Natural Ventilation in Thai Hospitals: A Field Study

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Abstract

Natural ventilation has been appraised as the main strategy in environmental control of airborne infection in resource-limited healthcare facilities. While natural ventilation offers a low-cost alternative in diluting and removing contaminated air, its' performance in actual settings is not fully understood. This paper reports a cross-sectional field study of six hospitals in Thailand with an emphasis on ventilation performance of naturally-ventilated hospital wards and AII rooms. The results showed that ventilation rates of 3-26 ACH could be achieved in hospital wards. Higher ventilation rates of 16-218 ACH were found in AII rooms. Our measurements also showed that a few locations within hospital wards had little or no air movement due to existing hospital ward designs. This study concludes that natural ventilation is suitable for resource-limited hospitals in tropical climates when windows are opened and exhaust fans are installed. Design guidelines that promote natural ventilation were discussed.

Keywords: Natural ventilation, Environmental control, Field study, Ventilation rate, Hospital design, Infection Control

Introduction

Nowadays, airborne infection of Tuberculosis (TB) is the cause of illness and death in many countries around the world. Although the prevalence and death rates have been falling in the past several years, the number of new TB cases is still rising slowly especially in the Southeast Asia region. Inpatients and health-care workers (HCWs) are at particularly high risk of infection with TB because of frequent exposure to patients with infectious TB disease. To minimize TB infection, the World Health Organization (WHO) and the U.S. Centers for Disease Control and Prevention (CDC) has proposed guideline for infection control through three-level hierarchy of control including administrative control, environmental control and personal respiratory protection. Natural ventilation is one of the strategies in environmental control of airborne infections that should be maximized in resource-limited health-care facilities [1-6].

Natural ventilation uses natural forces, i.e. pressure and thermal difference to drive air through buildings. While natural ventilation may offer a low-cost alternative in diluting and removing contaminated air when compare with mechanical ventilation, the pattern of air movement, however, is unreliable and hard to predict.

Previous researches have tried to understand the pattern of air movement in hospitals. Currently, there are many studies that examined various aspects related to the design and performance of ventilation system in health-care facilities through simulation [7-12]. The results from these simulation studies, however, had not taken into account of additional factors that may be found in actual settings such as the effect of opening windows and doors, the use of mechanical fans, and the impact from building occupants' behavior that could influence the pattern of ventilation. Thus far, there are only a limited number of studies that evaluate ventilation performance of actual naturally-ventilated hospitals. For example, Qian et al [6] showed that high ventilation rate could be achieved in naturally-ventilated isolation room in Hong Kong and installation of exhaust fan could create enough negative pressure when the natural forces are not sufficiently strong. Escombe et al. [13] found that opening windows and doors provided median ventilation of 28 ACH from eight hospitals in Lima, Peru. Both of the above-mentioned studies used a tracer gas concentration decay technique in determining air exchange rate. Recently, World Health Organization (WHO) published a comprehensive guideline for natural ventilation implementation [3]. Examples of naturally-ventilated health-care facilities were briefly described. Results from literature review showed that existing design guideline describes general hospital designs criteria that foster natural ventilation strategy. However, ventilation performance during normal operational condition had not been documented.

In summary, ventilation performance in actual hospital has not been examined thoroughly. If designers better understood factors that affect ventilation performance in actual settings, then it would be possible to design better naturally-ventilated hospital that can effectively control airborne infection.

The research described in this paper is a part of a larger study on enhancing occupational health surveillance in Thai Hospital. This research was funded by the Global Fund (Round 8) for fighting AIDS, Tuberculosis and Malaria and Thailand-US Centers for Disease Control and Prevention. The objectives of this study are to gain more understanding on current environmental control procedure in Thailand and to evaluate the effectiveness of using natural ventilation for airborne infection control. The ultimate goal is to develop a simple method for evaluating ventilation performance and to provide practical recommendations that promote the use of natural ventilation in resource-limited hospitals.

Methods

Settings

To achieve the research's objectives, we conducted a three-day visit to six hospitals in various part of Thailand during November 2009 – March 2010. The case study hospitals were selected based on two preliminary criteria. First, the hospital must have a substantial number of TB cases per year in the area. Second, as a part of the Global Fund project, hospitals in different part of Thailand were selected as a representative for each region of Thailand.

Case study hospitals in this paper were constructed between 1980s-1990s. For each hospital, ventilation related data were collected from outpatient department, general hospital ward, ICU ward, airborne infection isolation room (AII), TB/HIV Clinic, and emergency room. This paper only presents data from naturally-ventilated hospital wards and AII rooms were reported.

Building configurations

Room and window dimensional data were gathered from available construction drawings. In case that printed documents could not be located, room and window dimensional data were measured on-site. Flows of healthcare workers (HCWs) and TB patients through various spaces were documented based on observation and series of interview. These dimensional data were later used to create floor plans of targeted departments. Locations of TB patients in hospital ward and mechanical fans were marked on floor plans for functional analysis.

