DESIGN OF ATMOSPHERIC CONTROL SYSTEM FOR AN AIRBORNE INFECTION ISOLATION ROOM

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Mechanical and Process System Engineering

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การออกแบบระบบปรับสภาพบรรยากาศใน
ห้องแยกโรคผู้ป่วยแพร่เชื้อทางอากาศ

นายภานุเดช สารพัฒน์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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DESIGN OF ATMOSPHERIC CONTROL SYSTEM FOR AN AIRBORNE INFECTION ISOLATION ROOM

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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ภานุเดช สารพัฒน์ : การออกแบบระบบปรับสภาพบรรยากาศในห้องแยกโรคผู้ป่วยแพร่เชื้อทางอากาศ (DESIGN OF ATMOSPHERIC CONTROL SYSTEM FOR AN AIRBORNE INFECTION ISOLATION ROOM) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.กีรติ สุลักษณ์, 91 หน้า.

ห้องแยกโรคผู้ป่วยแพร่เชื้อทางอากาศ (AIIR) มีไว้สำหรับผู้ป่วยติดเชื้อทางอากาศ เช่น วัณโรค และอื่น ๆ อย่างไรก็ตาม ยังไม่มีรูปแบบการออกแบบสำหรับช่องระบายอากาศที่ชัดเจน ในการศึกษานี้ จึงใช้การคำนวณพลศาสตร์ของไหล (CFD) ในการออกแบบระบบสำหรับการควบคุมอัตราการแลกเปลี่ยนอากาศ อุณหภูมิ ความดัน และความชื้น เพื่อวิเคราะห์ประสิทธิภาพของระบบระบายอากาศ โดยแบ่งการศึกษาออกเป็น 2 ห้องที่มีขนาดแตกต่างกัน เพื่อวิเคราะห์ผลกระทบของตำแหน่งของช่องอากาศเข้า ช่องระบายอากาศระหว่างห้อง และช่องจ่ายอากาศสำหรับห้องผู้ป่วย ซึ่งอายุของอากาศ (Age of air) และ SVE-3 (Scale Ventilation Efficiency) ได้นำมาใช้เพื่อเป็นตัวบ่งชี้คุณภาพของอากาศ ผลการวิจัยพบ อัตราการแลกเปลี่ยนอากาศ ความดัน อุณหภูมิ และความชื้น มีค่าอยู่ในช่วงที่มาตรฐานกำหนด ส่วนตำแหน่งการติดตั้งช่องระบายอากาศที่แตกต่างกัน มีผลต่อรูปแบบการไหลของอากาศภายในห้อง

สาขาวิชา วิศวกรรมเครื่องกล ลายมือชื่อนักศึกษา ภานุเดช

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PANUDET SARAPAT : DESIGN OF ATMOSPHERIC CONTROL SYSTEM FOR AN AIRBORNE INFECTION ISOLATION ROOM. THESIS ADVISOR : ASST. PROF. KEERATI SULUKSNA, Ph.D., 91 PP.

AIRBORNE INFECTION ISOLATION ROOM/COMPUTATIONAL FLUID DYNAMICS/VENTILATION SYSTEM/AIR QUALITY

Airborne Infection Isolation Room (AIIR) is the room for patients infected by airborne diseases such as tuberculosis. However, there is no consensus uniform pattern for the position of air inlet channel, air damper and air return channels. In this study, the CFD technique was used to design the system for controlling the air change rate, temperature, pressure and humidity in AIIR based on standard. The study was investigated on two room size case. The effect of positions of the inlet air, air damper and return air channel have been analyzed. The age of air and SVE-3 (Scale Ventilation Efficiency) were used for predicting the air quality. The results shown that the predicted air change rate, pressure, temperature and relative humidity were satisfied with the conditions of standard range. The arrangement prattle of the inlet air, air damper and air return channel positions are affected the air flow behavior in the room.

School of Mechanical Engineering　　Student's Signature ____________

Academic Year 2018　　Advisor's Signature ____________

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SYMBOLS AND ABBREVIATIONS

ϕ	=	Relative humidity
p_w	=	Water vapor pressure, Pa
p_{ws}	=	Water saturated Pressure, Pa
p	=	Pressure, Pa
ω_w	=	Concentration of species, kg of species / kg of mixture
T	=	Temperature, ^oC
$\%RH$	=	Relative humidity
t_a	=	Air temperature $(^{\circ}C)$
v	=	Air velocity (m/s)
$C'_X(X)$	=	Concentration at point X which assume contaminants generated in every point, (kg/s)
C_S	=	Nominal concentration, (kg/s)
τ_P	=	Mean age of air (h)
τ_N	=	Nominal ventilation time (h)
μ_t	=	Turbulent viscosity
P	=	Diffusion value of the kinetic energy
σ_k	=	Turbulent Prandtl numbers for k

SYMBOLS AND ABBREVIATIONS (Continued)

