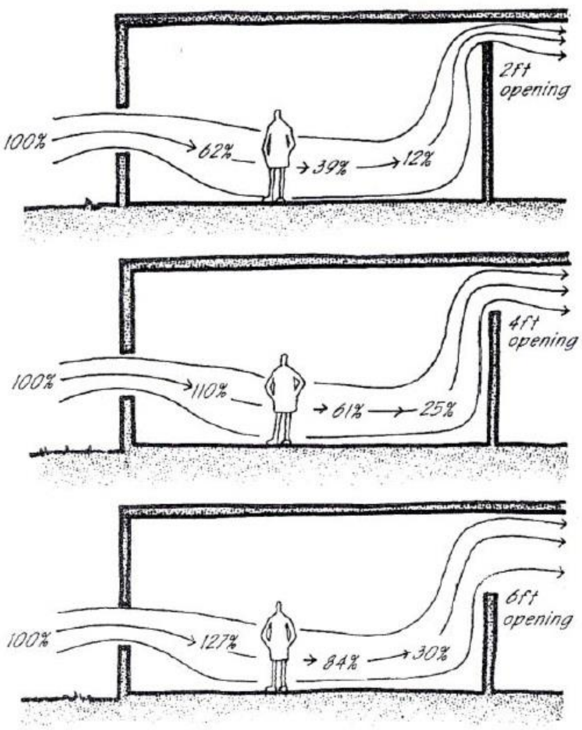


Figure 2.29 Illustration of height of the openings and air flow (Moore, 1992)

2.4.9.2.4. Type of Openings and Windows

Different types of windows, when serving as inlets. They can produce different patterns of indoor airflow and provide different option for controlling the direction and level of the flow (Moore, 1992).

1. Horizontally slide windows: produce 50% less airflow than the Pivot hung window. Provide less than half of the free opening area.
2. Double hung window: it can slide up and down vertically and use their height to determine the vertical level airflow. The maximum free opening is less than one half of the total area of the sashes which can limit the effective ventilation rate.

3. Center pivot hung window: it allows 100% airflow when open at 22 degree angle.
4. Vertically center pivot hung window: it only allows 40% less airflow when it opens at 22 degree angle.
5. Casement type of window allows the highest rate of airflow (see figure 2.30).

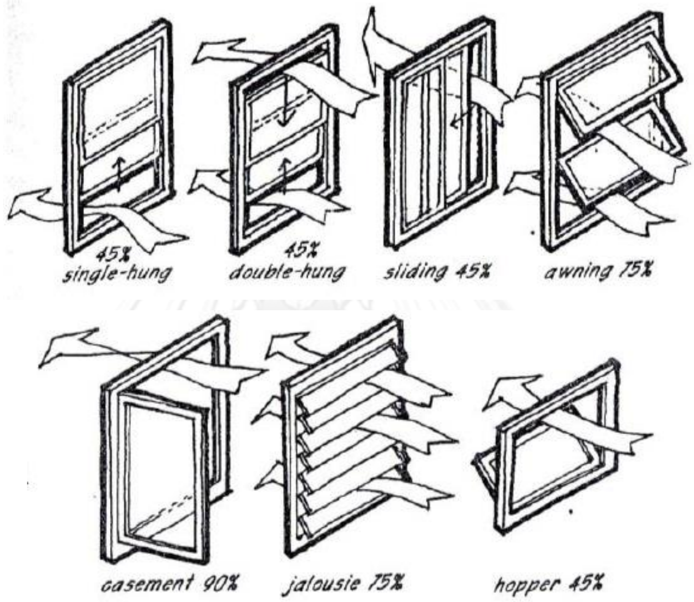


Figure 2.30 Illustration of different types of windows.

2.5. Laws and Regulations in Hospital Design

Hospital building is one of the most complex building types in architecture. To design one, the designer must be well aware of the hospital design foundation in order to avoid risk of design malfunction. With a careful attention to detail in the hospital design, it can affect the well-being of the occupant's daily life. Thus, architects should know the basic Laws and Regulations in hospital design and apply them in the design as followings;

1. พระราชบัญญัติผังเมือง
2. พระราชบัญญัติควบคุมอาคาร
3. กฎกระทรวงฉบับที่. 55 "อาคารขนาดใหญ่"
4. The Thai government that facilitates the handicapped and patient in hospital setting for their convenience, drafted in the year 2005
5. กฎกระทรวง ฉบับที่ 7 เรื่องที่ จอดรถ
6. กฎกระทรวง ฉบับที่ 39 พศ 2537 เรื่องจำนวนห้องน้ำ
7. พระราชบัญญัติสถานพยาบาล

2.6 Conclusion

2.6.1 TB healthcare center should locate in an open setting in order to maximize the use of natural ventilation.

2.6.2 Instead of relying on the high technology machine that is required high maintenance. Utilizing natural ventilation as a tool to prevent and reduce cross infection can easily be done without any cost.

2.6.3 The main details of building design that affect indoor ventilation conditions are:

- Geometric configuration of the building's envelope
- Location of openings with respect to wind direction
- Type of windows and details of their opening
- Vertical location of openings
- Interior obstruction to airflow from the inlet to the outlet openings, including the size and location of the openings connecting the adjacent rooms

CHAPTER III
DESIGN METHODOLOGY

This research studies critical examination of design options that foster infection control in healthcare settings by applying natural ventilation method. By understanding the relation between the administrative control and environmental control measure, it can enhance the mechanism of airborne infection prevention. The design is intended to demonstrate the different ways of achieving natural ventilation in order to prevent cross infection in resource limited health care settings. Through the study of basic natural ventilation methods and universal design applied in the study, it will be beneficial to the future TB hospital/healthcare setting designs in resource limited setting.

Design Methodology is consisted of;

1. Criterias from Literature review
2. Conducting a pilot study case in Thailand
3. Design
    - 3.1 Site Selection
    - 3.2 Programming
    - 3.3 Analysis
    - 3.4 Design

3.1 Criterias from Literature review

3.1.1 Building Orientation; to maximizing natural ventilation

3.1.2 Zoning; separate and/or creating buffer zone

3.1.3 Circulation; separate TB and non TB

3.1.4 Detail design; Opening and other elements

3.1.4 Specific Area; main waiting area, main entrance, sputum room, exam room, IPD

3.2. Conducting a Pilot Study

Hospital plays an important role within the environment; it can create a positive connection to the citizen and the community within that region. It conveys a sense of security and safety with the socio cultural context.

The objective of this study is to investigate the current practice in infection control especially environmental control aspect of naturally ventilated TB centers in Thailand. This study surveyed three clinics in Bangkok, Thailand. Data were collected from interviews of healthcare workers (HCWs) and observation of the user behavior of both HCWs and patients. In addition, airflow patterns of three centers were simulated using Computational Fluid Dynamic (CFD) program. This pilot study will reflect on the design process which focuses on and will improve the design part of chapter 4 as followings;

1. Planning of program
2. Ventilation
3. Administration

3.2.1. Review of Assessment Criteria

According to the CDC guideline (CDC, 2005), the probability of TB transmission increases as a result of various environmental factors.

1. Exposure to TB in small, enclosed spaces.

2. Inadequate local or general ventilation that results in insufficient dilution or removal of infectious droplet nuclei.
3. Recirculation of air containing infectious droplet nuclei.
4. Inadequate cleaning and disinfection of medical equipment.
5. Improper procedures for handling specimens.

Tuberculosis control policies at the three centers comply with the CDC guideline. There are strong and sufficient evidence of the association between the design guideline and the actual design, the control of airflow direction in buildings, and the transmission and spread of infectious diseases among patients in healthcare settings. However, the lack of sufficient data on the specification of the validated requirement in hospital design and other healthcare settings in relation to the spread of airborne infectious diseases, suggest the existence of a knowledge gap. In all three case studies revealed an important need for a study in investigating the origin of disease outbreaks in environmental control factor.

3.2.2. Study Areas

This study was conducted in 3 naturally ventilated Tuberculosis healthcare centers which are located in Bangkok, Thailand during May, 2012. Tuberculosis control policies at the three clinics followed with CDC guideline. All TB clinics were located in tropical areas with high temperature and humidity. Daily average temperature range is 24-26°C with the highest maximum recorded as 34-38°C and the average relative humidity is between 65-75% (TMD, 2012). The numbers of occupant of the 3 TB clinics studied were 30-40 TB infected patients with pulmonary TB and 5-10 non-TB patients per day and 25 healthcare workers (HCWs). Study area in each clinic consisted of patient care and ancillary area to support the patients. Patients care areas included the patient examination room in medical out-patient department (OPDs), the waiting area for out-patient (TB infected and non-TB infected), and the direct observe treatment room (D.O.T). Ancillary areas included in this survey were the radiology rooms, biomedical laboratories, and administrative departments.

3.2.2.1 Case Study 1:

3.2.2.1.1 Background

Location: The TB healthcare center is located in Nontaburi district, Thailand.

Physical aspect: This TB center is separated from the main building where other departments located. However, it still uses the facility inside the main building such as X-RAY room and blood specimen. It serves about 50 TB infected patients per day.

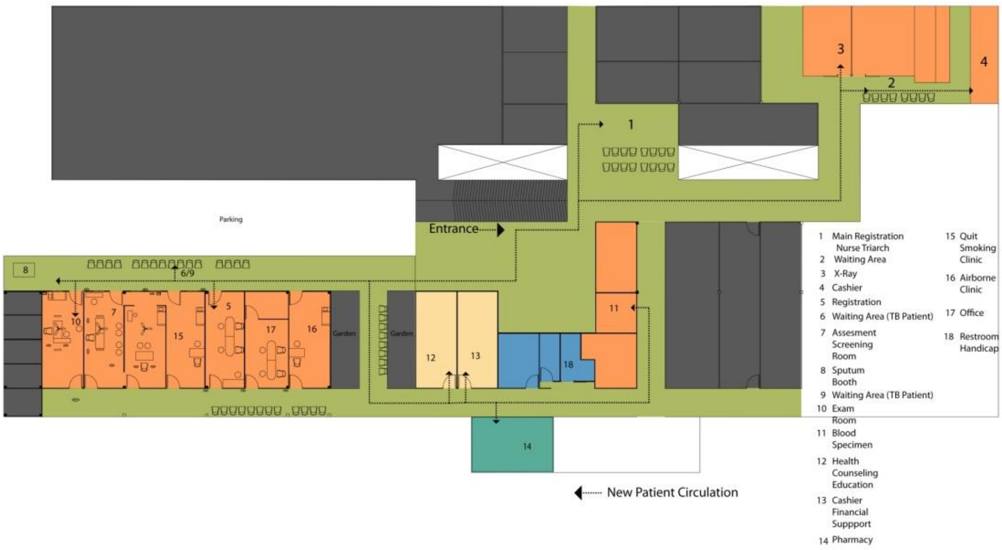


Figure 3.1 Case study 1: TB Clinic Floor Plan

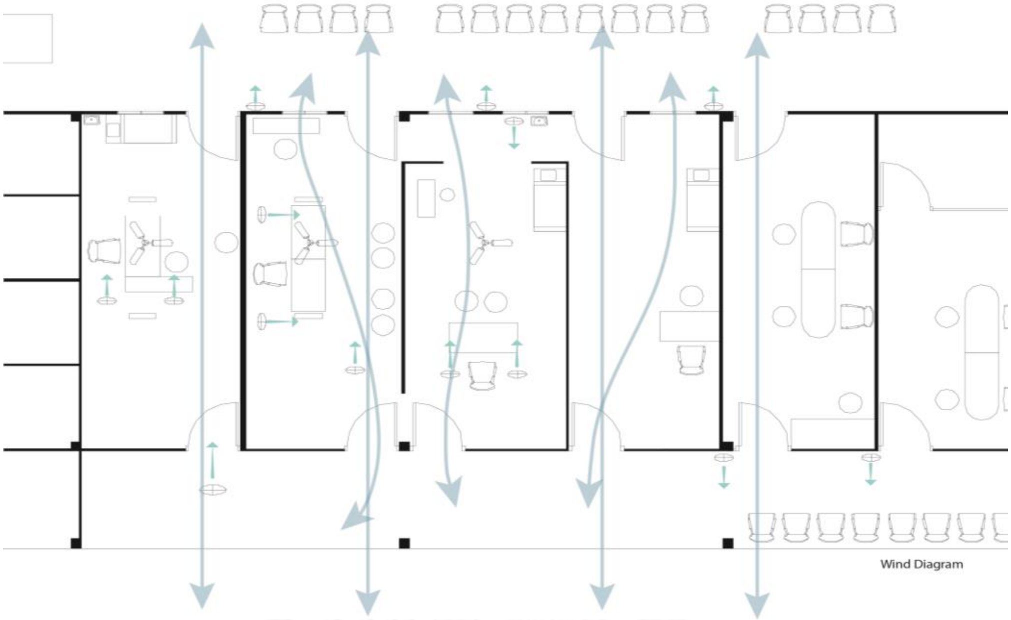


Figure 3.2 Case study 1: Wind diagram of the OPD examination room

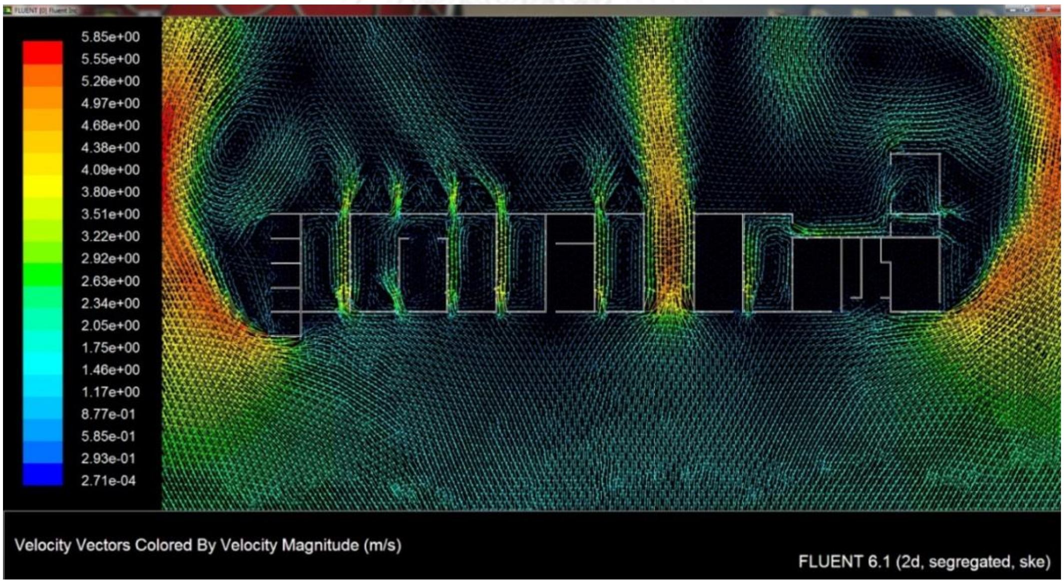


Figure 3.3 Case study 1: CFD simulation of the entire facility

Table 3.1 Evaluations

Criteria	Pros	Cons
1. Building Orientation	Good	
2. Zoning		Poor zoning
3. Circulation		Poor zoning
4. Detail Design		Double load corridor
5. Specific Area		OPD

3.2.2.1.2 Problems

1. The poor zoning of function, there is a mix use of space where non-TB patient and TB patient are in contact.
2. The long travel distance and cross circulation can promote the nosocomial and cross infection in healthcare setting.
3. The enclosed space such as the exam room (OPD) does not have enough openings to thoroughly ventilate the contaminated air out.

3.2.2.2 Case Study 2

3.2.2.2.1 Background

Location: Located in high populated community area in Bangkok.

Physical Aspect: A seven story tall building TB center is served as a TB clinic and a TB lab centre and office. The TB clinic is located on the first floor. The building itself has a open courtyard in the middle. It serves about 20 TB infected patients per day.