Ventilation measurement

In this assessment, simplified method for documenting ventilation performance in the field was developed. Air velocity data and airflow direction were measured at various spots in the targeted departments using a thermal anemometer (Velocicalc Model. 9535-A) and ventilation smoke tube kit (MSA Part No. 458481). These data were later used for the generation of preliminary air flow diagrams and analysis. This study also documented direction of airflow between the targeted and adjacent spaces and location of fresh air intake and exhaust.

Calculation of air change rate

The method for air change rate measurement was similar to method that was used in Aluclu and Dalgic's study [14] where the air velocity data were measured and averaged from three to six spots at the center of the opening.

In order to calculate air change rate, WHO [2] suggested that, as an approximation, the rate of air change per hour (ACH) for wind-driven natural ventilation through a room with two opposite openings, can be calculated as:

$$ACH = \frac{0.8 \times v_{air} \times a_{inlet} \times 3600}{volume} \quad \text{(Eq. 1)}$$

where

ACH = air change rate (measured as volume of room air change per hour)

v_{air} = average air velocity at inlet (m/s)

a_{inlet} = area of smaller inlet (m^2)

volume = volume of room (m^3)

Finally, calculated air change rates were compared with CDC guideline [4] for determination of ventilation performance.

Building Survey

The architectural and ventilation data were collected during normal building operation hours. Position and operational behavior of windows, doors, and mechanical fans in hospital wards were not adjusted. For AII rooms, however, we examined ventilation performance in an empty room in which windows and doors were opened and closed to measure the effect of openings on ventilation performance. Exhaust fans were switched under the closed window position. We spent approximate two hours at each location for data collection. Permission to take photograph of building occupants and to measure ventilation performance was granted prior to measurement session.

Data Analysis

Field study data were represented in two forms. First, for hospital wards, air velocity data, air flow direction and location of TB patient (if they were placed in the hospital ward) were mapped onto the building floor plan. Second, configurations and ventilation performance of hospital wards and AII rooms were tabulated for comparison and analysis.

Results and Discussion

Hospital wards: Building configurations and ventilation performance

Figure 1-9 shows building floor plan of nine inpatient wards from six case study hospitals. The data showed that these hospital wards share similar planning characteristics.

First, the majority of these wards were oriented on the cardinal axis where the shorter sides (elevator lobby & fire exit) of the ward faced east-west and the longer side (bed area) faced north-south direction. It was hypothesized that these wards were designed in response to local climate (i.e. to catch the local wind and to avoid direct solar penetration). Building occupants enter these hospital wards from the entrance door on the "shorter side" of the floor plan. The entrance doors were kept open most of the time and they would be closed during non-visiting hours.

Second, the windows and doors on the patient side of the wards typically consisted of six sets of jalousie window and a door per structural bay. Insect screen was installed at each window. Based on our interview, these doors were kept open at all time while the windows would be opened or closed by patients who reside next to them. Since the time of our field study was in the winter season of Thailand, a few of the windows were closed. Although, the assumption is that these windows are expected to be opened all year round since the weather in Thailand is hot and humid.

Third, the nurse stations and single-room (special) wards usually occupied one side of the ward except for ward E1 and E3 where the nurse stations were placed next to the entrance. It was found that inpatients' beds were typically arranged in rows of four to six on the opposite side of the nurse station. Based on the interview, TB patients who had been treated would be moved to and placed at the far corner of the main ward. The locations of TB patients within each are marked on Figure 1-9.

Finally, it was found that all nurse stations and single-room ward had air-conditioning system installed. Therefore, the windows and doors in these areas were kept close most of the time except for a few hours after sunset for energy conservation.

Results from the field study showed that ceiling fans and/or wall-type fans were installed in the main ward area. In a few hospitals, occupants were free to turn these fans on/off to maintain their comfort status. While most hospitals have ceiling type fan or wall-type fan installed, two of the hospital installed exhaust fan to increase ventilation rate within the ward. At inpatient ward of hospital C, the fans were place at the upper portion of internal window (see Figure 10). This exhaust fan was found to flush air from the ward out to the corridor on the back side of the ward. For hospital D (see Figure 11), the exhaust fans were installed at the upper portion of the jalousie windows to flush the air from the ward to outdoor air space. Additional fans were installed inside the ward to push air toward the building envelope.

Table 1 describes building configurations and ventilation performance of hospital wards. The data showed that the number of beds in hospital ward ranges between 28-47 beds per ward. All of these hospitals have floor-to-ceiling height of 3.0-3.5 m. The results showed that calculated air change ranges between 3.08-26.80 air-change per hour (ACH) were found in these wards. High ventilation rates (17.75 and 26.80 ACH) were found in hospital wards which had exhaust fans installed. Low ventilation rates which are lowered than the CDC recommended value were found in hospital wards in which the air inlets and outlets were small in size and not aligned.

Airborne infection isolation room: Building configuration and ventilation performance

Figure 12 shows typical floor plans of naturally-ventilated airborne infection isolation (AII) rooms that were found during the field study. Typical floor plan consisted of a single-bed or a double-bed room, each with its own toilet (see Figure 12). Table 2 describes building configuration and ventilation performance of airborne infection isolation rooms from 4 hospitals. Data showed that when all openings were fully open, the ventilation rates were between 65-218 ACH. When the door/windows on one side were closed and the exhaust fans were turned on, the measured ventilation rates ranged between 16-36 ACH which was higher than CDC recommended value of 12 ACH.