σ_{ε}	=	Turbulent Prandtl numbers for ε
S_k, S_{ε}	=	Source
$C_{\varepsilon 1}, C_{\varepsilon 2}, C_{\mu}$	=	Turbulence constant
η_0, β	=	Turbulence constant

CHAPTER I

INTRODUCTION

1.1 Background and motivation

Infection in hospitals is very important and dangerous. It happens all over the world. Particularly, infections from airborne pathogens such as Tuberculosis, Influenza, etc. In 2010, there were 8.8 million people infected with tuberculosis in the world and 1.4 million people died from tuberculosis (WHO, 2010). Information of the World Health Organization is found that Thailand is ranked as one of the 22 countries with the highest TB burden in the world. About 130,000 people were infected with tuberculosis, 11,000 were dead from tuberculosis and 1,920 people got drug-resistant tuberculosis (WHO, 2010). In order to prevent the infection of other patients and the hospital staff in the hospital, one of the suggested solutions is to design the rooms with negative pressure. So, the airborne pathogens cannot spread out to the another room.

Thailand has 723 community hospitals (Bureau of Policy and Strategy, Ministry of Public Health (Thailand), 2009). Each hospital has an average of one Airborne Infection Isolation Room (AIIR) (Medical Engineering Division, Ministry of Public Health (Thailand) 2009) to support airborne infected patients and protect airborne pathogens spreading in the hospital. In addition, 56.1% of the hospitals report that tuberculosis patients are in an average of 1 - 6 patients per day (Charoen, 2009). The problem is there are more than one patient need to admit in the AIIR at the same time. In case of over supporting of the room, the patients must be admitted in a room without sterilization system and the airborne pathogens are likely to spread to other areas of the hospital. As a result, the safety of medical staff and hospital staff are at greater risk. At present, the AIIR has been implemented in many hospitals. It has been designed from standards of the Medical Engineering Division (Thailand). However, there is no consensus uniform pattern for the position of the inlet air, air damper and return air channel. The placement of the mentioned above has not been tested if the ventilation system is appropriate. If the ventilation systems are not proper, the distribution of pathogens in the air will spread and cannot be controlled both in the room and the hospital area. Li, et al. (2014) proved that the spread of airborne pathogens in indoor environment is related with the air circulation and the direction of airflow. However, the accumulation of pathogens cannot be avoided. The good designing arrangement of air channels in the room can reduce the risk of pathogen accumulation because ventilation and air conditioning affects the indoor environment quality.

Computational Fluid Dynamics (CFD) is one of the most commonly used methods for predicting air flow behavior. The systems for controlling the air change rate, temperature, pressure and humidity were designed by changing the positions of air channels in the AIIR with the fixed position of the outlet air channels and bed.

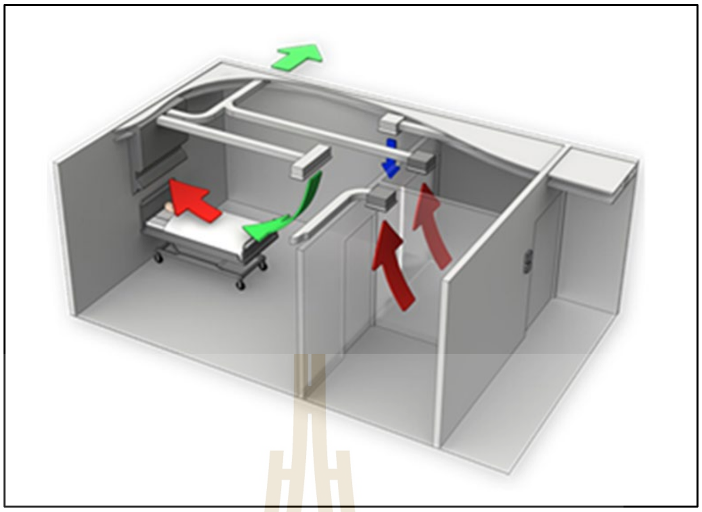

Figure 1.1 Airborne Infection Isolation Room (AIIR).

1.2 Research objectives

To design the system for controlling the air change rate, temperature, pressure and humidity in an Airborne Infection Isolation Room based on standard conditions.

1.3 Scopes and limitations of the study

1.3.1 The AIIR prototype was designed based on standard conditions of Medical Engineering Division (Thailand) (วศ.1/2549), as follows:

- Temperature:	24 – 26 ºC	
- Pressure:	Anteroom	-2.5 Pa
	Patient room	-5 Pa
- Air change rate:	≥ 12 Air change per hour	
- Air intake rate:	≥ 2 Air change per hours	

1.3.2 The AIIR using STREAM CRADLE V.14 is used as the software to simulate the air flow behavior in the room.

1.3.3 The RNG $k-\varepsilon$ turbulence model has been implemented based on steady state flow.

1.3.4 Toilet is not included in the room.

1.3.5 Effect of the heat radiation are not considered.

1.3.6 Energy consumption is not considered.

1.3.7 Two room sizes are considered; 3 × 6 × 3 m and 3.5 × 5.5 × 3 m.

1.3.8 Positions of the air conditioner in anteroom, outlet air and bed are fixed.

1.3.9 Number of air channels are as follows:

- 1 inlet channel
- 1 damper channel
- 2 return channels
- 2 outlet channels

1.4 Expected Benefits

The improvement guideline for installing the position of the air inlet channel, air damper and air return channels in the room.