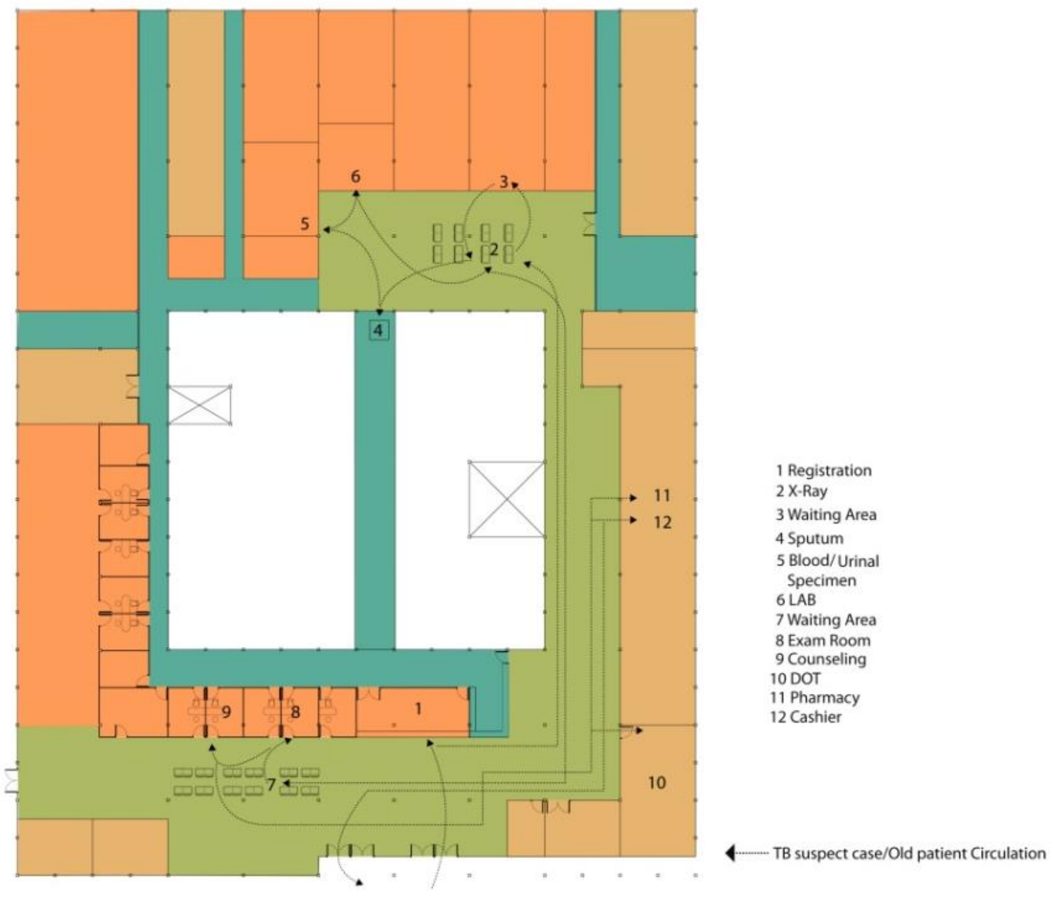


Figure 3.4 Case study 2: TB Clinic Floor Plan

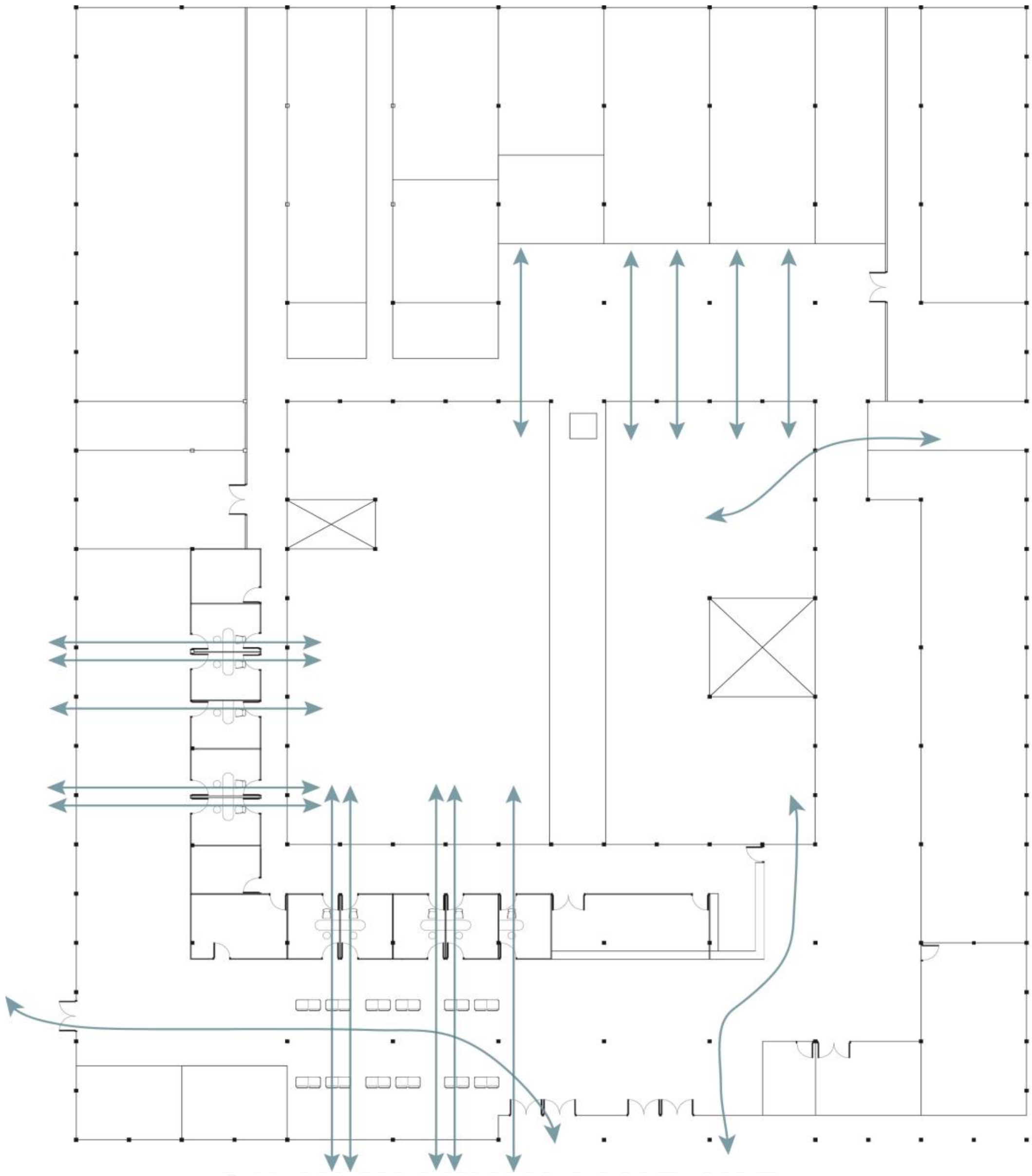


Figure 3.5 Case study 2: TB Clinic wind diagram

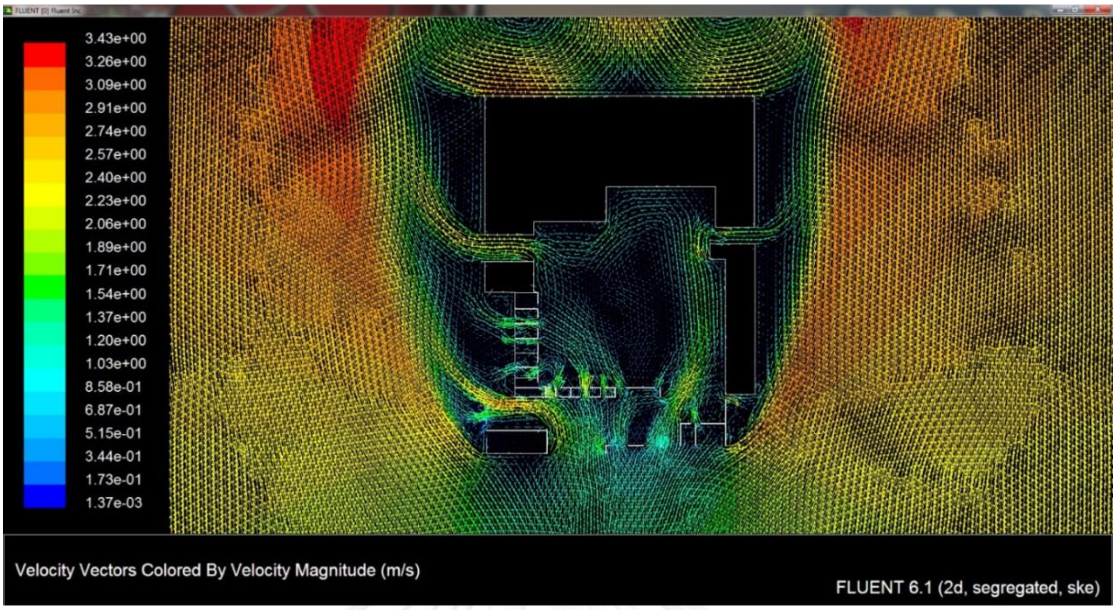


Figure 3.6 Case study 2: CFD simulation of the entire facility

Table 1Table 3.2 Evaluations

Criteria	Pros	Cons
1. Building Orientation	Good	
2. Zoning		The Adjacency of program
3. Circulation		Poor circulation
4. Detail Design		Double load corridor
5. Specific Area		Sputum area

3.2.2.2.2 Problems

1. The adjacency of programs can be altered so patient's circulation does not cross between the non-TB, TB patients, and HCWs.

2. The location of sputum booth is located outside roof of the courtyard, which is opened to the waiting area in front of the lab and blood specimen. With the high ventilation rate,

this may promote the TB bacteria to travel and spread into the waiting area where both TB and non-TB patients are occupied.

3.2.2.3. Case Study 3

3.2.2.3.1 Background:

Location: This TB clinic is located in Nontaburi district, Thailand

Physical Aspect: A one story tall small scale TB clinic serves about 50 TB infected patients per day. It is considered as the best infection control with one stop service TB healthcare center in Thailand.

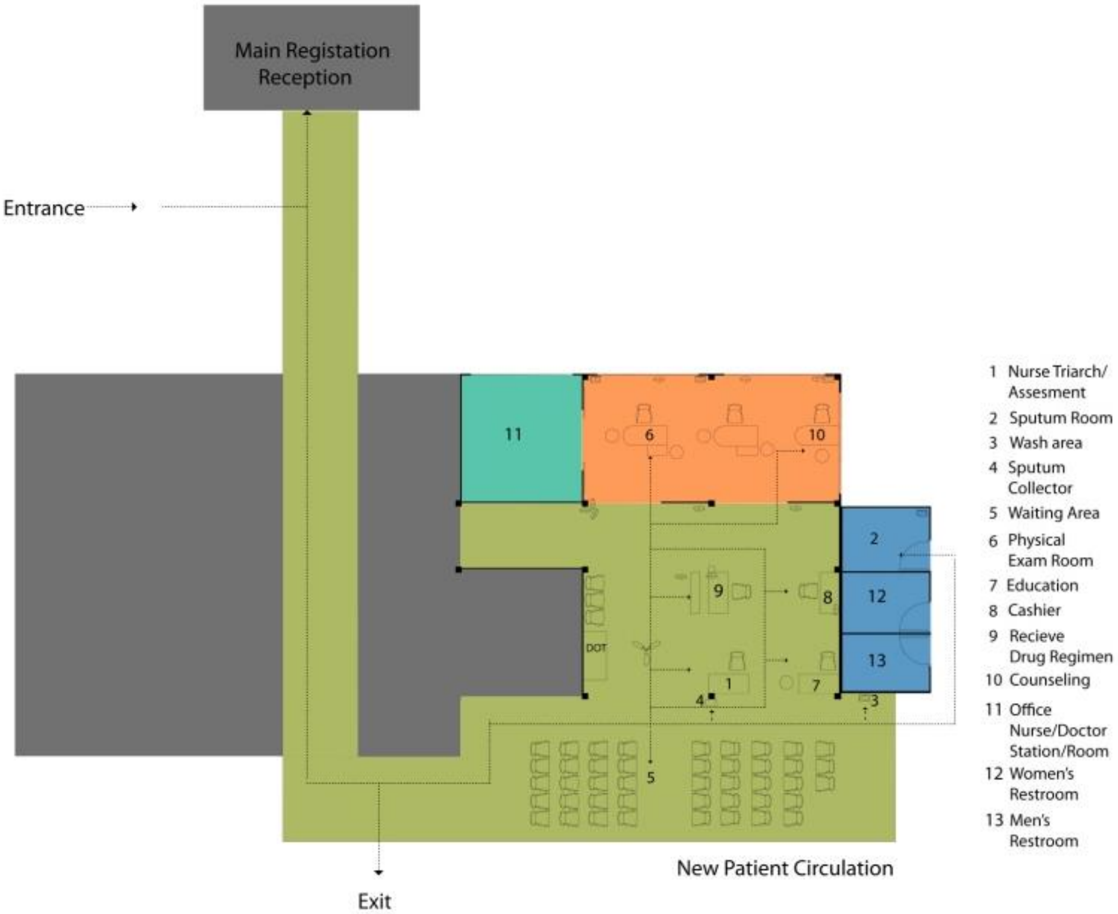


Figure 3.7 Case study 3: TB Clinic Floor Plan

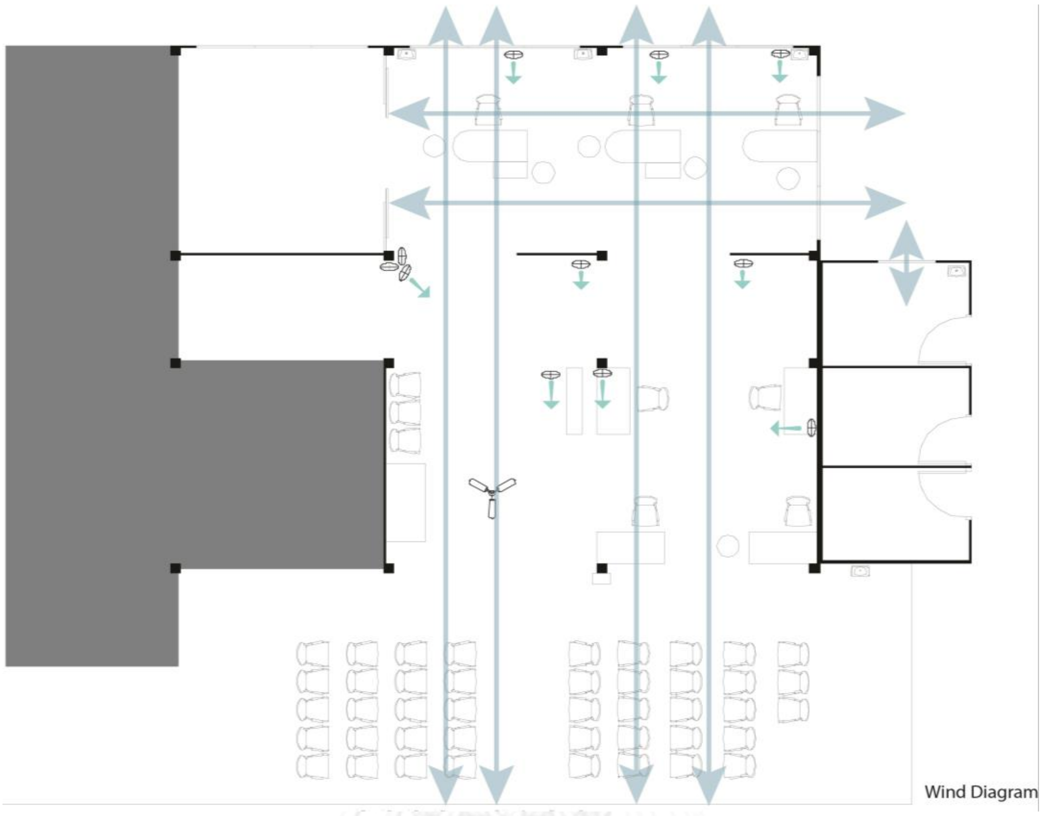


Figure 3.8 Case study 3: TB Clinic Wind Diagram

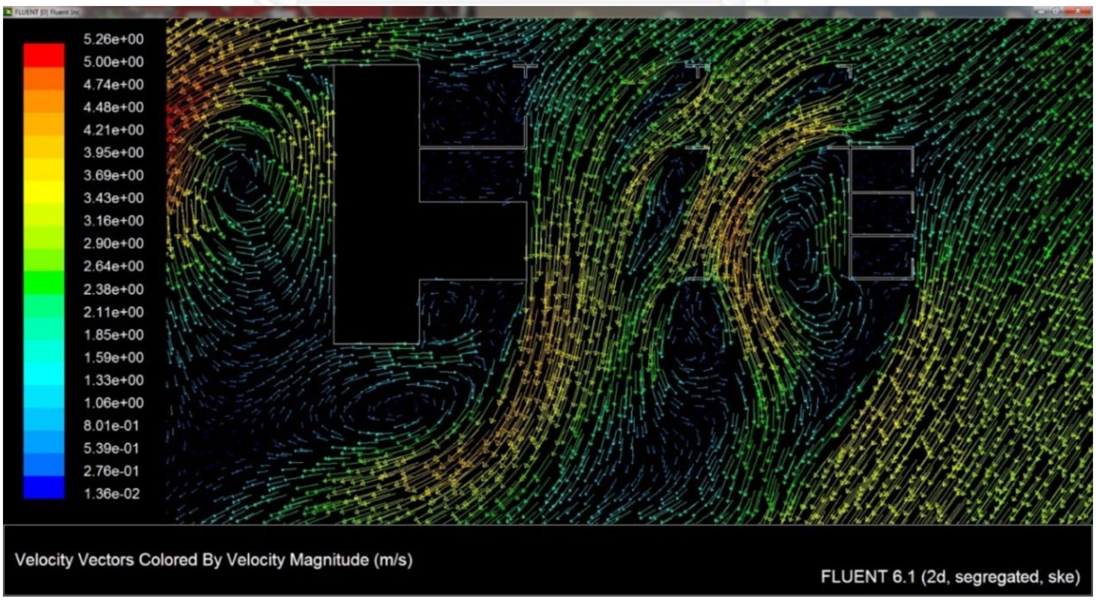


Figure 3.9 Case study 3: CFD simulation of the entire facility.