Effect of windows and doors

It was found that the design of most hospital wards in this study did not promote the use of natural ventilation strategy. Since these hospitals were built in the early 1980s, it was hypothesized that no air-conditioning systems were installed in the nurse station area at that time. In the past windows and doors of nurse station would be opened to maximize natural ventilation. Nowadays, air-conditioning systems were installed in these nurse stations which lead to the permanent closure of windows and doors in these areas. Since effective natural ventilation relies on opening of windows and doors on the opposite side of the space, it was found that the air-conditioned nurse stations blocked path of natural wind. In many hospital wards, there was no natural air inlet or outlet except for the entrance door.

In addition, field study data showed that windows on the patient side were controlled by the building occupants who reside next to those windows. Since the temperature at the perimeter zone fluctuate more than the interior zone, a few of these windows were found closed during the time of investigation. Furthermore, a few of these windows and doors were malfunctioned, i.e. they could not be closed nor opened. Together with the installed insect screen, path of natural ventilation were blocked for multiple reasons. This leads to a lower than expected air change rate in many of the hospital wards.

Effect of exhaust fan on ventilation performance

It was found that there were two hospital wards with exhaust fans. These hospital wards were found to achieve higher ventilation rate than hospitals without exhaust fan. The airflow direction, shown by smoke visualization, showed that when the exhaust fans were turned on, the air flow outward in a good fashion. However, since the wind direction changes all the time, ventilation rate could be lowered due to the natural wind that flow against the exhaust direction.

For inpatient ward of hospital D, the contaminated air was moved toward the back corridor which connects the main ward with isolation rooms and staff rooms. This configuration could present a great risk to the HCWs and patients who suffer from low-immune function in the isolation room.

This research suggests that since natural ventilation is unreliable and unpredictable, mechanical fan should be installed to increase air change rate. Furthermore, the location of exhaust fan/duct should be carefully design to maximize the potential of natural ventilation.

ACH vs. Air movement

Results from our study clearly demonstrate that high air change rate could be achieved via natural ventilation. However, while the ACH criterion had been satisfied, analysis of spot air velocity data showed a few locations within the hospital wards with little or no air movement (less than 0.3 m/s [15]). These areas were found at the corner of the ward and, sometime, in the middle of the ward. Data analysis showed that lay-out of the existing floor plan, the location of existing air inlets/outlets which were not aligned, and the installation of interior curtain/partitions may block or divert airflow within interior space.

Figure 13 showed Floor plan and airflow direction of airborne infection isolation (AII) ward at hospital F. Since the upper portion of the AII rooms in this ward were left opened (see Figure 14), this results in possibly contaminated air moving from the upstream ward to the downstream ward.

Therefore, it is suggested that while air change criterion is a compulsory measure that needs to be satisfied in infection control, additional attention should be given to spot measurement of air velocity as well as monitoring of air movement. Locations with no air movement should be avoided, especially for the placement of TB patient within the hospital wards.

Conclusion

This paper presented a field measurement study on the performance of natural ventilation in six hospitals in Thailand. Design guidelines that promote natural ventilation for airborne infection control were discussed. The results showed that ventilation rates of 3-26 ACH could be achieved in hospital wards. The highest ventilation rates were found in hospital wards which had exhaust fans installed. For the AII rooms, high ventilation rates were found for both opened and closed window position. Our measurements also showed that a few locations within hospital wards had little or no air movement due to existing hospital ward designs.

The results confirmed that high ventilation rate could be achieved via natural ventilation and it is suitable for resource-limited hospitals in tropical climates. However, due to its unpredictability, this research suggests that mechanical ventilation system should be installed to supplement the natural ventilation.

As a cross-sectional field study, however, data collected were representative of the assessment date only. Data may not necessary represent typical operational circumstance. In addition, due to the limitation of available equipments and the availability of study sites, this field study only inspected preliminary ventilation performance under actual settings. Further studies are needed to improve our holistic understanding of factors that affect ventilation performance in actual settings. In pursuing this research further, we plan to expand the study to examine ventilation performance during other months of the year. The effect of windows and doors would also be investigated.

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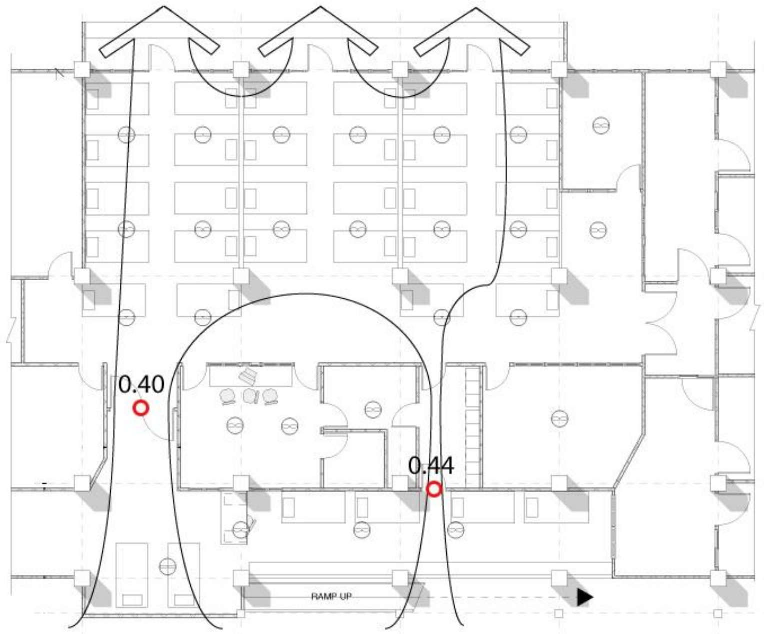