CHAPTER II

LITERATURE REVIEW

2.1 Airborne Infection Isolation Room

An Airborne Infection Isolation Room is created to prevent the infectious diseases such as avian influenza, tuberculosis from spreading to another area of the hospital. Inside the room, there is a dilution and removal of infectious disease to ensure the safety of people in the room. The room consists of facilities to support the patient such as a bathroom, telephone, television window for the patient to look outside the room, and the medical appliance such as blood pressure gauge, respirator, oxygen aspirator, and suction as shown in Figure 2.1.

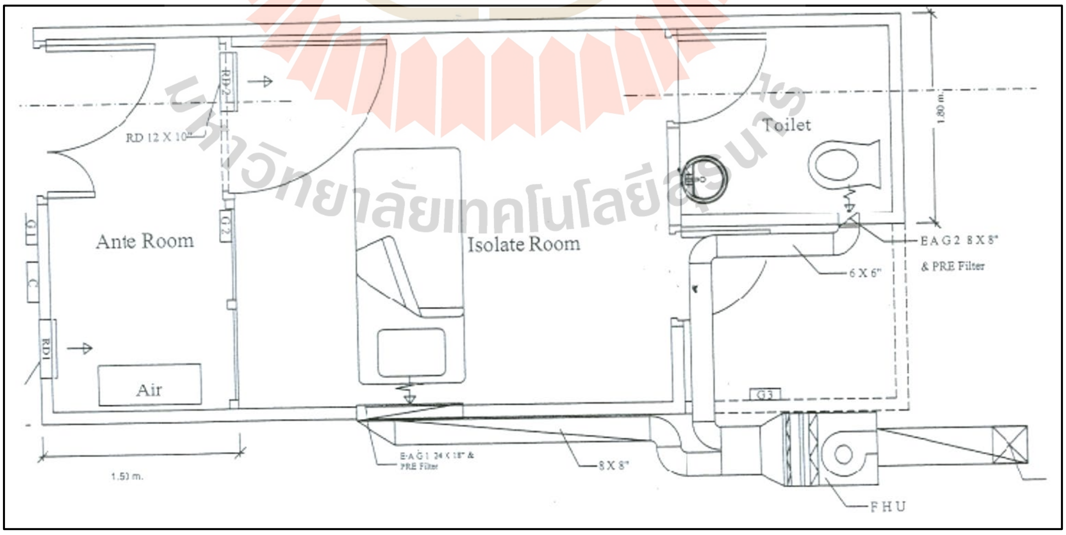

Figure 2.1 Components of AIIR.

In order to prevent medical staff from contacting the patient directly, the blood pressure gauge is connected to the nurse office and installed CCTV cameras to observe the patient's symptoms (Bamrasnaradura Institute, 2007).

The design and construction of the AIIR in this study has been used based on standard from American Institute of Architects (AIA), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and The Engineering Institute of Thailand under H.M. the King’s Patronage (EIT). The air flow and relative pressure are determined in Table 2.1.

Table 2.1 The rate of incoming air outside, internal air circulation and pressure relationship (The Engineering Institute of Thailand under H.M. the King’s Patronage, EIT).

No.	Location	The rate of external air intake is not less than the volume of room per hour [ACH]	The air change rate in the room is not less than the volume of room per hour [ACH]	Relative pressure between the room and adjacent areas
1	Operating room (O.R)	5	25	Higher
2	Labor room (L.R)	5	25	Higher
3	Nursery room	5	12	Higher
4	Intensive care unit (ICU)	2	6	Higher
5	Ward	2	6	Higher
6	Emergency room (E.R)	5	12	Higher
7	Rest areas for patient and emergency rooms.	2	12	Lower
8	Patient Room	2	6	Higher
9	Airborne Infection Isolation Room (AIIR)	2	12	Lower
10	Isolation Room	2	12	Higher
11	Laboratory	2	6	Lower
12	Autopsy room	2	12	Lower

2.2 Standard of the AIIR

2.2.1 Temperature

According to AIA (2006) and ASHRAE (2008), the appropriate temperature for the patients in the AIIR should be controlled in the range of 24 - 26 ^{o}C (75.2 – 78.8 ^{o}F).

2.2.2 Humidity

The standard condition based on AIA (2006) and ASHRAE (2008) specify the relative humidity in the air-conditioned room should be controlled in the range of 40 – 60 %RH.