Table 3.3 Evaluations

Criteria	PROS	CONS
1. Building Orientation	Good	
2. Zoning		Mixed use
3. Circulation		Mixed use
4. Detail Design		
5. Specific Area		

3.2.2.3.2 Problems

1. The location of the waiting area is located in front of the HCWs and nurse triage station, where it can easily promote a nosocomial.

2. The zoning of function and circulation of patients are constantly revolved around HCWs.

3. The location and the opening of the sputum booth. With the opening located next to the OPD window opening, this can promote a cross infection.

3.2.3 Data Analysis

Data were collected from interview of HCWs and observation of the user behavior of both HCWs and patients. In addition, airflow patterns of three clinics were simulated using Computational Fluid Dynamics (CFD) program. Floor plans were used to analyze in relation to function of program and user behavior included patients and HCWs.

From data analysis showed that in all centers share similar architectural features.

1. The current floor plans in figure 3.1- 3.9 of the centers prevent good airflow into the room. Ventilation is the key in TB clinic. Lack of ventilation can create cross infection

which could occur between patients and HCWs. According to CFD result, it showed that the measured airflow in all three OPD waiting area is lack of good ventilation. It is where TB infected and non-TB infected patients spend their time while waiting for the examination.

Thus, waiting area is one of the critical area that the cross infection takes place regardless of the personal protection equipment (PPE).

2. The window position and size of the opened window is too small and prevents good ventilation.

3. The function of spaces does not serve the sequence of the user behavior. Circulation of HCWs and patients analysis showed that there is a mixed circulation between them, which could create a high risk of airborne transmission in the clinics.

3.2.4. Discussion and Implication

CDC has published a guideline on the optimal use of natural ventilation when designing healthcare or upgrading existing structures (CDC, 2003). It has been proven in many studies that natural ventilation can prevent airborne infection in healthcare setting. Escombe revealed in his study that the old-fashioned clinic areas with high ceilings and large windows provide greatest protection. With opening windows and door maximizes natural ventilation so that the risk of airborne contagion is low (Escombe, 2007). Natural ventilation can deliver much higher ventilation rate than mechanical ventilation in an energy-efficient manner, and it is suitable for tropical climate like Thailand. Installation of air-conditioning system in the high risk areas such as TB clinic decreases indoor ventilation and increases the risk of airborne contagion. It can turn into a long term investment in order to achieve the infection control standard which can be costly and insufficient energy in a lifetime. The present study investigates the current practice in infection control especially in the context of environmental control of naturally ventilated TB clinics in Bangkok, Thailand during the summer time in which the risk of airborne transmission is higher than that of the general hospital. It is an implementation for infection control guideline. The findings are consistent with the previous studies conducting in the general and referral hospitals both in central Bangkok and provincial areas in Thailand (Pipat Luksamijarulkul et al, 2004:35; Wiroj Jiamjarasrangsi, Niti Hirunsuthikul, and Prirom Kamolratnakul, 2005:9; Wiroj Jiamjarasrangsi, Sarawuth Urith, and Wisaruth Srisintorn, 2006:89; Yanai et al., 2003:7).

The results suggest the lack of sufficient data on the specification of the validated requirement in architectural aspect of TB clinic design and other healthcare settings in relation to the spread of airborne infectious diseases. It also suggests that guideline should be able to alter to fit with the actual setting and practice. This study concludes that the modification of floor plan arrangement and maximizing the openings for natural ventilation can enhance the environmental control procedure immensely in case study. Environmental control measures still have a significant impact on TB control in Thailand and utilizing both administrative and environmental control measures can synergistically improve the infection control aspect because human or user is a carrier of the disease (Chatsuda Phuapradit and Vorapat Inkarojrit, 2013).

3.3 Design

3.3.1. Site Selection Criteria

TB has widely spread in Nakorn Ratchasima province. Therefore, TB professional and specialized health facilities need to be provided throughout the country (Posttoday, 2012). The proposed TB hospital project has been initiated. This TB hospital is located in Nakorn Ratchasima, Pak Chong, Pong Talong district.

Location information (see figure 3.10 and 3.11)

Location: Wat Makut Kiriwan, Khoayai, 86 Moo 1, Pong Talong, Pak Chong, Nakhon Ratchasima 30130

Land Size: 18,000 sq.m.

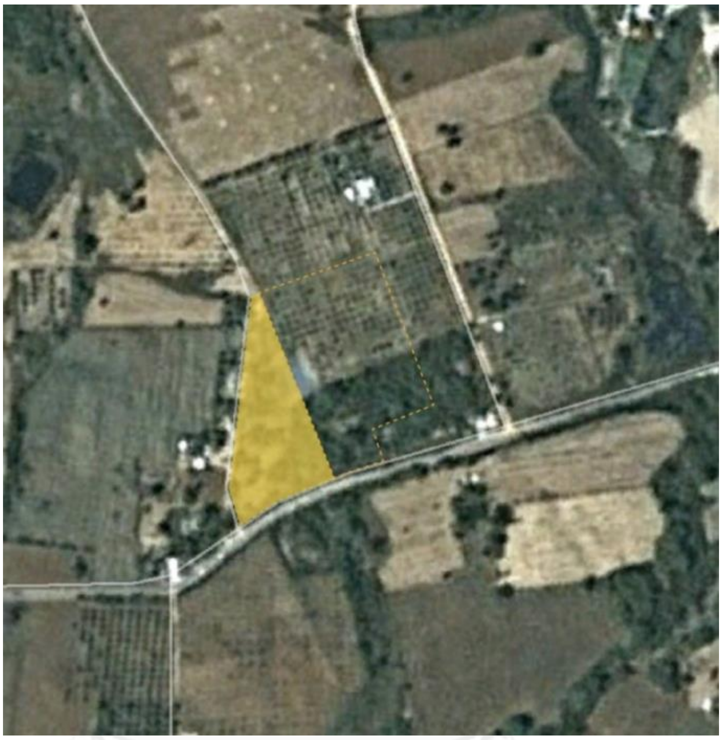


Figure 3.10 The proposed TB hospital site is located next to the health care facility in a rural area of Pong Talong district. It's about 50 km. from the inner city where the cluster of hospitals is located.

Figure 3.11 Site Layout shows the current existing healthcare district of Pong Talong. The total area of the existing building is 6,900 sq.m.

3.3.2 Program

Hospital information:

Out Patients: 80 Person/Day

Service: Monday-Friday 300 Days 24,000 Person/Year

Ration between Out-Patient and Inpatient 20:1

Out-Patient	24,000 Person/Year
Inpatient	1,200 Person/Year
Length of stay	6 Days
No. of Bed	20 Beds

Project: Design of TB hospital for limited resource setting in Thailand

Project Owner: 5th Division of Disease Prevention Control Center, Ministry of Public Health

Program is consisted;

1. Public area
2. Out-patient Department
3. Clinical Support Facilities
4. In-Patient Department (20 Beds)
5. Administration Facilities
6. Service Facilities
7. Engineering Department

Table 3.4 Programming of the design facilities

	Unit Size (sq.m.)	Quantity	Total Size (sq.m.)
Public area			
Main Entrance hall	100	1	100
Coffee corner	100	1	100
Reception and Registration	30	1	30
Pharmacy and Cashier	30	1	30
Waiting Area	30	1	30
Stretcher	10	1	10
Circulation	90		90
Total			390

Table 3.4 Programming of the design facilities (Continued)

	Unit Size (sq.m.)	Quantity	Total Size (sq.m.)
Diagnostic and Therapeutic Facilities (Out-patient Department)			
Waiting Area	80	1	80
Nurse Triage	30	1	30
Exam Room	12	3	36
Isolated Room	12	1	12
Counseling	24	1	24
D.O.T	24	1	24
Doctor/Nurse Lounge	45	1	45
Clean Storage	10	1	10
Dirty Storage	10	1	10
Sputum Room	6	1	6
Restroom for TB	50	1	50
Circulation			98
Total			
425			

Clinical Support Facilities			
Waiting Area	80	1	80
Pharmacy Department	40	1	40
Radiology Department	80	1	80

Laboratory Room	60	1	60
Blood and Urinal Specimen	30	1	30
Restroom for non TB	50	1	50
Circulation			102
Total			442
IPD			
Inpatient Department	80	2	160
Nurse Station	20	2	40
In-Patient room	120	2	240
Storage	10	2	20
Clean Storage	10	2	20
Dirty Storage	10	2	20
Restroom for TB	40	2	80
Circulation			168
Total			748

Administrative Facilities			
Reception	30	1	30
Director Office	15	1	15
Administrative Office	10	1	10
Accounting Office	20	1	20
Medical Record and Statistic Office	30	1	30
Operator and Public Relation Office	20	1	20
Computer Office	20	1	20
Education/Financial Aid	20	1	20

Table 3.4 Programming of the design facilities (Continued)

Meeting Room	30	1	30
Staff Lounge	50	1	50
On call	10	4	40
Staff Room	50	1	50
Circulation			84
Total			419
Service Facilities			
Central sterile supply department	30	1	30
Dietary Department	10	1	10
Main Kitchen	50	1	50
Staff Canteen	30	1	30
Laundry Department	30	1	30
Security Department	20	1	20
Maintenance Office	15	1	15
House-keeping Department	15	1	15
General Storage Department	15	1	15
Chemical Storage	15	1	15
Circulation			58
Total			288
MEP			
Electrical Room	30	1	30
Pump Room	30	1	30

Table 3.4 Programming of the design facilities (Continued)

Mechanical Room	30	1	30
Garbage Room	50	1	50
Total			140
Main Circulation			600
Grand Total Area			3,452
Parking			
General Parking	25	14	350
Ambulance Parking	25	1	25
Service Parking	25	4	100
Total			475

3.3.3 Analysis

3.3.3.1 Site Analysis

3.3.3.1.1 Characteristics of local climate in Nakorn Ratchasima

Table 2Table 3.5 Characteristics of local wind in Nakorn Ratchasima

	Months												
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	**Avg.**
Avg. Velocity (m/s)	0.50	0.70	0.80	0.80	1.20	1.20	1.20	1.10	0.50	0.60	0.70	0.70	**0.80**
Prevailing Wind	NE	NE	S	S	S	SW	SW	SW	SW	NE	NE	NE	**NE**
Highest Velocity (m/s)	6.70	7.20	12.9	24.2	12.00	9.30	10.30	10.30	7.20	10.30	9.30	8.20	**10.66**

1. Highest velocity rate is during June/July 1.20 m/s (miles per second)
2. Average velocity at 0.80 m/s (see table 3.1)
3. Wind direction: Flown from Northeastern
4. Highest Velocity: 24.20m/s

5. Lowest Velocity: 6.70 m/s in January
6. Prevailing wind: Northeastern from October-February (see figure 3.12)

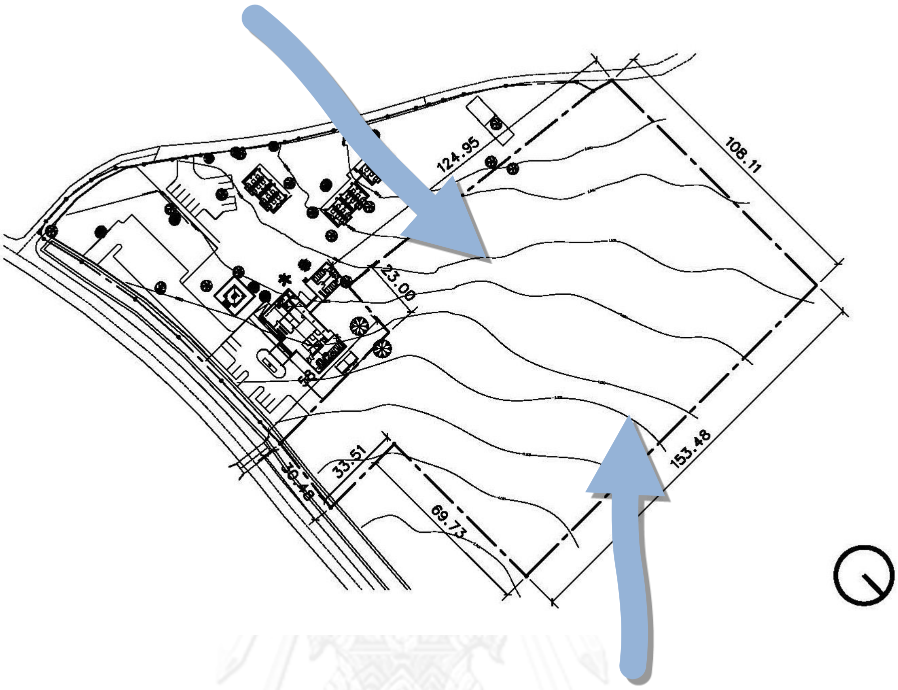


Figure 3.12 Diagram of prevailing winds from Northeastern and South

Landscape strategies for mountain sites, the site suitable for the construction of the proposed TB healthcare center is in the hill. To provide storm drainage and choreograph entry sequence into the building, the design has to be adapted by raising the floor level higher than the neutral soil level. The landscape ramps up gently on slope with grand stairs in exterior and interior connecting steps when the level changes where pockets of courtyards are planted on to create a buffer zone between buildings.

3.3.3.2 Program Analysis

3.3.3.2.1 Building Orientation

The permeability design concept is driven by the wind direction. Precedent study of current hospital typology of building is normally built as a stack of programs with core for services and utilize the use of vertical space since land has become expensive. However, this healthcare setting is treated as a special clinic where only serves TB infected patiens. Taking the advantage of the site, location, and clean natural ventilation of Nakorn Ratchasima, the scattered of building with a connected path is being introduced in the design (see figure 3.13).

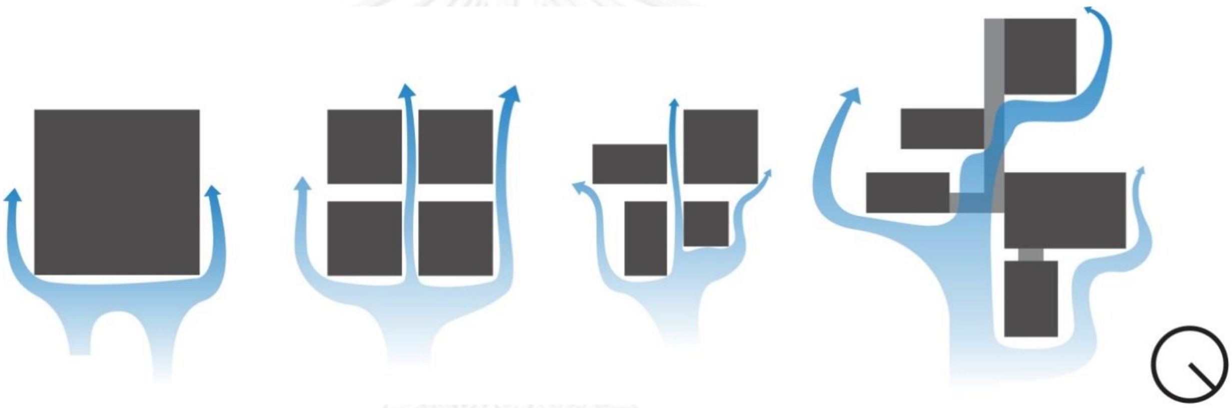


Figure 3.13 Diagram of expansion of building that allows air flow throughout the entire space compound.