Fig. 1 Floor plan and ventilation data of hospital A inpatient ward

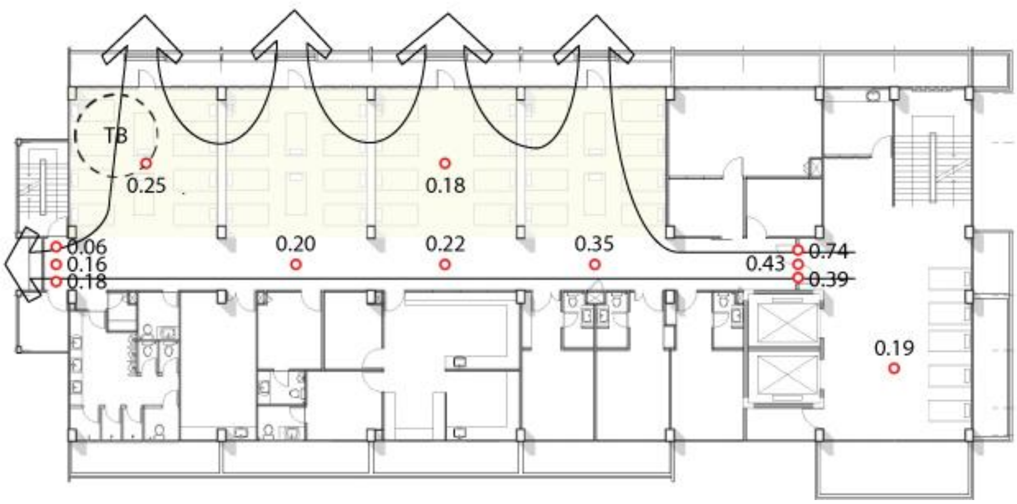

Fig. 2 Floor plan and ventilation data of hospital B inpatient ward

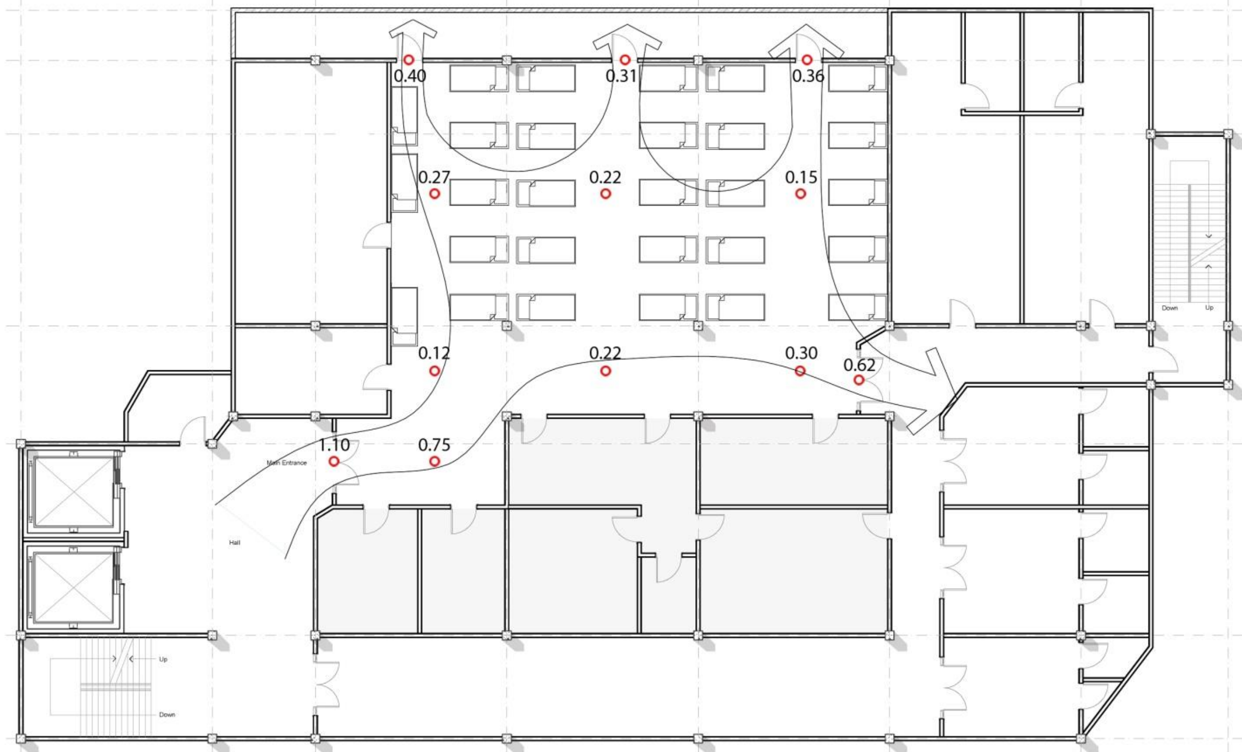

Fig. 3 Floor plan and ventilation data of hospital C inpatient ward