Relative humidity can be obtained from the primary variables including temperature, water vapor concentration, and pressure, (ASHRAE Fundamentals Handbook, 2005). The related equations are explained as follows:

$$\phi = \frac{p_w}{p_{ws}} \tag{2.1}$$

$$p_w = \frac{(101325 + p)\,\omega_w}{0.62198 + 0.37802\omega_w} \tag{2.2}$$

$$p_{ws} = \exp\begin{bmatrix} -0.58002206\times10^{4}\left(T+273.15^{-1}\right)+0.13914993\times10^{1} \\ -0.48640239\times10^{-1}\left(T+273.15\right) \\ +0.41764768\times10^{-4}\left(T+273.15\right)^{2} \\ -0.14452093\times10^{-7}\left(T+273.15\right)^{3} \\ +0.65459673\times10^{1}\ln\left(T+273.15\right) \end{bmatrix} \tag{2.3}$$

where ϕ is the relative humidity

p_w is the water vapor pressure, Pa

p_{ws} is the water saturated pressure, Pa

p is the pressure, Pa

ω_w is the concentration of species, kg of species / kg of mixture

T is the temperature, ^oC

2.2.3 Pressure

AIA (2006) and ASHRAE (2008) stated that the gauge pressure in the anteroom of AIIR must set to be less than -2.5 Pa. For the patient room, the pressure must set lower than in the anteroom and should be less than -5 Pa. This is monitored with pressure gauge installed in the room to indicate the clearly visible level.

The causes the AIIR must be controlled as negative pressure is needing to suck out the air inside the room to protect the infectious diseases. The air moves from the clean area to the contaminated area. The air is sucked out of the patient's headboard and filtered by a High Efficiency Particulate Air (HEPA) before being released into the atmosphere as shown in Figure 2.2.

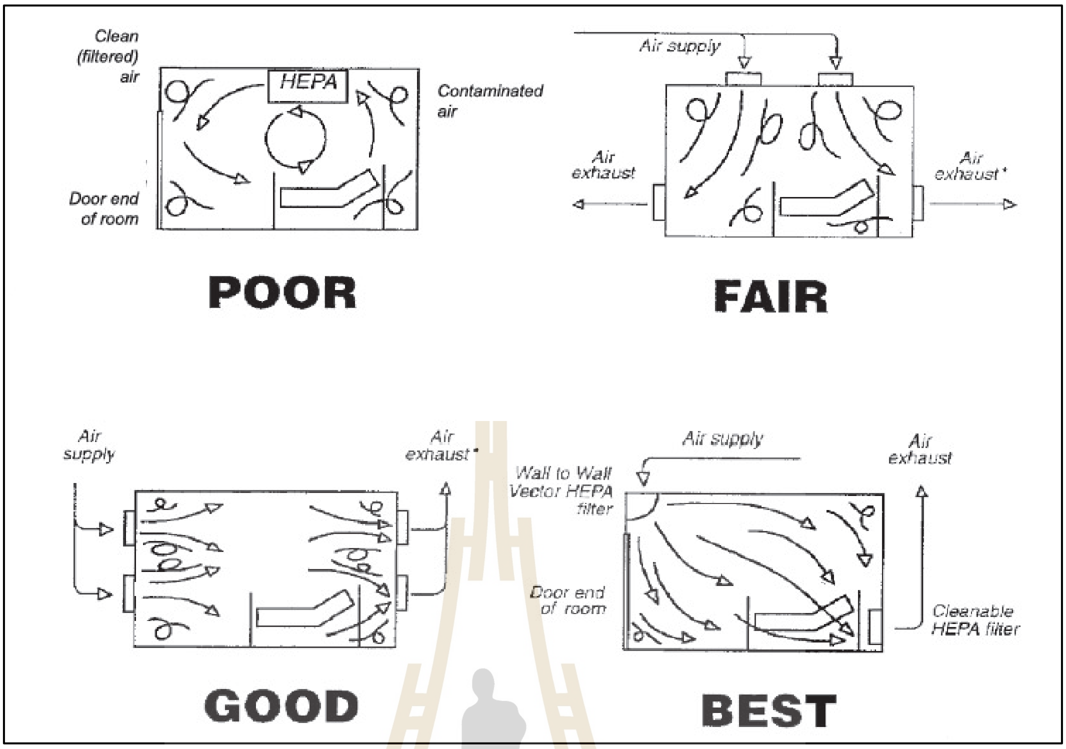

Figure 2.2 Alignment of the inlet air and the suction air.

(Designated by the institution).