3.3.3.2.2 Zoning

Zoning diagram are divided into 3 parts of program hierarchy as followings (see figure 3.14);

- Main building consists of Nurse Triage, OPD, and support facility such as X-ray and lab
- IPD ward, separated between men and women ward with nurse station on call 24 hours
- Service compound consists of administration office, main kitchen, MEP, and staff lounge

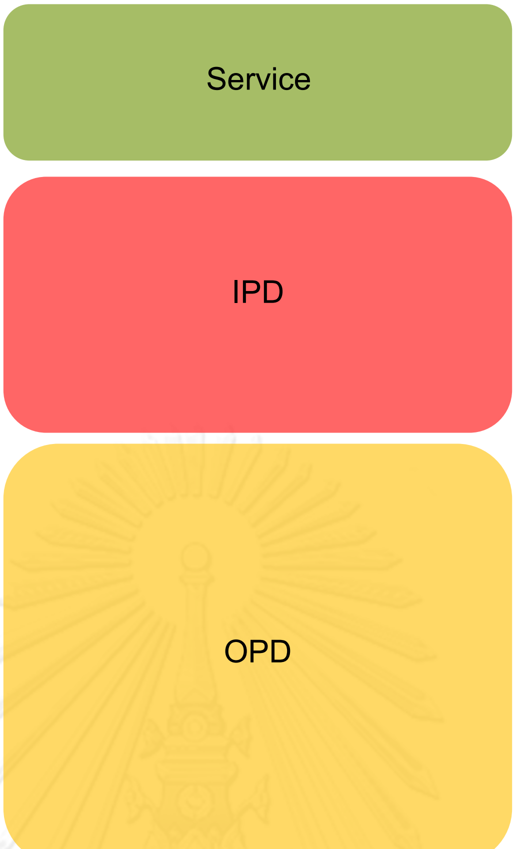


Figure 3.14 Zoning diagram

3.3.3.2.3 Circulation of Different Types of User

In TB healthcare facility planning, controlling access point and minimizing the travel distance are crucial and certainly dictate the layout of function. These affect and challenge both administrative and environmental control system since patient is the most important variable of disease carrier. In this design, the travel distance is shortened and controlled in a closed loop with administration control. IPD patients must remain isolated within the facility during the course of their treatment and undiagnosed new patients must be separated from the out-patients returning for exams or the direct observe treatment (D.O.T) (see figure 3.15).

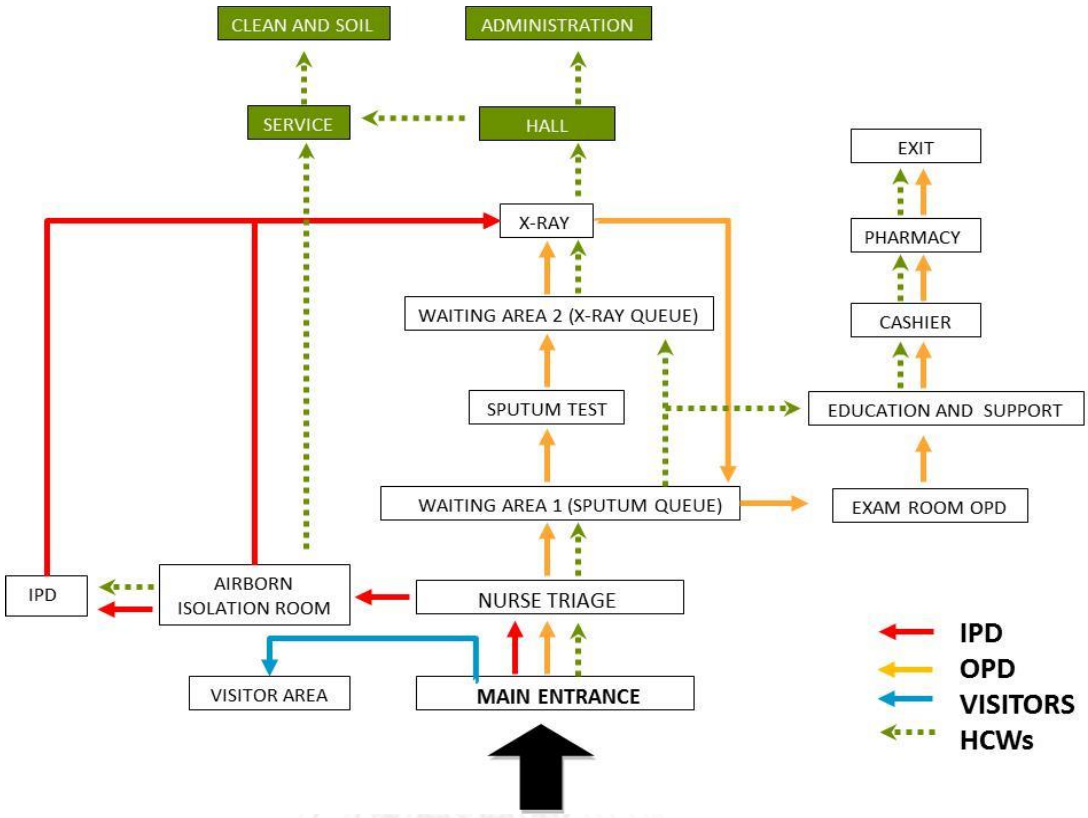


Figure 3.15 circulation chart

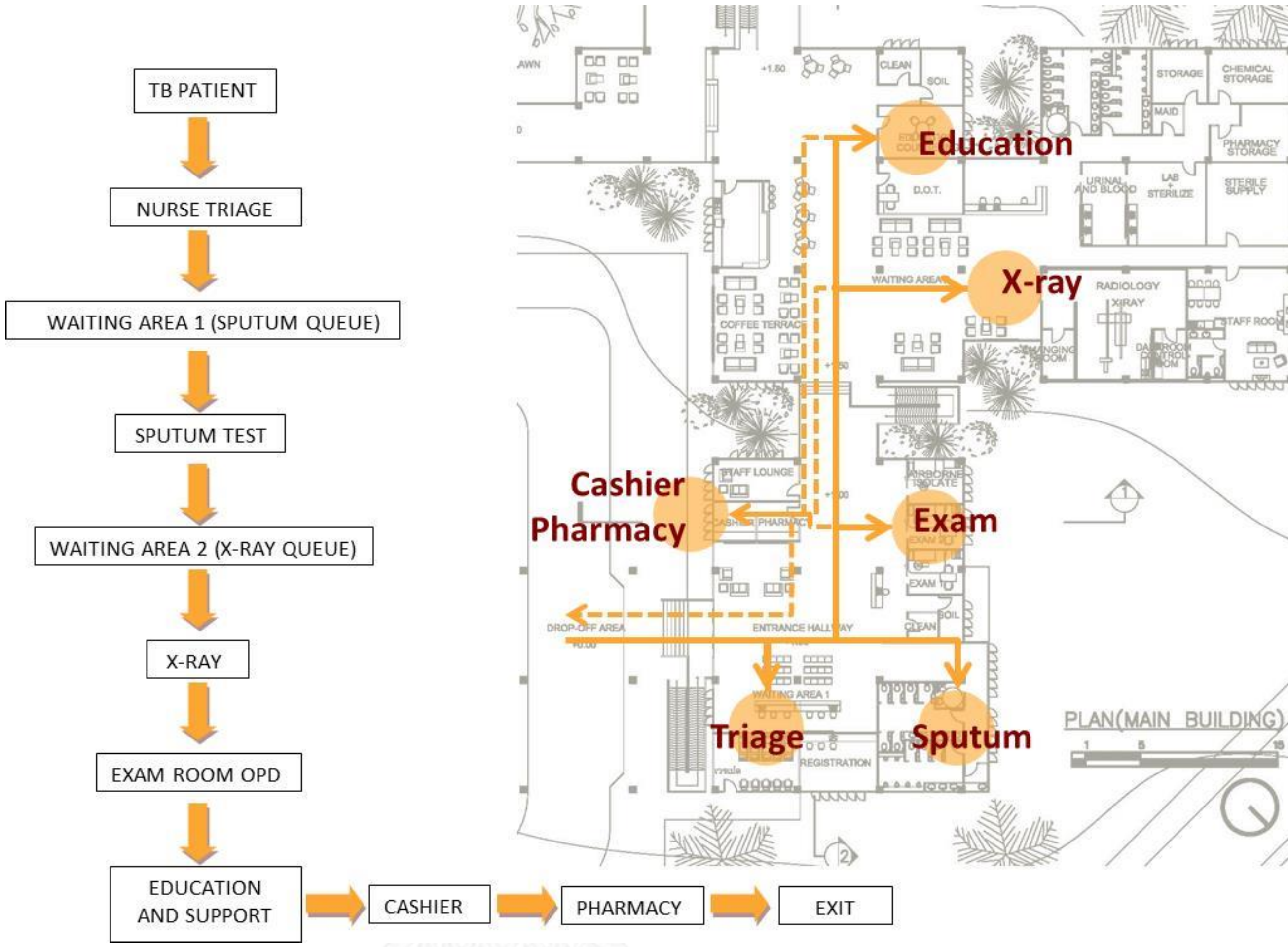


Figure 3.16 Patient flow of main building (OPD)

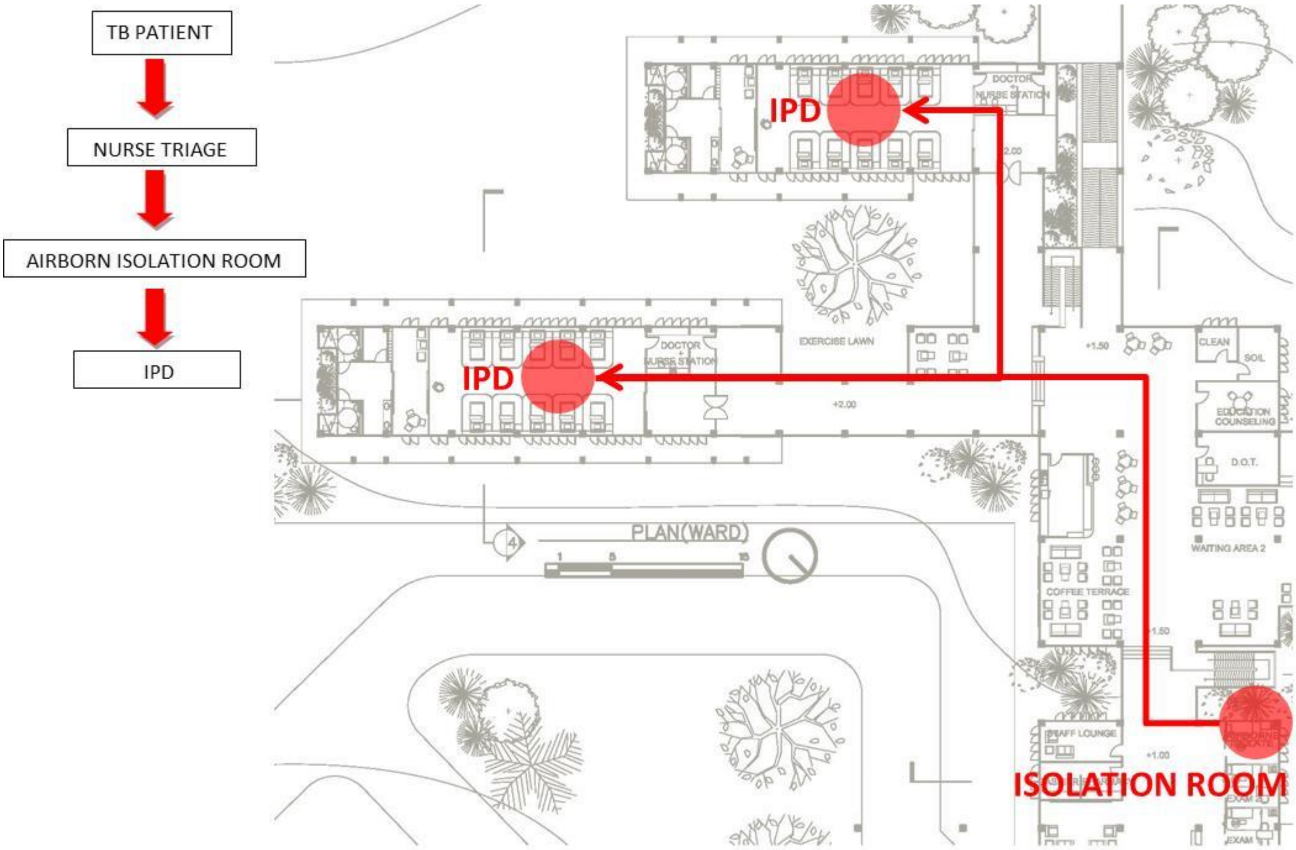


Figure 3.17 Patient Flow of IPD Ward

CHAPTER IV
RESULT

4.1 Architectural Design

Spaciousness within a site, reducing the risk of airborne infection is the primary goal in the design. For a facility comprising mainly In-Patient Department (IPD), exam room (OPD), and airborne precaution room, adopting an ideal massing for building in achieving the best natural ventilation. A hybrid single load corridor and room are oriented perpendicularly to the prevailing wind direction. Spreading mass of building creates a pocket of green area which allows cross ventilation throughout the area and provides a healing atmosphere for TB patients to sit outside when buildings are not compacted.

Open waiting area on the main level takes airflow across the building, and operable window door openings and fin of the façade design capture prevailing breezes to diffuse and exhaust the contaminated air out. Materials and details were selected to blend in with the nature. The mood and tone of the materials convey a positive atmosphere, designed fin façade provide interplays of shadow, light, and trees are planted and weaved onto the faced which producing a communal spaces semi outdoor.