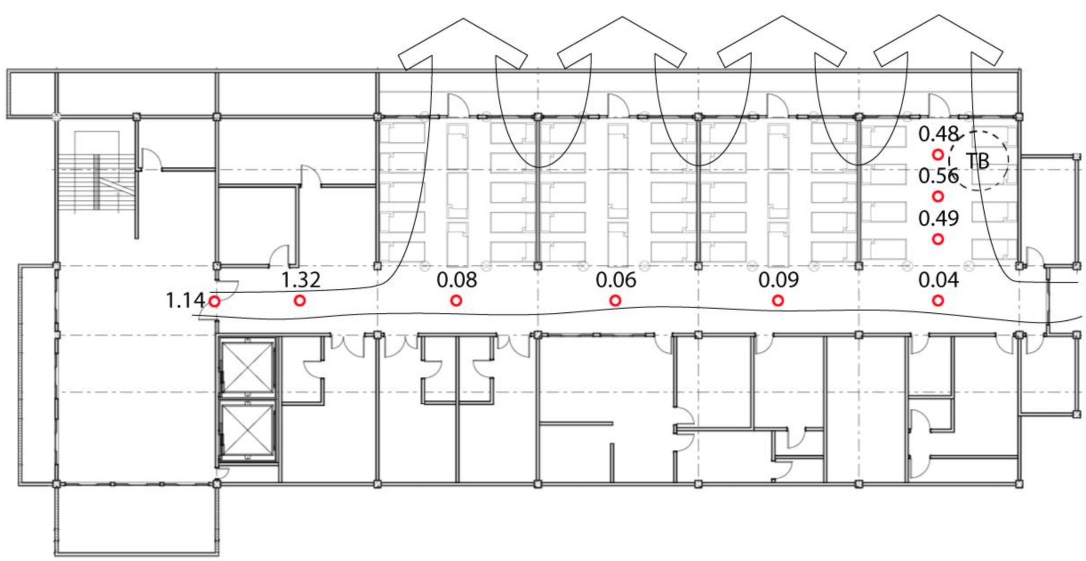

Fig. 4 Floor plan and ventilation data of hospital D inpatient ward

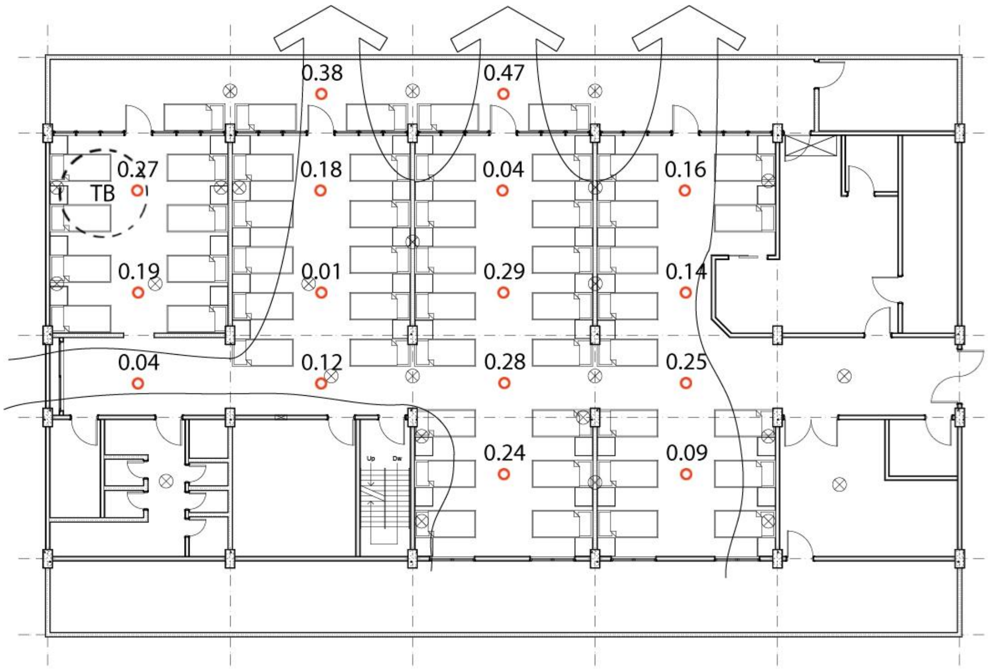

Fig. 5 Floor plan and ventilation data of hospital E inpatient ward#1