2.2.4 Air change rate

Air change rate is the air volume flowing in or from of the room compared to the volume of the room in one hour. Cause of the air flowing in or out of the room is such as sending and sucking the air by the fan or flowing out of the room from inattention such as leakage. The air change rate is important as it is to ventilate the room that is not clean due to dust or chemicals. The air change rate is related to the cleanliness of the room or popularly called the clean room because the air inside the clean room requires fresh air to replace the air in the room. The greater the cleanliness level of the room, the more increase of air change rate will also increase and has a relatively high cost of preparing such air. The air change rate unit, popularly compared to 1 hour and not popularizing the writing unit. For example, the air change rate per hour is 12 means that in 1 hour there will be air entering or sucking out the room equal to 12 times of the room volume. The effective rate of air change can be achieved in many ways but the most satisfying thing is the design of the air conditioner to get the appropriate air change rate.

The air change can be calculated as follows:

$$ACH = \frac{A\upsilon \times 60}{V} \tag{2.4}$$

Where ACH is the air change per hour

A is the air outlet area, ft^2

υ is the air velocity, $ft/\min$

V is the room volume, ft^3

2.3 Computational fluid dynamics (CFD)

2.3.1 Meaning and principle

Computational fluid dynamics (CFD) is a computerized system for analyzing fluid dynamics problem and using computer to solve the problem and simulate the behavior such as thermodynamics, airflow, and particle distribution. CFD is based on fluid continuity in the form of intervals by computer. The most commonly used method is to split the range of spatial domains into small cells to create a volume mesh or grid and use the appropriate algorithm to solve the equation of Navier-Stokes Equation. Navier-Stokes Equation discusses one-phase fluid flow. All flow control equations are created on the basis rules of mass conservation, momentum conservation, and energy conservation.

2.3.2 CFD solving

In general, creating equations to describe flow behavior is not difficult. The difficulty is to solve the solution equation. The Naver-Stokes equation is so complex that it cannot be completely solved. So, the computer will be used to solve this solution because computer is performing as computationally efficient calculations. However, it is not possible to import the equation into the computer directly. The special techniques must be used to help transform what man understand (mathematical derivative) to what the computer understands (algebraic mathematic). This process is the so called discretization**.**

2.3.2.1 CFD process

The CFD process includes 3 steps:

1. Pre-processing- it includes the setting data for the program such as the shape of the domain to be analyzed, creation of a grid or volume control or element, configuration of fluid properties such as density, viscosity, configuration, boundary conditions. Generally, about half of the time used in CFD process is used to prepare the appropriate grid data to solve the problem. Therefore, the input to the calculation to solve the problem is concern about the appropriate of the two main components. It is the number of points appropriate to obtain acceptable solutions and processing time is not too long.

2. Processor- it is the process of choosing the form of discretization to create equations of discretization. Generally, each CFD software will develop one discretization process. Not available items are FLUENT, CFX, STAR-

CCM + developed on finite volume method. For the ANSYS, EasyFEM, and EOSMOS are developed on finite element method. In this processing step, developers or users of the software need to select the appropriate numerical scheme for the analysis to make the calculation as accurate and stable as required.

3. Post processing- it is the last step in the CFD process. This process takes the solution from the calculation process into graphical form such as the problem shape, grid position, movement, rotation, etc.

The successful of the solved CFD flow solution will be considered in three principles: (1) Convergence, it is an important factor in numerical solutions. The convergence of the solution means that the solution converges and approximates the correct solution. (2) Consistency, the discretized solution is synthesized by numerical method and equivalent to the original equation when the grid is approaching zero and (3) Stability, which is related to decreased error value of the solution during the calculation. Unstable calculations mean that the tolerances have increased. Then, the result will be swinging. This problem could lead to a divergence.

2.3.2.2 Mesh

Mesh is a grid or volume control or element that was created in 2 types: structured and unstructured. Mesh is made up from mesh point to point in order to be a mesh structure. The accuracy of the solutions depends on several factors. One of the main factors is the number of points to use in the same problem. If the number of points is different, the accuracy of the result will also be different. In general, if the number of dots per area is more in the same point, the accuracy will be higher. There are lots of points, so that it will take more time to calculate.

2.3.2.3 Boundary condition

Determining the boundary condition of the flow problem is an important step in simulation flow problem with a software rather than to understand the physical of the flow behavior and must understand the limitation of the program. There are various types of boundary conditions that must be chosen as appropriate. For example,

1) Inlet: the flow condition for specifying the flow at inlet.

2) Outlet: the flow condition for specifying the flow at outlet.

3) Opening: the flow to both in and out of the surface. This type of boundary condition is not suitable for more than one fluid flow problem.

4) Wall: the flow condition for specifying the flow at the wall.

5) Symmetry plane cannot flow in or out through this surface. The symmetrical surface acts as a mirror reflecting the calculated value. The flow behavior or properties within the domain are the same distance when measured from the symmetry surface. This type of condition applies to symmetric problems.

6) Periodic pair is the transfer of calculated data from one surface to another. This type of boundary condition is not suitable for multiphase simulation.