Figure 4.1 Layout Plan

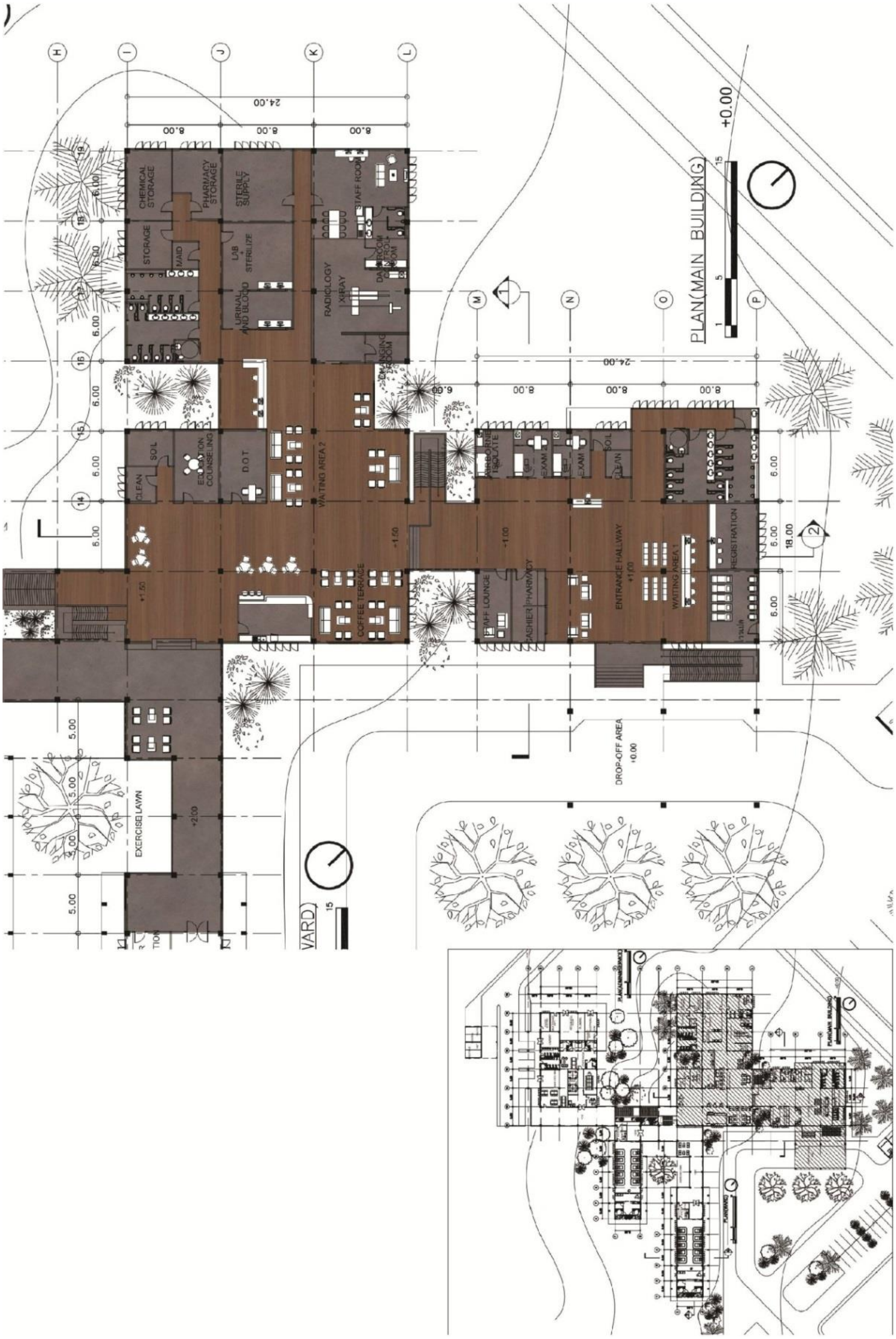


Figure 4.2 Main Building Plan

Figure 4.3 Waiting area 1 in OPD

Figure 4.4 Waiting area 2 in OPD

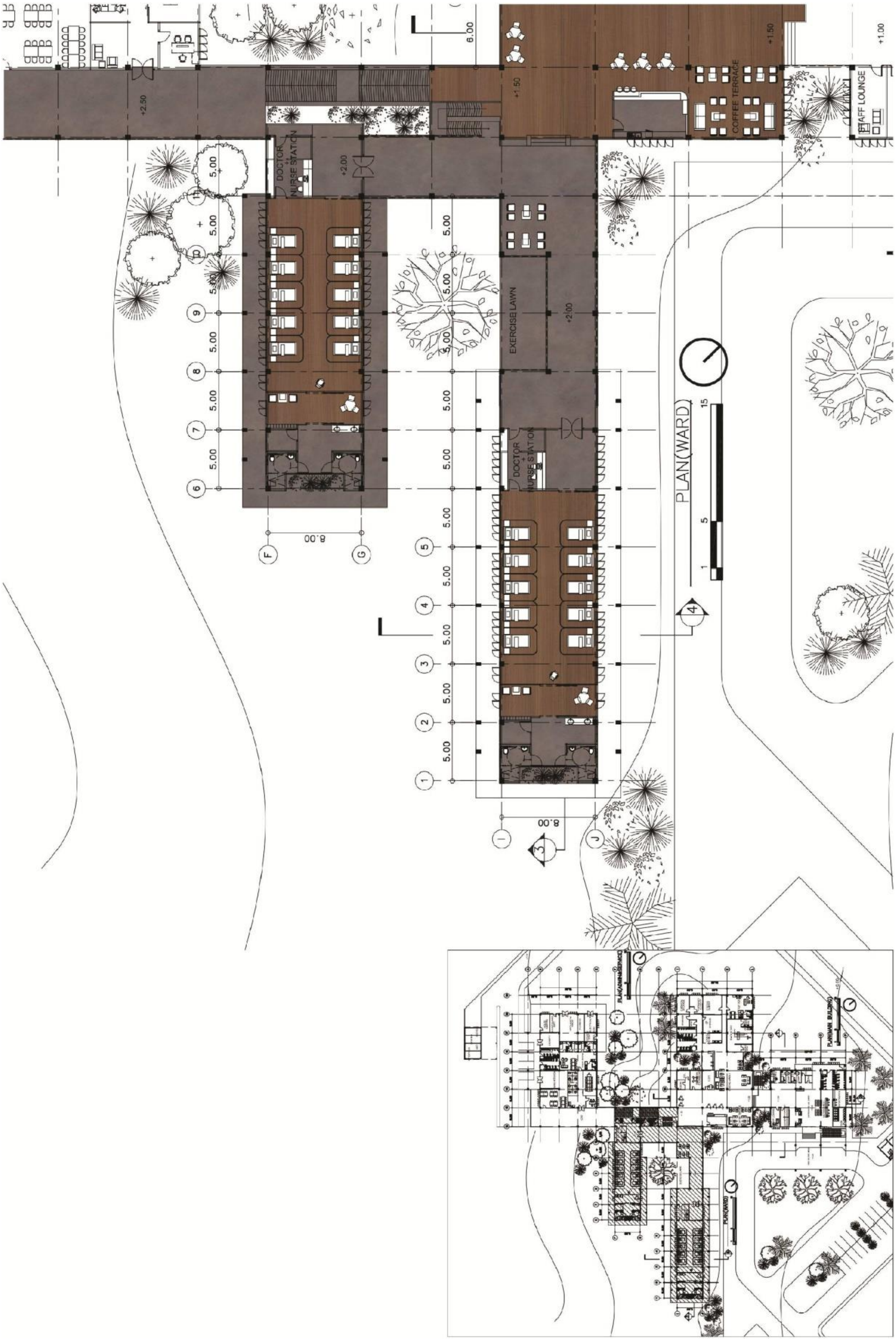


Figure 4.5 IPD Ward Plan

Figure 4.6 Courtyard between IPD

Figure 4.7 IPD Interior perspective

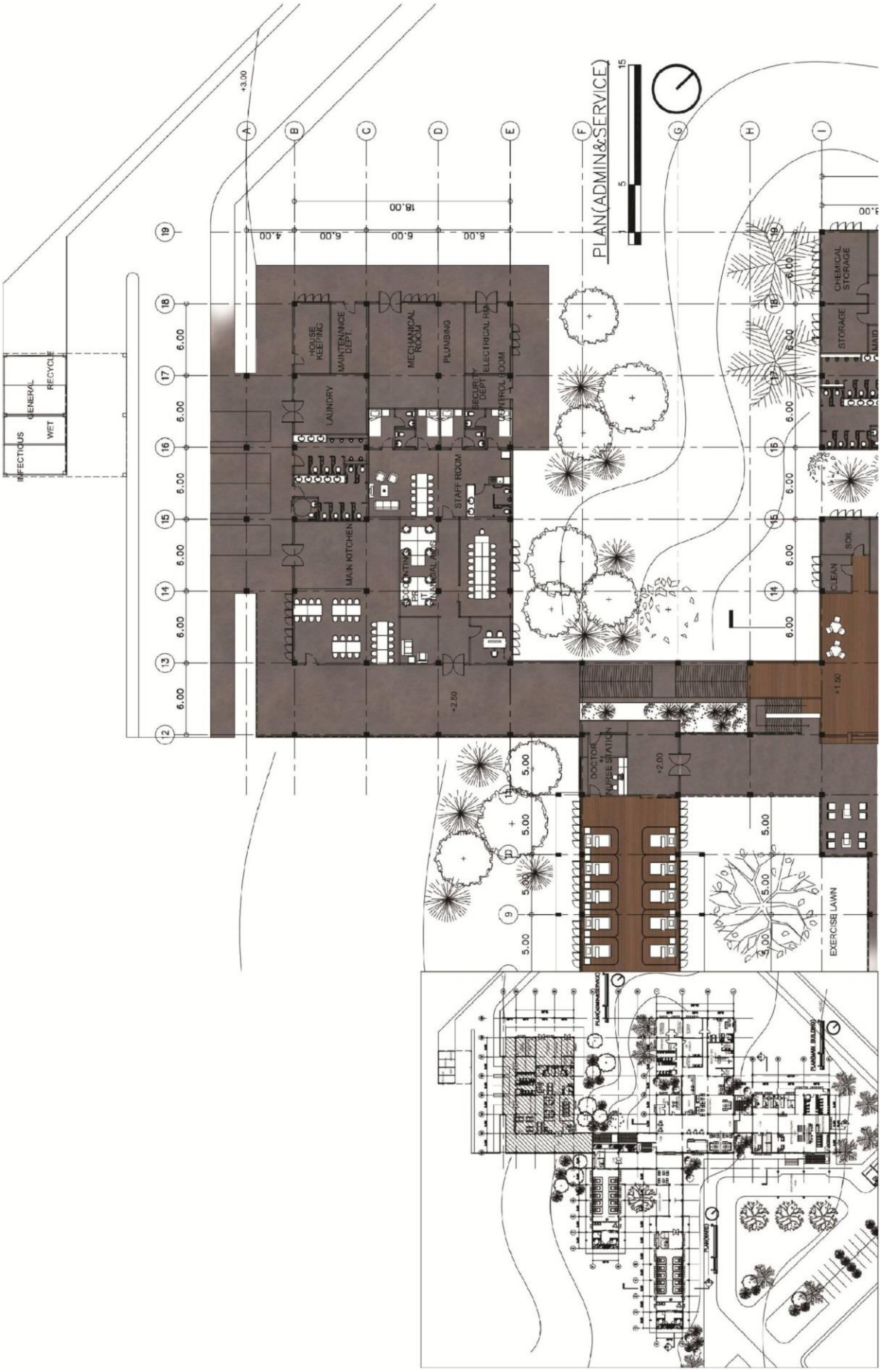


Figure 4.8 Administrative and Service Plan

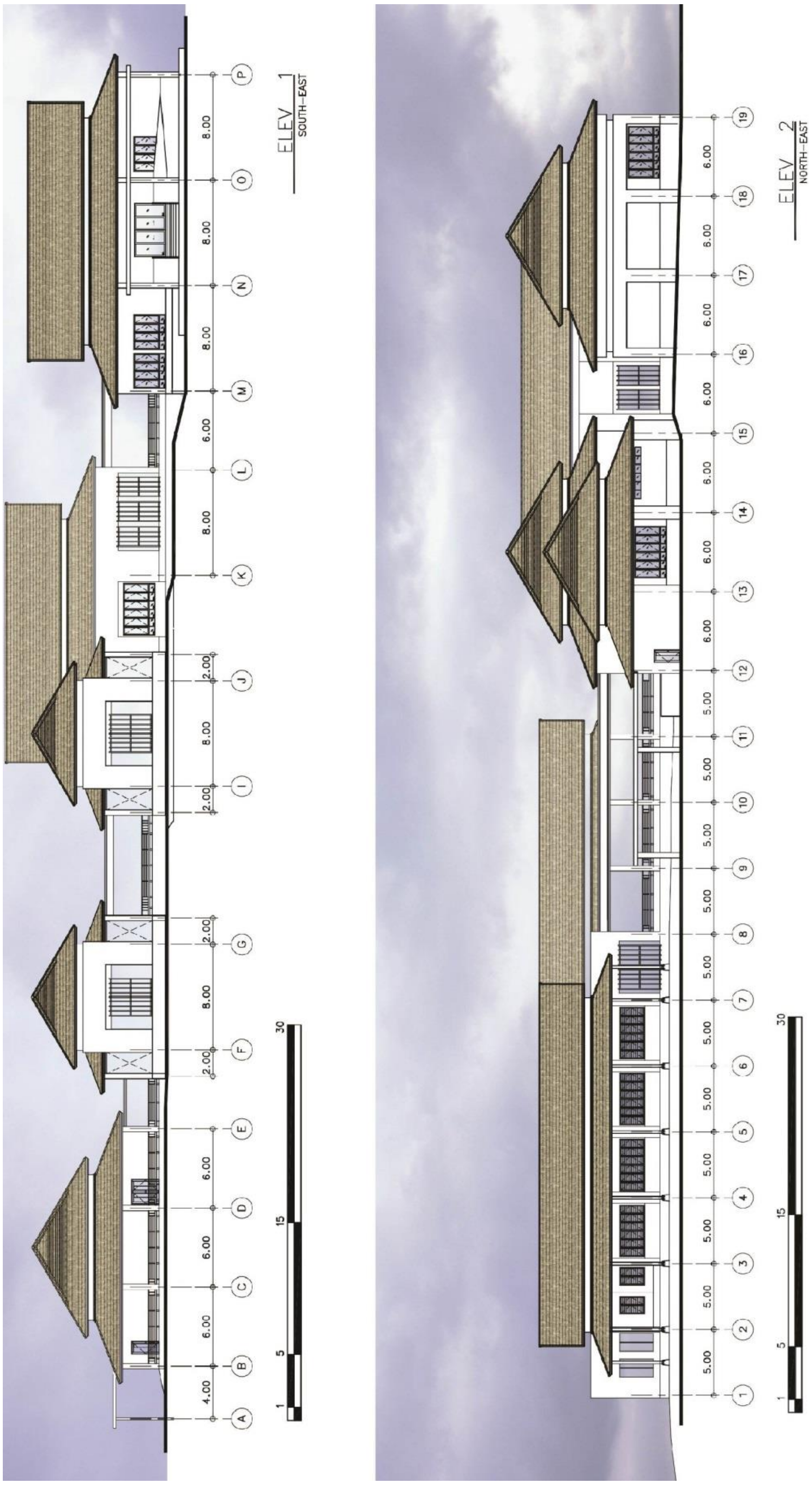


Figure 4.9 South East Elevation and North East Elevation

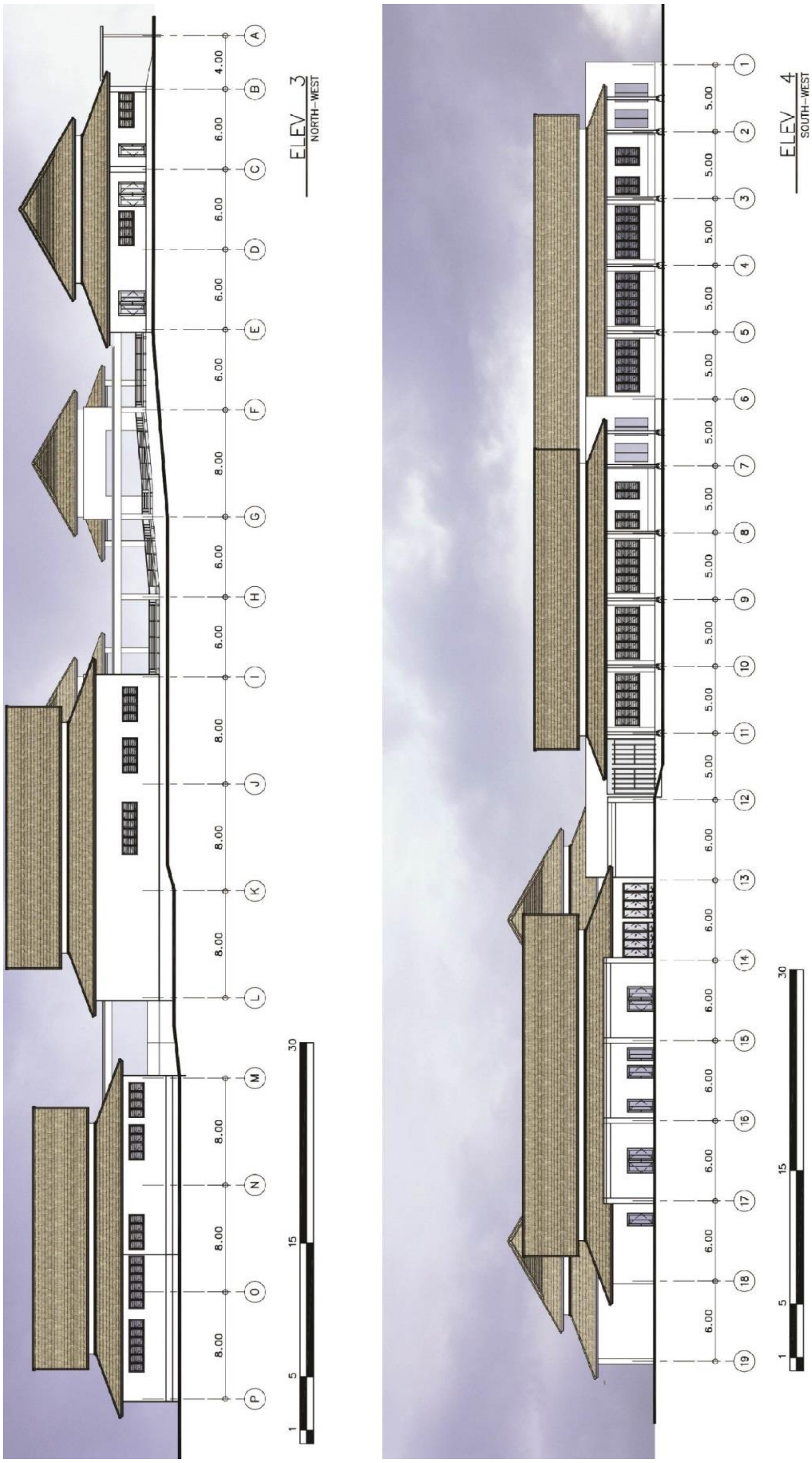


Figure 4.10 North West Elevation and South West Elevation

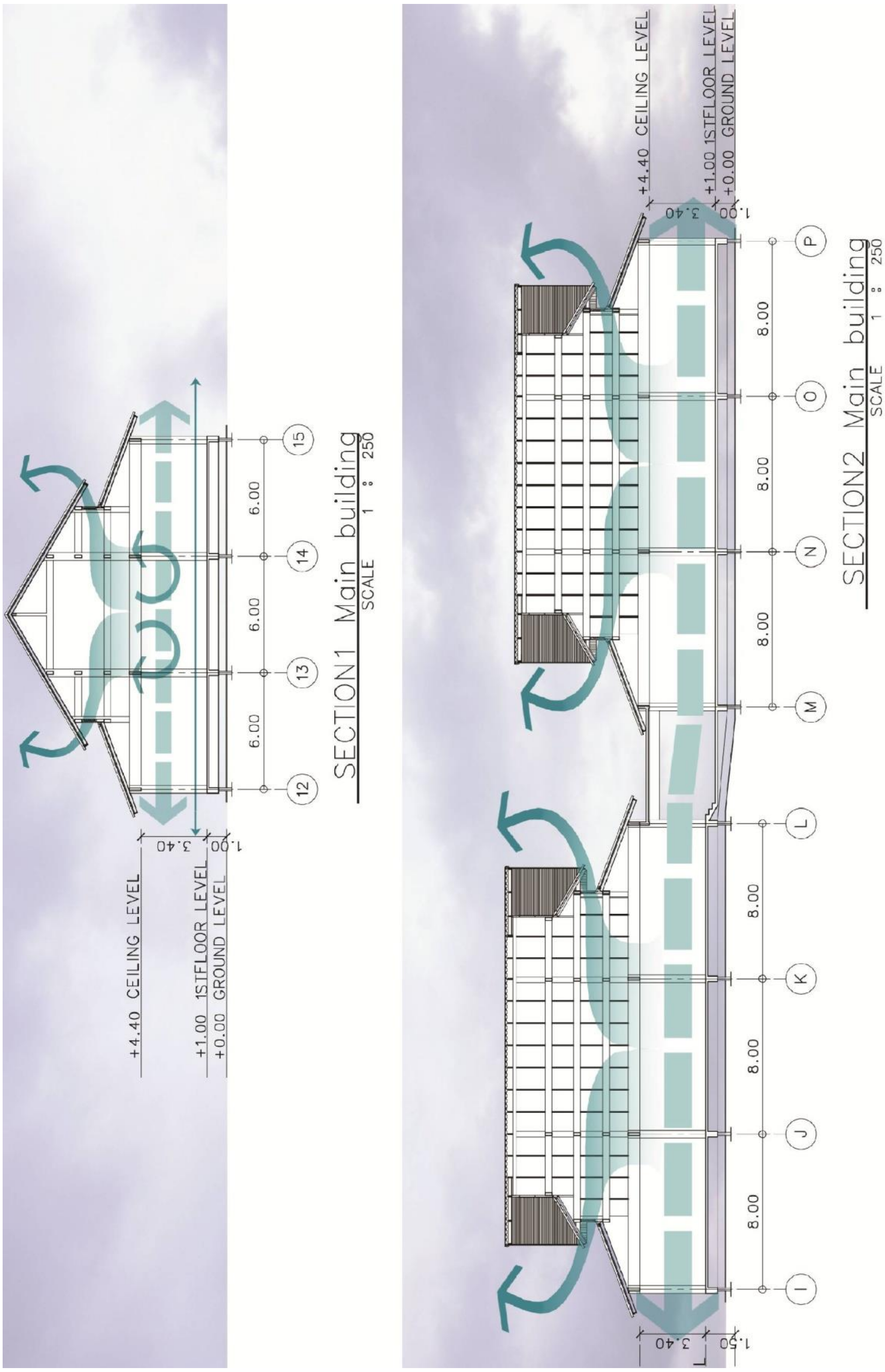


Figure 4.11 Section of Main Building

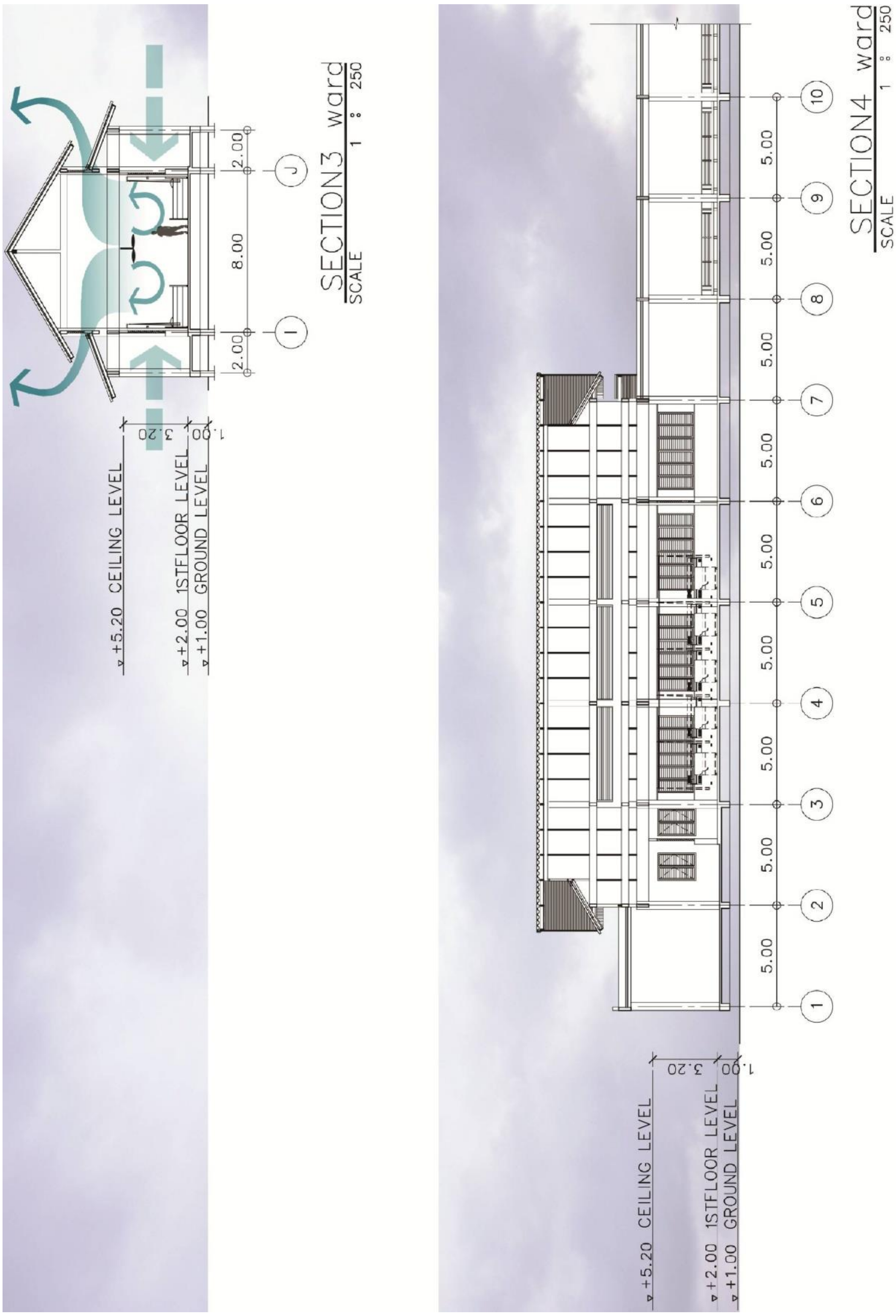


Figure 4.12 Section of IPD Ward

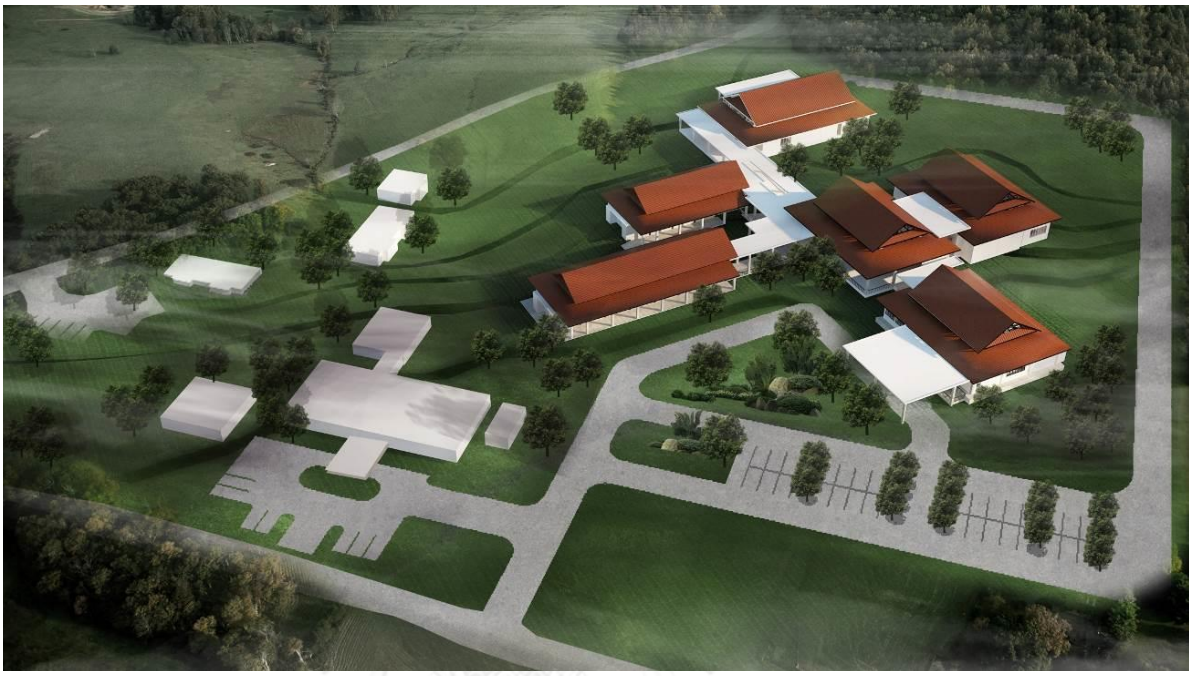


Figure 4.13 Overview Perspective

Figure 4.14 Perspective view Main Entrance Approach

Figure 4.15 Perspective of Drop-off area

4.2 Ventilation Design

The design of planning is influenced by the wind direction. The study of prevailing wind from the Northeastern and the local wind from the South dictate the design in order to maximize the use of natural ventilation. The main building is orientated