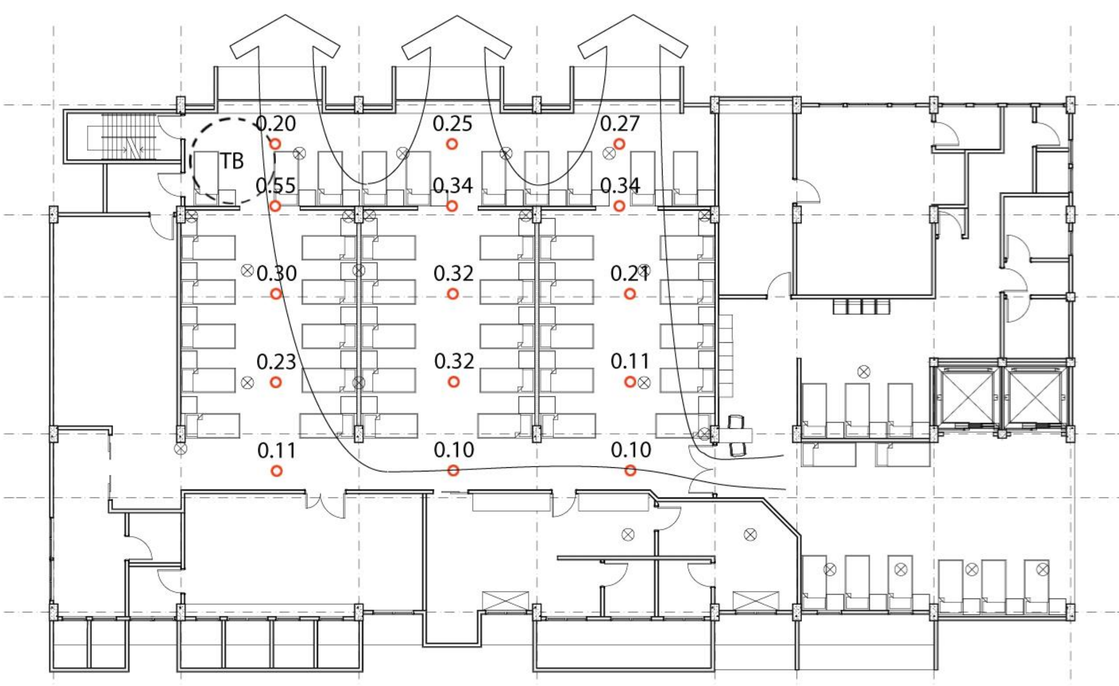

Fig. 6 Floor plan and ventilation data of hospital E inpatient ward#2

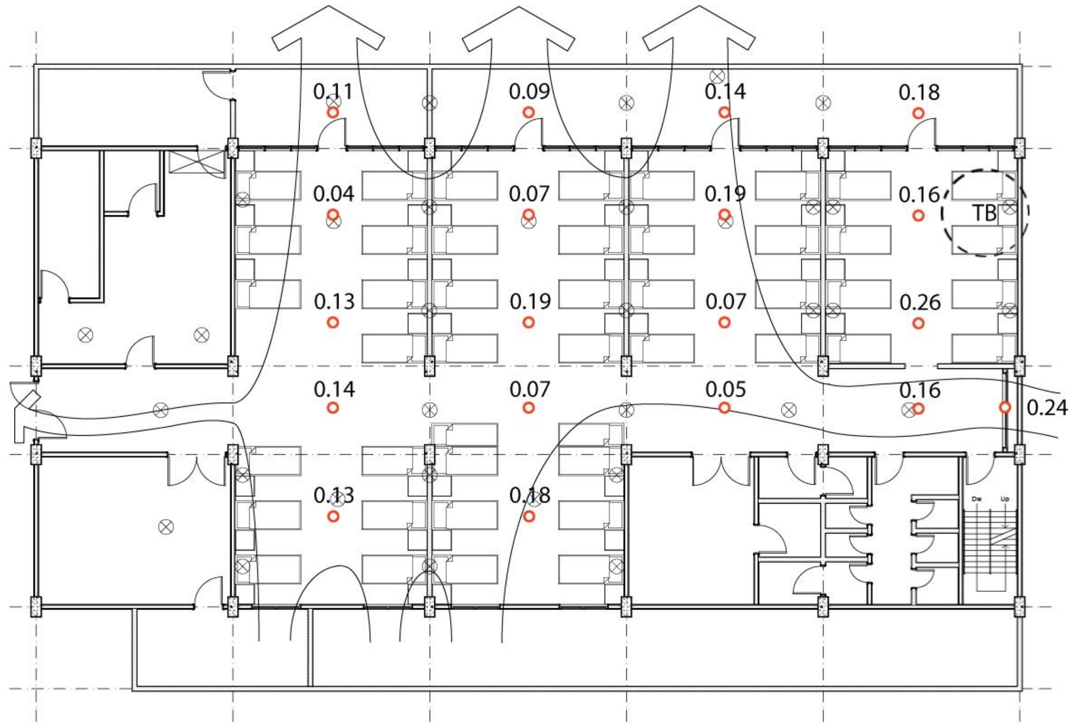

Fig. 7 Floor plan and ventilation data of hospital E inpatient ward#3

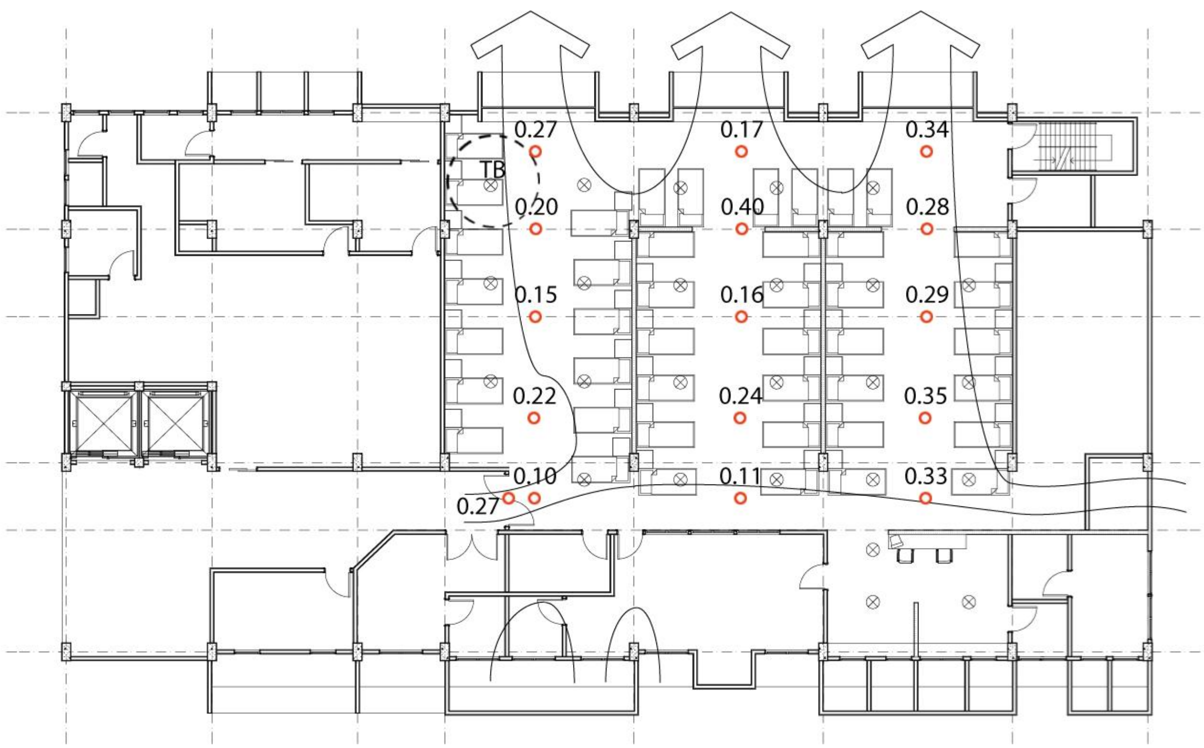