2.3.2.4 Governing equations of fluid motion

All flow governing equations were created on the base rules of

1) Continuity equation:

$$\frac{\partial \rho}{\partial t} + \left(\overline{\nabla} \cdot \rho u\right) = 0 \tag{2.5}$$

2) Momentum conservation equation:

$$\frac{\partial(\rho u)}{\partial t}+\left(\overline{\nabla}\cdot\rho uu\right)=-\overline{\nabla}p+\mu\overline{\nabla}^{2}u+\rho g \tag{2.6}$$

3) Energy conservation equation.

$$\frac{\partial(\rho C_p T)}{\partial t}+\rho C_p\overline{\nabla}\cdot(Tu)=k\overline{\nabla^{2}}T-p\overline{\nabla}u+q \tag{2.7}$$

Where ρ is density

u, v, w is average velocities

μ is viscosity

P is pressure

C_p is specific heat capacity

k is thermal conductivity

T is temperature

2.3.2.5 Turbulence models

The turbulent model has a variety of formats including standard, RNG and realizable, which each type has the same k- equation and different ε- equations. Each equation has a different variable and constant. This study will use the RNG $k-\varepsilon$ model to simulate the air flow, which is commonly used in the industry and applies the solution into engineering design. The $k-\varepsilon$ equation is shown below (Choudhury,1993).

Turbulence kinetic energy equation (k):

$$\frac{\partial}{\partial x_j}(\rho v_j k) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right) + P - \rho\varepsilon - \rho\varepsilon_p \tag{2.8}$$

Dissipation rate equation (ε):

$$\frac{\partial}{\partial x_j}(\rho v_j \varepsilon) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right) + (C_{\varepsilon 1}P - c^*_{\varepsilon 2}\rho\varepsilon)\frac{\varepsilon}{k} - S_\varepsilon \tag{2.9}$$

$$c^*_{\varepsilon 2} = c_{\varepsilon 2} + \frac{c_\mu \rho \eta^3 \left(1 - \frac{\eta}{\eta_0}\right)}{1 + \beta\eta^3} \tag{2.10}$$

$$\eta = \left(\frac{S_k}{\varepsilon}\right) \tag{2.11}$$

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{2.12}$$

where $\eta_0 = 4.38$, $\beta = 0.012$, $C_{\varepsilon 1} = 1.42$, $C_{\varepsilon 2} = 1.68$, $C_\mu = 0.00845$

μ_t is the turbulent viscosity

P is the production of the kinetic energy

σ_k is the turbulent Prandtl numbers for k

σ_ε is the turbulent Prandtl numbers for ε

S_k, S_ε is the source term

$C_{\varepsilon 1}, C_{\varepsilon 2}, C_\mu, \eta_0, \beta$ is the model constant

Rouaud and Havet (2002) studied the difference of result between standard $k-\varepsilon$ and Renormalization Group (RNG) $k-\varepsilon$ turbulence model in the clean room based on CFD simulation. The result showed that RNG $k-\varepsilon$ was appropriate to simulate the air flow more than standard $k-\varepsilon$ because the standard $k-\varepsilon$ has viscosity of turbulence that obtained from simulation higher than reality. Therefore, resulting in the high turbulence kinetic energy and makes the area where air circulation is faultier, which RNG $k-\varepsilon$ gives more realistic viscosity.

Siriboonluckul, et al. (2004) developed turbulence model focusing the effects of particle in the mixing layer based on CFD simulation. The various turbulent models such as standard $k-\varepsilon$, RNG $k-\varepsilon$, realizable $k-\varepsilon$ and standard $k-\omega$ were used to study the effect of turbulent kinetic energy in the form of dimensionless variables compared with the different velocity of point 1 and point 2. The results showed that standard $k-\varepsilon$ and RNG $k-\varepsilon$ gave similar results which could be used to simulate the flow. For realizable $k-\varepsilon$, the result is closed to the experimental result but it takes more time to calculate because it requires a higher number of grids. For standard $k-\omega$, it is able to explain the flow behavior of only particles with high velocity.

2.4 Air Quality

Age of air and SVE-3 are used to evaluate the air quality in the room. Age of air is defined as the elapsed time passed after a unit of air is supplied to an arbitrary position as shown in Figure 2.3. A zone where age of air shows a large value has less ventilation performance and there is a higher possibility of contamination. On the other hand, SVE-3 is the normalized age of air with nominal ventilation time when a uniformly distributed source of contaminant is assumed. SVE-3 is advantageous when analyzing airflow pattern in a room. An ensemble averaged-value of the SVE-3 is used in the following sections. For example, the AIIR in patient room requires an air exchange rate per hour greater than 12 ACH. The air must flow in and out of the patient room area at least 12 times within 1 hour. Therefore, the air in the room will flow 60 minutes per 12 rounds per hour. As a result, the maximum age of air is for 12 ACH is 5 minutes. If any area in the room has the age of air more than 5 minutes, the air exchange rate is lower than the standard. This can be improved by adding an opening inlet area, which air can flow through it or adding a fan or a fresh air supply. This affects the direction of the airflow in the room. The equation is explained as follow:

$$SVE3(X) = \frac{C'_X(X)}{C_S} = \frac{\tau_P}{\tau_N} \tag{2.16}$$

where $SVE3(X)$ is the scale ventilation efficiency

$C'_X(X)$ is the concentration at point X which assume contaminants generated in every point, (*kg/s*)