perpendicularly to the wind. Another important aspect is the position of the occupants such as the seating position of doctor and TB infected patients. The doctor and patient should sit opposite from each other and the seating position is located along the wind direction to prevent the cross infection from the patient to HCWs (see figure 3.18 - 3.20).

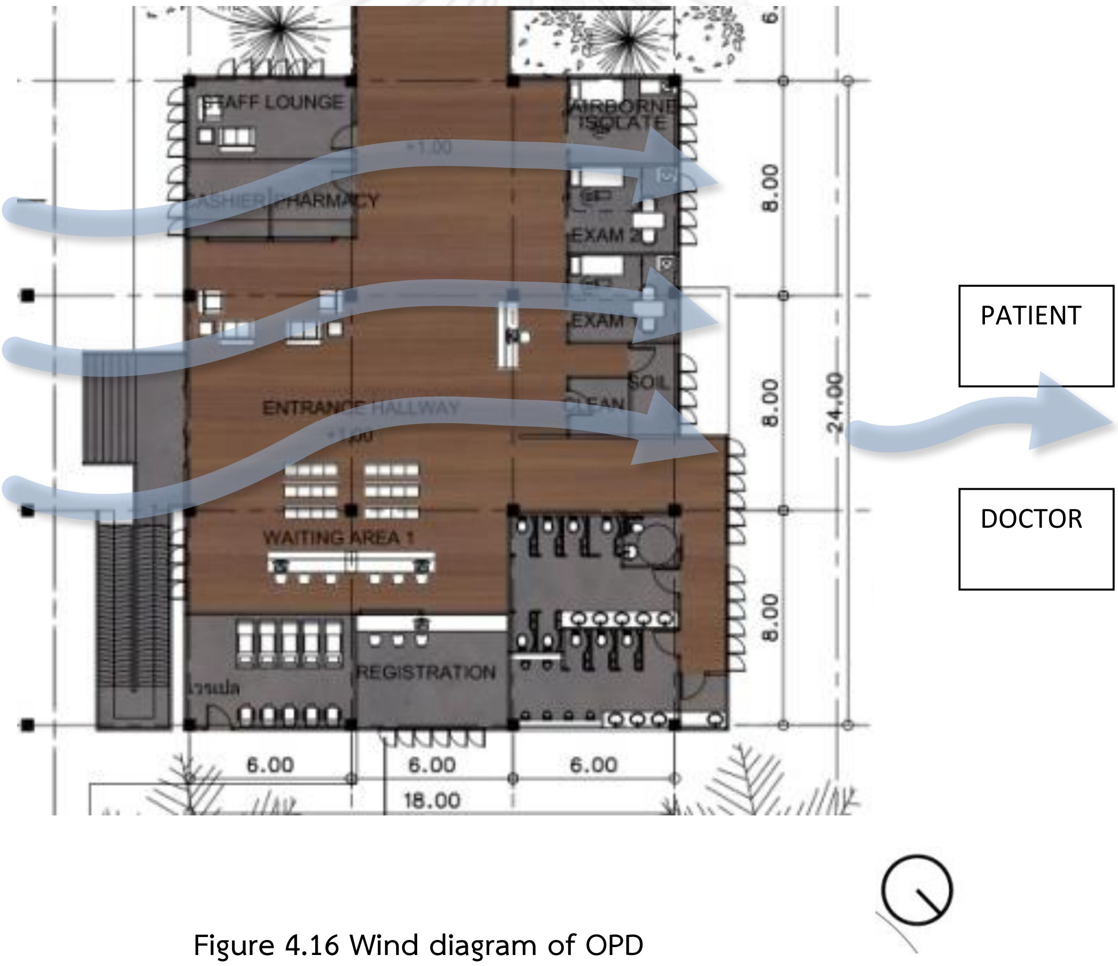


Figure 4.16 Wind diagram of OPD

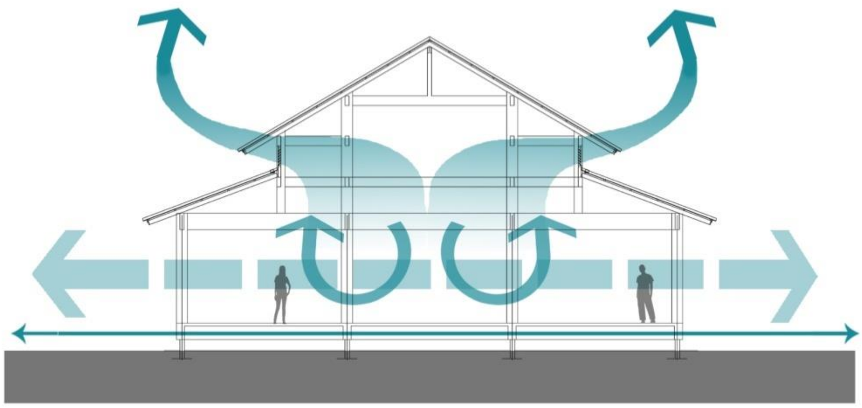


Figure 4.16 Wind diagram shows in cross section of OPD hallway

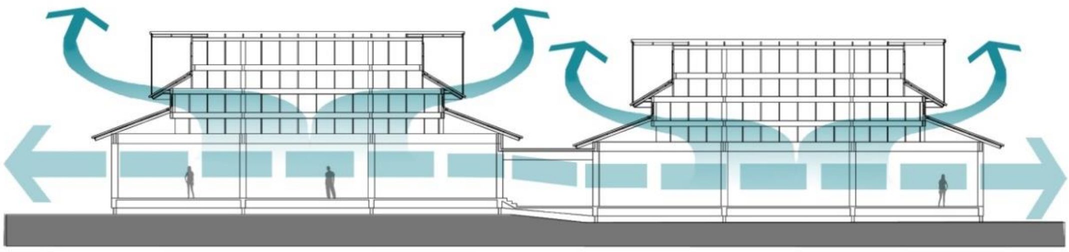


Figure 4.17 Wind diagram shows in cross section of OPD hallway and the support facility

In addition, another focus area is the IPD ward compound. This is the area where bacteria are found the most. Thus, the airflow needs to regulate enough to diffuse and flush away the micro organisms. The double load corridors on an open plan with operable windows allow air to flow throughout the entire space without any interruption. As well as the implementation of stack ventilation effect moves the heat up and provide cooling sensation throughout the space. Thus, air change rate is higher (see figure 3.21 – 3.23).