Fig. 8 Floor plan and ventilation data of hospital E inpatient ward#4

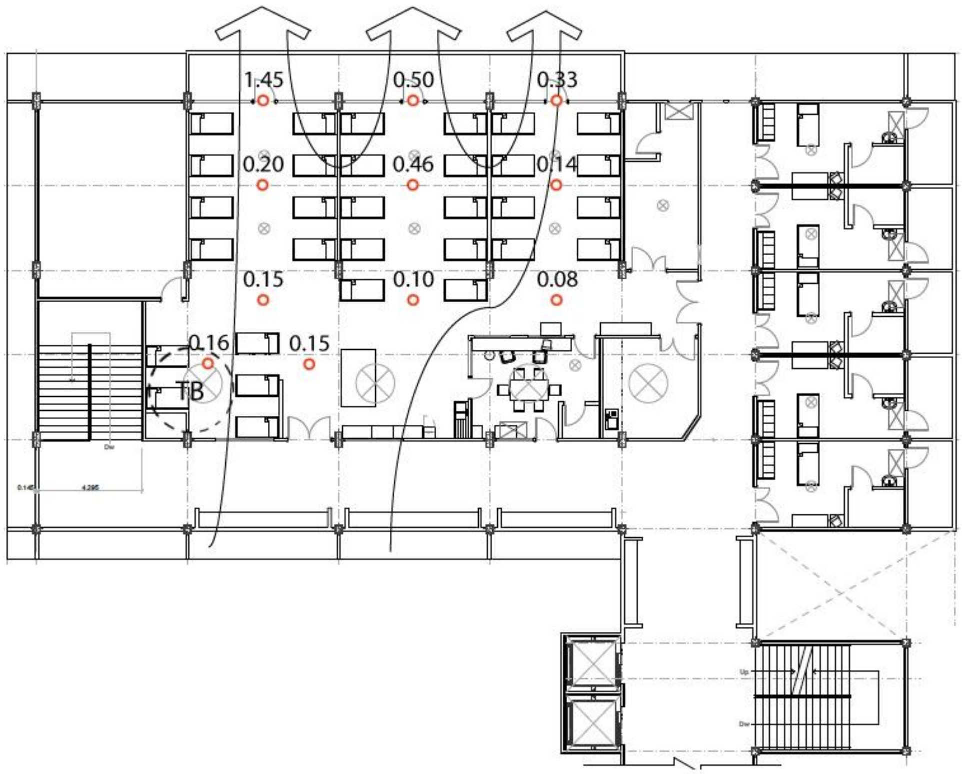

Fig. 9 Floor plan and ventilation data of hospital F inpatient ward

Fig. 10 Industrial type exhaust fan that was installed in the inpatient ward of hospital C