C_S is the nominal concentration, (*kg/s*)

τ_P is the mean age of air, (*h*)

τ_N is the nominal ventilation time, (*h*)

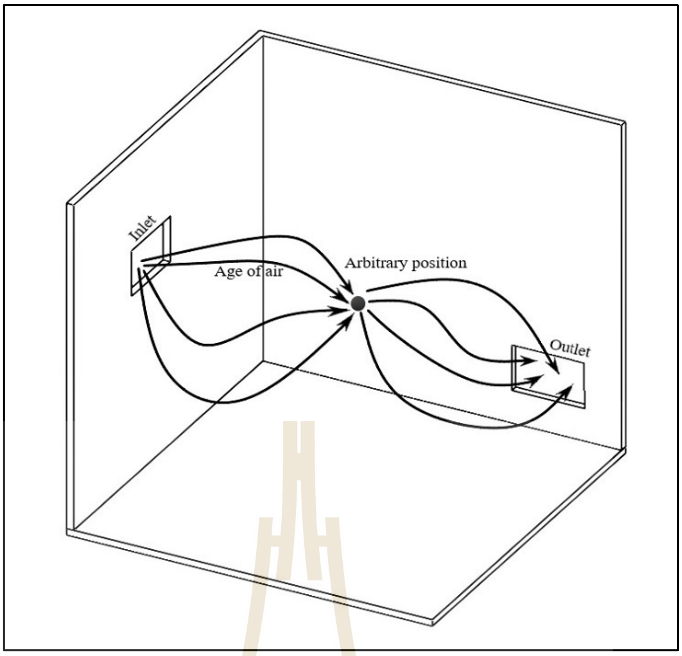

Figure 2.3 Conceptual diagram of age of air.

Table 2.2 Performance evaluation of clean room by SVE-3.

Conditions	Unidirectional cleanroom	Non-unidirectional cleanroom
Good performance, perfect mixing	< 0.5	≤ 1.0
Some improvement maybe necessary	0.5 – 1.0	1.0 – 1.5
Does not function as a cleanroom	> 1.0	>1.5

From Table 2.2, displays the ventilation mixing type focused on unidirectional and non-unidirectional flow as shown in Figure 2.4. The SVE-3 values show the complete mixing method and the one-way flow method. In the one-way system using only unidirectional flow, it flows from one side to another side, the air stagnation is less likely to occur as shown in Figure 2.5. It requires that the air at the inlet air is equal to

0 unit of time, outlet air is 1 unit of time. The best performance is SVE-3 at 0.5 for unidirectional and 1.0 for non-unidirectional, the air must flow in and out at all. There is no accumulation of air. In the case that occurs the short-circuits and stagnation area will increase the SVE-3 to greater than 0.5 for unidirectional and 1.0 for non-unidirectional as shown in Figure 2.6 and Figure 2.7, respectively.