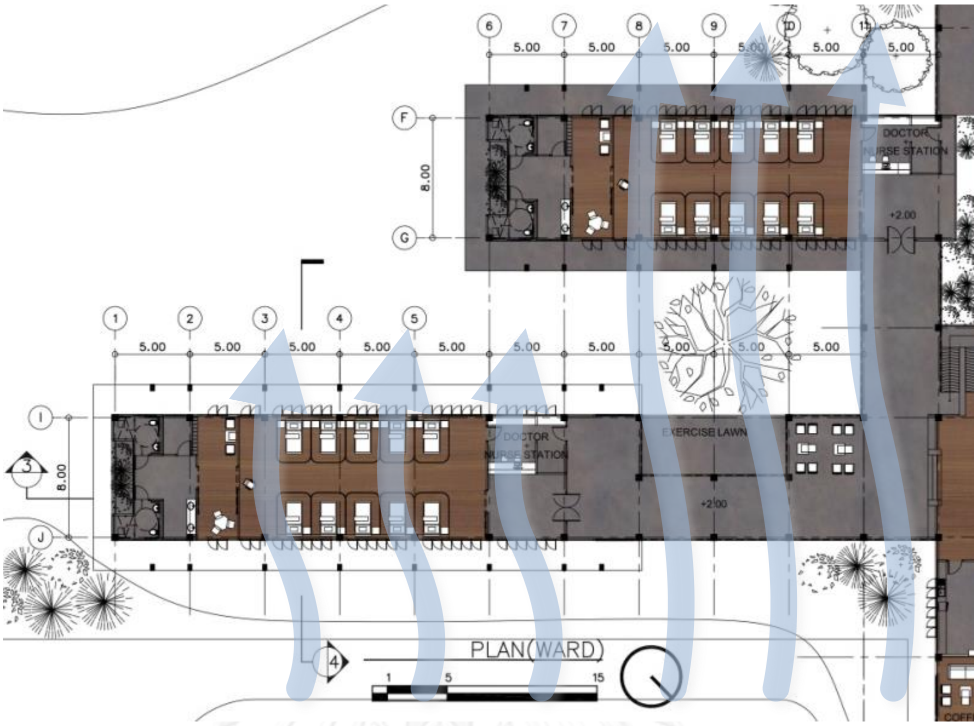


Figure 4.18 Wind diagram of IPD

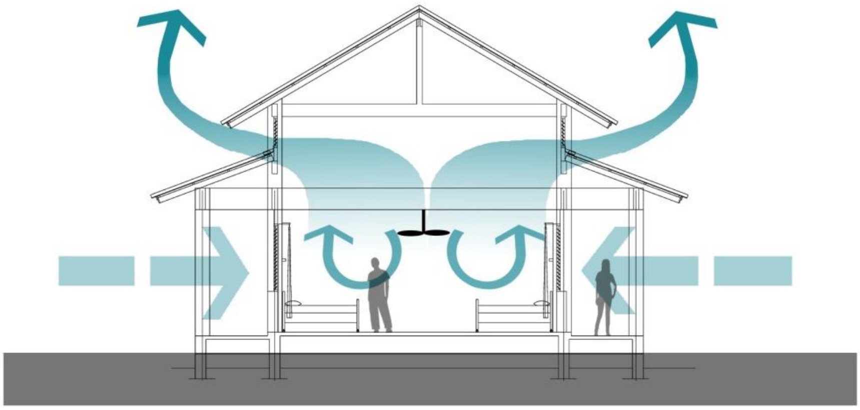


Figure 4.19 Wind diagram of IPD section

1 Figure 4.20 Wind diagram of IPD section

4.3 Specific Area Design

4.3.1 Exam room

Good air in, contaminated air out. The good wind always blows from the healthy person to sick person.

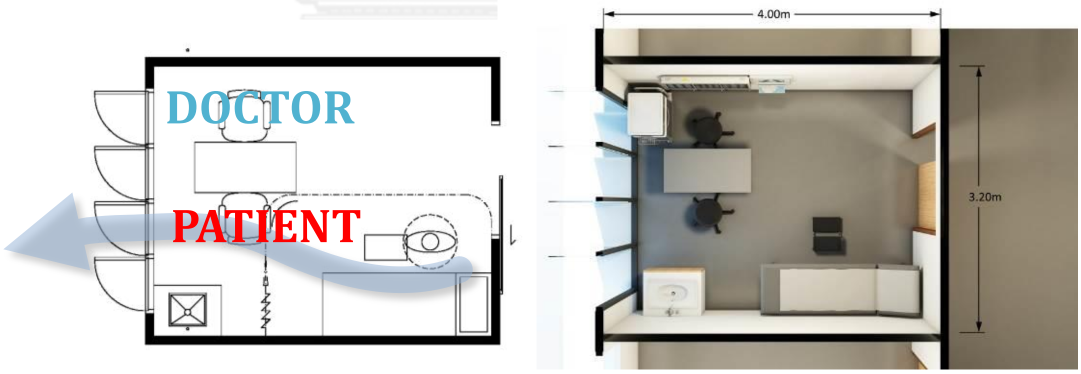


Figure 4.21 Exam Room Plan

Figure 4.22 Exam Room Perspective

4.3.2 Sputum room

Openings located next to each other will drive the good airflow to bring the contaminated air out.

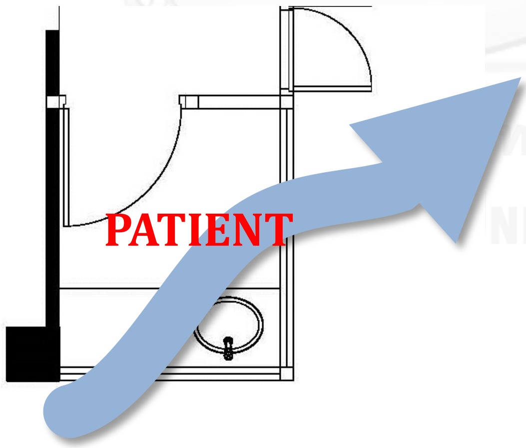


Figure 4.23 Sputum room plan

Figure 4.24 Sputum room perspective

4.3.3 In-Patient room

The mixed use of cross ventilation and stack ventilation will drive the fresh airflow in and pull the hot airflow out.

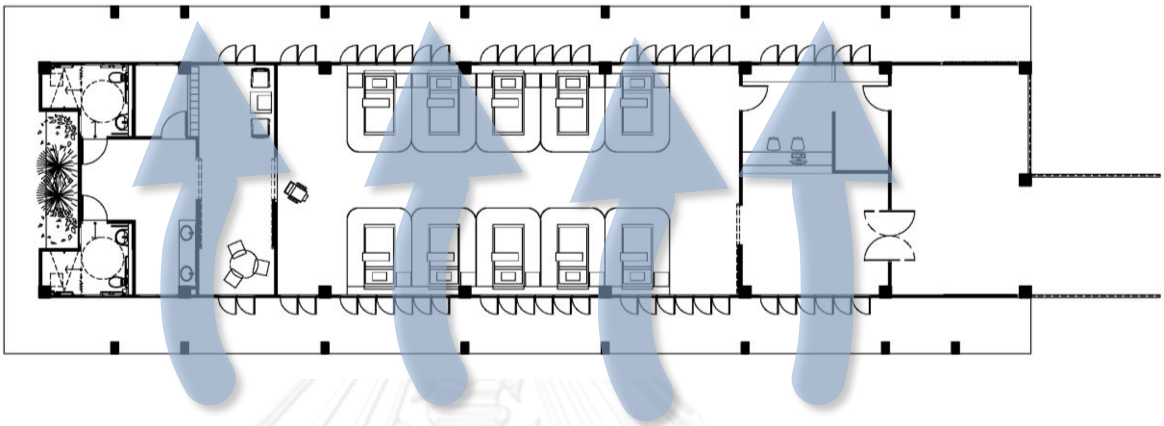


Figure 4.25 IPD plan

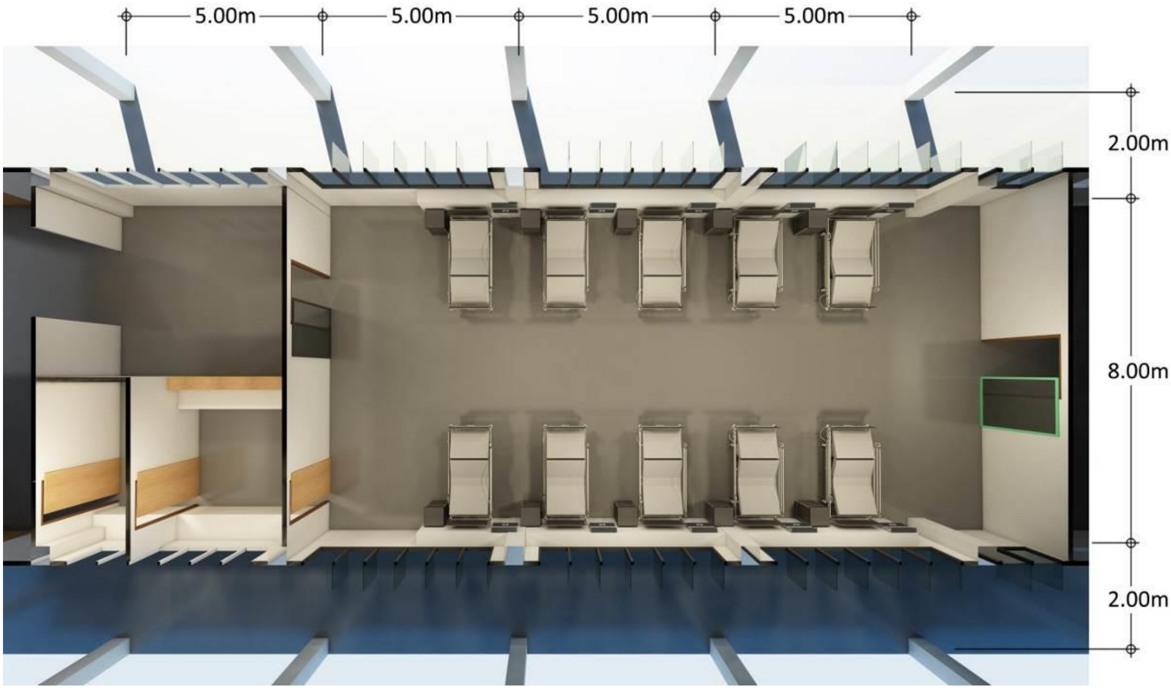


Figure 4.26 IPD plan in perspective

4.4 Conclusion

Table 4.1 Area of openings

Type of Opening	Size		QTY.	Opening Area (Sq.m)
	Width	Length	Set	Sq.m
Main Building (OPD zone)				
1. Window	0.6	1.8	48	51.84
2. Main Entrance	2.4	4	1	9.60
3. Wall louver opening	5.6	2.4	2	9.60
4. Wall louver opening	5.6	2.4	2	26.88
5. Ceiling louver opening	0.7	7	2	9.80
6. Roof louver opening	-	-	2	15.30
Total				107.72
Building Area				490.00
%				22%

Main Building (Support Zone)				
1. Window	0.6	1.8	54	58.32
2. Wall louver opening	5.6	2.4	8	107.52

3. Ceiling louver opening	0.7	7	2	9.80
4. Roof louver opening	-	-	2	15.30
Total				190.94
Building area				940.00
%				20%
IPD Section				
1. Window	0.6	1.8	56	60.48
2. Ceiling louver opening	0.7	4.6	6	19.32
3. Roof louver opening	-	-	2	7.34
Total				87.14
Building area				200.00
%				44%

The TB hospital design in this study utilizes the concept of having openings and maximizing ventilation rate through the followings:

1. Orientation to optimize wind exposure for building occupants
2. Development of appropriate opening size and location
3. Spread of function creates wind gap and courtyard
4. Use of designed façade to provide ventilation and to create a sense of privacy for the patient

According to the standard ventilation in hospital guideline, hospital is a building type that is required high maintenance in order to decrease the infection that is dwell in the building. Due to the high risk of infection that is being generated daily, it is crucial that hospital do concern on the standard guideline of infection especially the disease that can be transmitted via airborne such as Tuberculosis. CDC (Center of Disease Control and Prevention) and WHO (World Health Organization) seek to provide infection guideline with natural ventilation. Environmental control method is one of them, stated that in order to achieve the efficient infection control, the intake air exchange rate from the outside must be higher than the area of room per hour. And the indoor ventilation rate must be higher that the area of room per hour (ASHRAE, 2003). In Thailand, the standard guideline for indoor air quality has not been established yet. However, in กฎหระทรวงฉบับที่ 33 (พ.ศ. 2535) section 2 number 9 states that natural ventilation can only be used in the area that has exterior wall at least on one side with openings such as doors, windows, and window louver. The opening should not be less than 10% of the total area. Thus, the opening area of main focuses area exceeded the requirement (see table 4.1).

CHAPTER IV
CONCLUSION AND SUGGESTION

The objective of this thesis is to design a TB hospital for limited resources area in Thailand and focuses the use of natural ventilation and planning of departments and functions that related to TB healthcare setting only. And to analyze hospital design planning by conducting a pilot study of 3 TB healthcare centers in Bangkok, Thailand. To find problem in relation to the environmental control and administrative control, in order to implement it in the design and finding of design solution. In order to understand the issues of current status quo of healthcare design, past literatures on the topic and pilot study of TB clinics were reviewed. To identify areas in the setting with an increased risk for HCWs associated of TB transmission and target for TB infection control. To provide proper implementation of the TB infection control by reducing contact opportunities through a circulation path of TB infected, non-TB patients, and HCWs.

Studies on the functions planning and natural ventilation were the main point of the review. CDC, WHO guideline in addition to the Laws and Regulations concerning the well-being and convenience of the patients were implemented into the design. Understanding and identifying the issues within the healthcare design by presenting it from an architect's point of view so the outcome of this design can be utilized as a prototype of TB healthcare design in resource limited setting.

5.2 Suggested Design Criteria for TB healthcare in limited setting

5.2.1 Building Orientation

A. Linear grouping of building. It is the best type to achieve high cross ventilation. However, it takes up too much space and not cost effective (see figure 5.6).

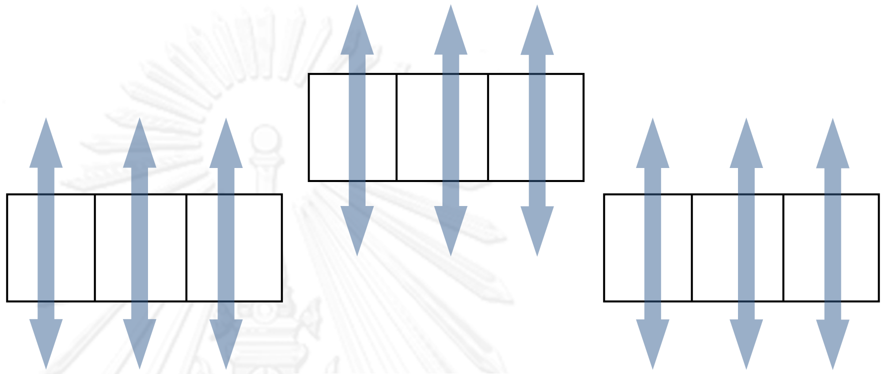


Figure 5.1 Illustration of linear grouping of building

B. Overlapping of building. This type is less expensive. However, it will increase the risk of TB infection to spread from one area to another area (see figure 5.7).

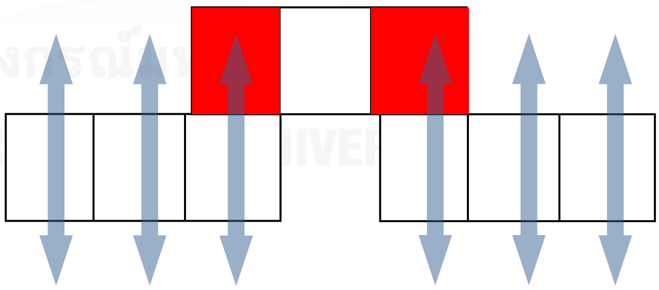


Figure 5.2 Illustration of overlapping of building

C. Scattering of building. It creates a pocket green area for a buffer zone. Each building is connected by walkway. Orientating the building towards the prevailing wind will achieve best ventilation and reduce cross infection (see figure 5.8).