Fig. 11 Exhaust fans that were installed in the inpatient ward of hospital D

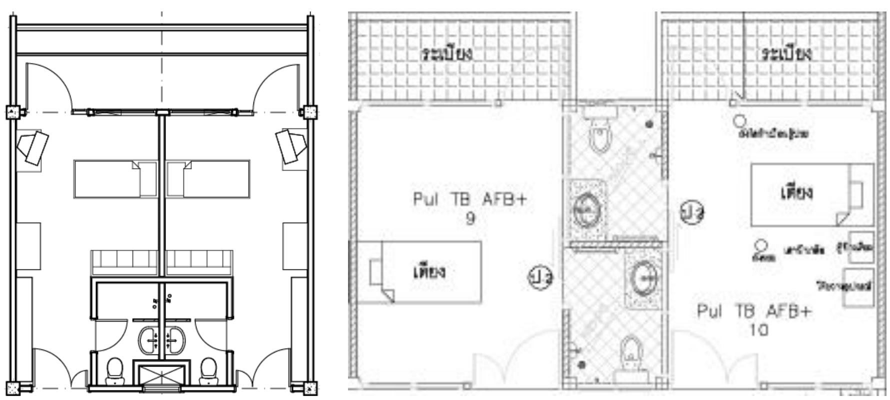

Fig. 12 Typical floor plans of naturally-ventilated airborne infection isolation (AII) room

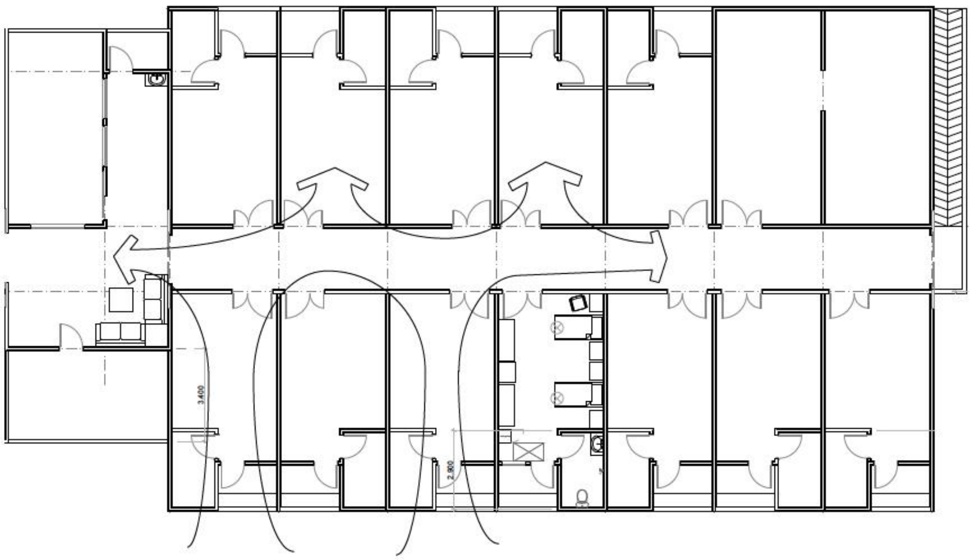

Fig. 13 Floor plan and airflow direction hospital F airborne infection isolation (AII) ward

Fig. 14 A central type corridor of AII ward at hospital F

Table 1 Building configurations and ventilation performance of hospital wards

Hospital	No. of Beds	Volume (m^3)	Area of smaller opening (m^2)	Average air flow at opening (m/s)	Calculated Air Change Rate (ACH)	Additional ventilation system
A	28	428	6	0.42	16.98	Ceiling Fans
B	38	931	4	0.52	6.43	Ceiling Fans
C	28	714	4	1.10	17.75	Exhaust Fans
D	47	980	8	1.14	26.80	Exhaust Fans
E1	47	897	6	0.63	12.14	Ceiling Fans
E2	40	955	4	0.32	3.86	Ceiling Fans
E3	43	897	4	0.24	3.08	Ceiling Fans
E4	43	955	4	0.27	3.26	Ceiling Fans
F	31	805	6	0.75	16.10	Ceiling Fans

Table 2 Building configurations and ventilation performance of AII rooms

Hospital	No. of Beds	Volume (m^3)	Area of smaller opening (m^2)	Average air flow at opening (m/s)	Calculated Air Change Rate (ACH)	Additional ventilation system
B	1	44	3	0.45(open)	88.36	3x12” exhaust fans
C	1	46	3	0.35(open)	65.74	None
D	1	62	2	0.18(close)	16.72	8” and 12” exhaust fans
F	2	63	2.40	1.99 (open) 0.36 (close)	218.33(open) 36.50 (close)	2x Ceiling Fans