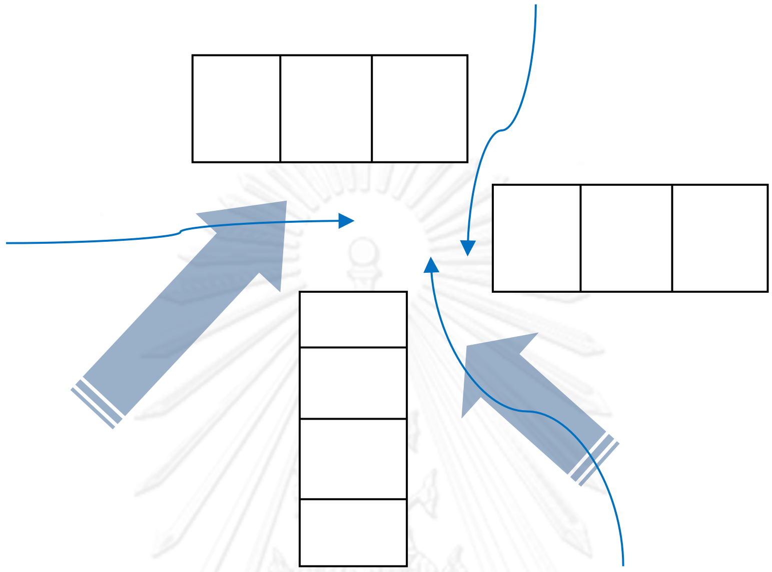


Figure 5.3 Illustration of the scattering of building

5.2.2 Finding Best Type of Zoning

A. All zoning is being grouped next to each other without any separation, thus there is no buffer zone (see figure 5.4).

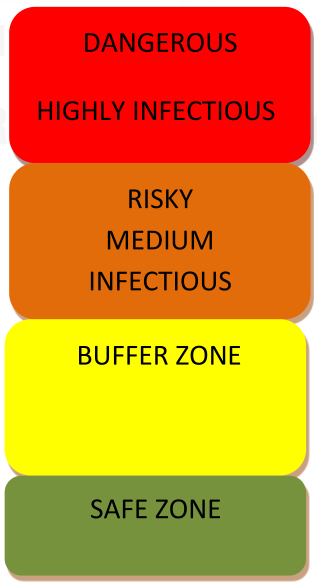


Figure 5.4 Illustration of stack zoning

B. Each zoning is being scattered in order to achieve the ventilation and creates an opened buffer zone for the bacteria to diffuse in between them (see figure 5.5).

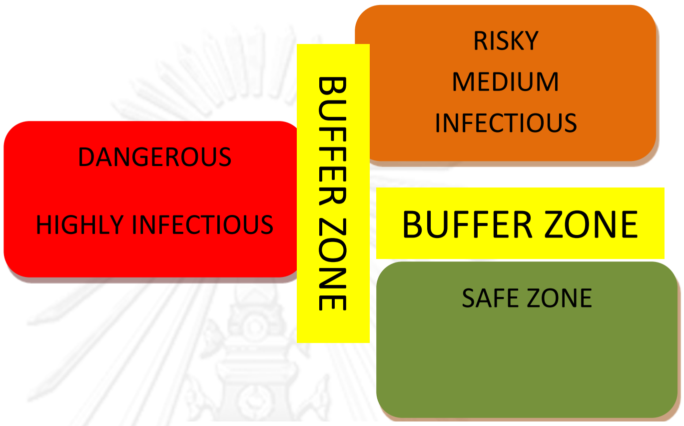


Figure 5.5 Illustration of scattered zoning

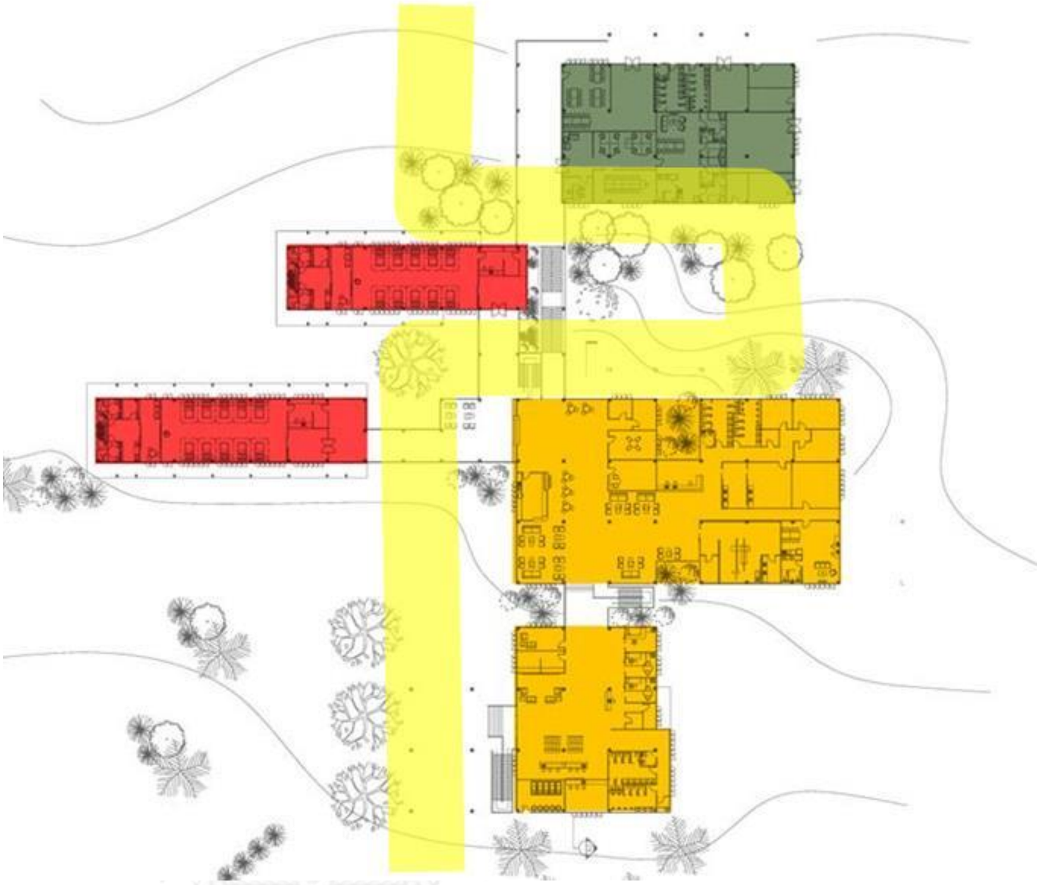


Figure 5.6 Illustration of scattered zoning

5.2.3 Circulation arrangement

A. Double load corridor with separated soil clean corridor. This is the typical type of hospital corridor. However, this type does not suit with the design of resource limited setting hospital since it would cost more to build. It also promotes the cross infection (see figure 5.1).

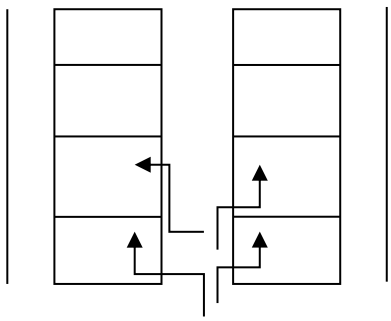


Figure 5.7 Illustration of double load corridor

B. Single load corridor is best type of corridor to promote the cross infection. However, the downside of it is that it takes up a lot of space and it creates longer travel distance for the patient (see figure 5.2).

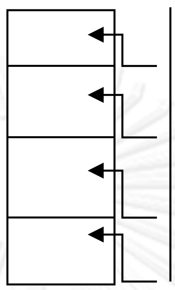


Figure 5.8 Illustration of single load corridor

C. The hybrid type of double load and single load corridor, combined with the administrative control to set boundary for patient travel distance is the best fit for designing TB hospital in resource limited setting (see figure 5.3).

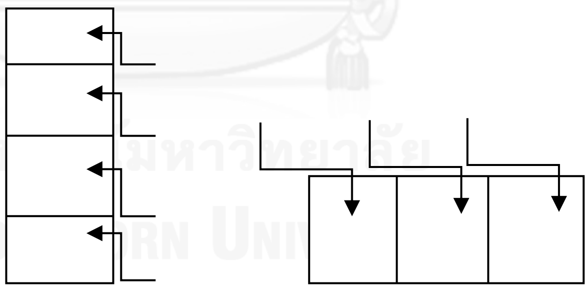


Figure 5.9 Illustration of hybrid type corridor

5.3 Recommendations

This study focuses on the transmission of airborne infection in healthcare setting. The study will focus on the prime contamination area such as the Out-patient

Department (OPD) and In-patient Ward (IPD) in hospital which excluded the other supporting facility such as dormitories. The objective of this study is to design Tuberculosis hospital in a resource limited setting context of Nakorn Ratchasima by implementing design experimentation with a variety of ventilation methods that could solve the problem of cross infection and minimize the airborne infection. This study focuses on the design and implementation of natural ventilation which is applicable for the utilization in resource limited healthcare setting, even though the financial analysis is not included in the study.

Due to a limited frame, the design does not include the ventilation performance through simulation tool. However, it is accurately referred to the published design guidelines and basic natural ventilation methods. The design does not accommodate other factor such as energy usage. Due to this special type of hospital, the design is a small scale resource limited setting with specific program of TB hospital. This design can be used as a prototype of TB healthcare setting. As a potential enhancement and future research direction to extend the work in this thesis, the study design can be applied for simulation with the program such as Computational Fluid Dynamics (CFD) to test for a better result as well as further study on the acceptable thermal comfort to provide the improvement of the TB hospital design.

REFERENCES

Baussano, I., Nunn,P., Williams,B., Pivette,E., Bugian M., and Scano F. . (2011). Tuberculosis among health care workers. *Emerging Infectious Diseases 17*(March), 488-494.

Beggs, C. B., Noakes, C.J., Sleigh, P.A., Fletcher, L.A., and Siddiqi, K. (2003). The transmission of tuberculosis in confined spaces: an analytical review of alternative epidemiological models. *International Journal Tuberculosis and Lung Disease November*(7), 1015-1026.

Boonyakiat., J. (2003). *A Model-Based Approach to Ventilation Control in Buildings.* (PA), Carnegie Mellon University, Pittsburgh.

Brown, G. Z., and Dekay, M. (2011). *Sun, wind, and light: architectural design strategies*: John Wiley & Sons.

Campbell, M. (2005). What tuberculosis did for modernism: the influence of a curative environment on modernist design and architecture. *Medical History, 49*, 463-488.

CDC. (2003). *Guidelines for environmental infection control in health care facilities*. Centers for Disease Control and Prevention.

Corrigan, P. W., and Penn D.L. (1999). Lessons from social psychology on discrediting psychiatric stigma. *American Psychologist, 54*, 765-776.

Do, A. N., et al. . (1999). Increased risk of Mycobacterium tuberculosis infection related to the occupational exposures of health care workers in Chiang Rai,Thailand. *International Journal Tuberculosis and Lung Disease, 3*, 377-381.

Egan, D. M. (1975). *Concept in Thermal Comfort*: Prentice Hall.

Escombe, A. R., et al. . (2007, February 27). Natural ventilation for the prevention of airborne contagion. PLoS Medicine. from http://www.plosmedicine.org/article/info:doi/10.1371/journal.pmed.0040068

Gibbs, J. W., and Wilson, E.B. . (2012). Vector Analysis: A Textbook for the use of Students of Mathematics & Physics: Founded Upon the Lectures of J.W. Gibbs. *Ulan Press*.

Givoni, B. (1994). Passive low energy cooling of buildings. *John Wiley & Sons*.

Givoni, B. (1998). Climate Considerations in Building and Urban Design. *John Wiley & Sons, 1998*.

Granich, R., Binkin, N.J., Jarvis, W.R., and Simone, P.M. (1999). Guidelines for the prevention of tuberculosis in health care facilities in resource-limited settings. *WHO/CDS/*(TB99), 269.

Handbook, A. (2005). *American Society of Heating, Refrigerating and Air Conditioning* (GA Ed.). Atlanta: Engineers, Inc.

In Sokhanya, S. S., and Jiraporn Chompikul. . (2008). TB preventive behavior of patients consulting at the general out-patient department at Paholpolpayuhasana hospital, Kanchanaburi province. *Journal of Public Health and Development, 6*, 59-67.

Jensen, P. A., Lambert, lL.A., Lademarco, M.F., and Ridzon. R. . (2005). Guidelines for preventing the transmission of Mycobacterium tuberculosis in health settings. *CDC Morbidity Mortality Weekly Report* (54), 1-141.

Jittimanee., S. (2012). Reality Check:Tuberculosis control in Thailand from http://www.tbonline.info/posts/2012/11/29/reality-check-tuberculosis-control-thailand/

Joshi, R., Reingold, A.L., Menzies, D., and Pai, M. . (2008). Tuberculosis among health-care workers in low and middle income countries: A systematic review. *PLoS Medicine, 26*(December).

Kittisak Sawanyawisuth, N. C., Kanlayanee Sawanyawisuth, Panita Limpawattana, Janpen Bourpoern, and Wipa Reechaipichitkul. (2012). Can job titles be predictors for recent onset latent tuberculosis in health care workers? *Asian Biomedicine, 6*(August), 535-539.

Koenigsberger, O. H. (2001). Effects of roof shapes on wind-induced air motion inside buildings. from http://www.scholarbank.nus.edu.sg/bitstream/handle/10635/13922/

Koenigsberger, O. H., Ingersoll, T., Mayhew, A., and Szokolay, S. (1973). Manual of Tropical Housing and Building. *Climatic Design. London*.

Melaragno, M. G. (1982). Wind in Architectural and Environmental Design. *New York*.

Moore, F. (1992). Environmental control system. *Heating, Cooling, Lighting.* .

Nightingale, F. (2013). Notes on nursing., from http://www.digital.library.upenn.edu/women/nightingale/nursing/nursing.html

Pipat Luksamijarulkul, C. S., Preecha Loosereewanich, and Pornapa Aiumlaor. (2004). Risk assessment towards Tuberculosis among hospital personnel administrative. control, risk exposure, use of protective barriers and microbial air quality. *Southeast Asian Journal Tropical Medicine Public Health 35*(December), 1005-1011.

Saucier, W. J. (2003.). Principles of Meteorological Analysis. *Courier Dover Publications*.

Sengupta, S., et al. (2006). Social impact of tuberculosis in southern Thailand: views from patients, care providers and the community. *International Journal Tuberculosis and Lung Disease 10*, 1008-1012.

WHO. (2007). *Infection prevention and control of epidemic and pandemic-prone acute respiratory diseases in health care: WHO Interim Guidelines*. Geneva.

WHO. (2012). Global Tuberculosis Report. . Geneva: World Health Organization.

Wind. (2012). (October).

Wiroj Jamjarasrangsi, S. B., Anan Chongthaleong, Ariya Chaiindamporn, Nibondh Udomsantisuk,and Wichit Euasamarnjit. (2009). Inadequate ventilation for nosocomial Tuberculosis prevention in public hospitals in Central Thailand. *International Journal Tuberculosis and Lung Disease 13*(April), 454-459.

Wiroj Jiamjarasrangsi, N. H., and Pirom Kamolratanakul. . (2005). Tuberculosis among health care workers at King Chulalongkorn Memorial Hospital. *9*(March), 1253-1258. .

Wiroj Jiamjarasrangsi, S. U., and Wisaruth Srisintorn. (2006). Nosocomial Tuberculosis Risk Assessment and Management Recommendation for an Emergency Department in a University Hospital. *Journal Medical Association of Thailand, 89* (October), 1733-1741.

Wongsaheam, M. (1999). *Protection of tuberculosis infection in health care worker. In: Pichayanon.* Chulalongkorn University, Bangkok.

Yanai, H., Limpakarnjanarat, K., Uthaivoravit, W., Mastro, T.D., Mori, T., and Tappero, J.W. (2003). Risk of Mycobacterium tuberculosis infection and disease among health care workers, Chiang Rai, Thailand. *International Journal Tuberculosis and Lung Disease Jan*(7), 36-45.

VITA

Name: Chatsuda Phuapradit

Date of Birth: July 10, 1987

High School: Mater Dei School,Bangkok, Montville Township,New Jersey

Undergraduate: Milwaukee Institute of Art and Design,Wisconsin (BFA-Interior Architecture and Design)

INTERNSHIPS: ARDEC Design Group,Bangkok, Aesthetic Design Group,Bangkok, Office of Bangkok Architect (OBA)

MEMBERSHIPS: American Institute of Architecture Students(AIAS), American Society of Interior Design(ASID), (2008-2009)

PUBLICATIONS

CONFERENCE PRESENTATION: Evaluation of Environmental Aspect of Infection Control Strategy in Healthcare Facility: Case Study from Three TB Clinics in Thailand (accepted for International Conference in Medicine and Public Health (ICMPH), Bangkok, June 24, 2013.