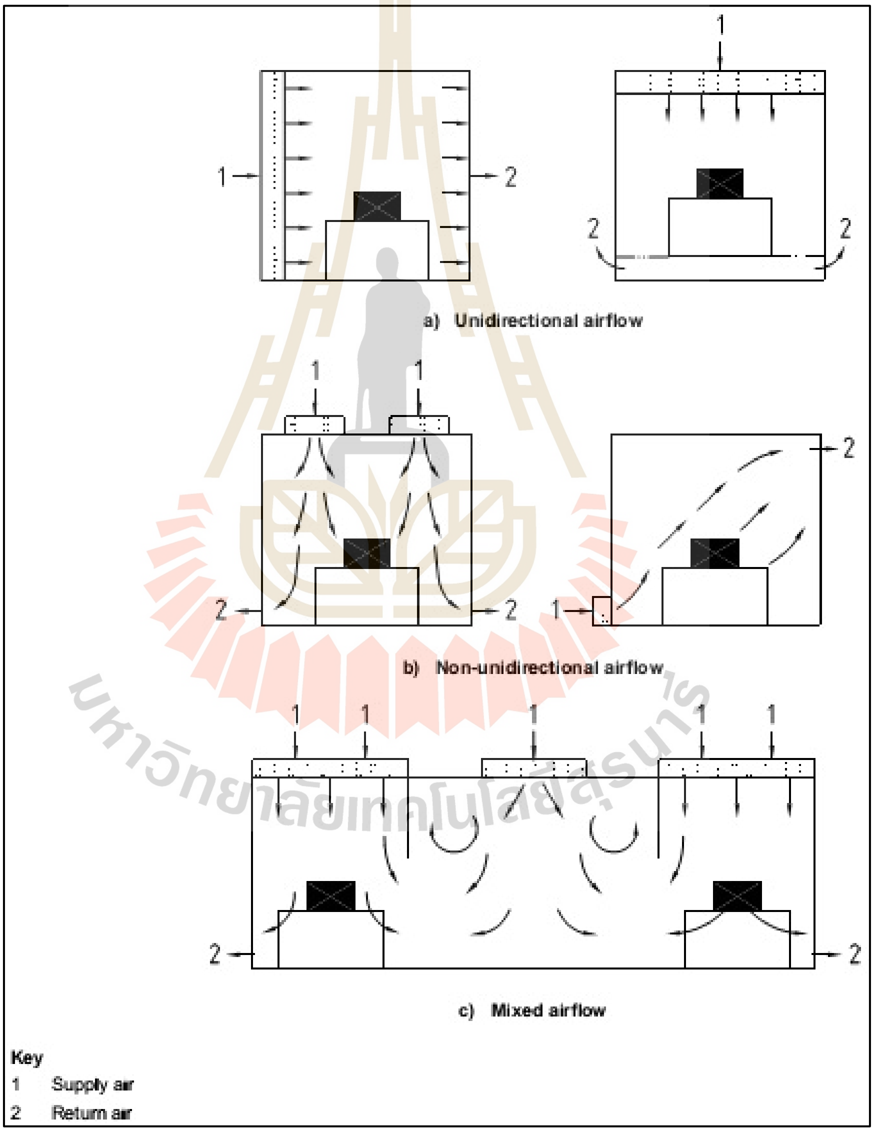

Figure 2.4 Ventilation mixing type.

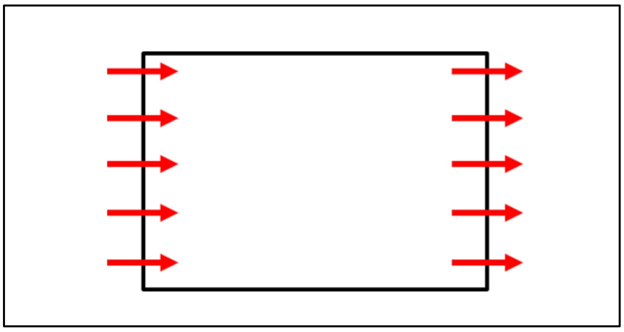

Figure 2.5 Unidirectional (SVE-3 = 0.5).

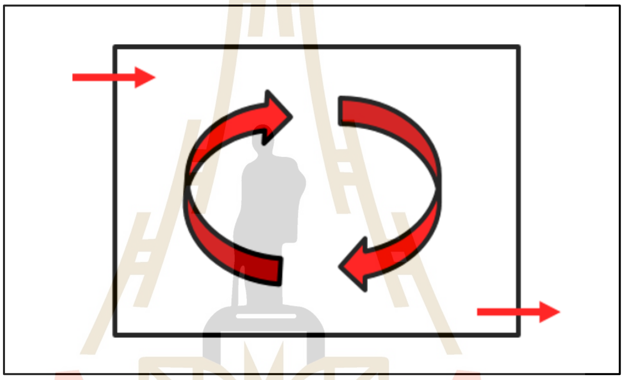

Figure 2.6 Unidirectional (SVE-3 = 1.0).

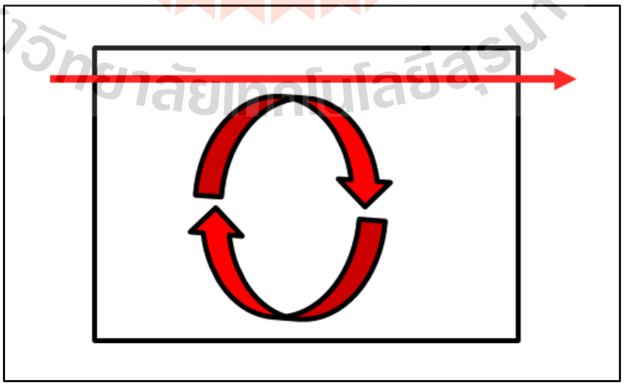

Figure 2.7 Unidirectional (SVE-3 = 1.5).

Buratti, et al. (2011) investigated the nature ventilation rates of an office by using the CFD method. The mean age of air was used to calculate the ventilation efficiency. The results showed that the higher indoor-outdoor temperature difference obtained the lower value of the mean age of good air quality due to the higher air velocity (high air change rate) across the openings.

Yang (2013) examined the effect of positions and numbers of the supply air opening and exhaust air opening in the inpatients room by using Computational Fluid Dynamics (CFD) technique. The results showed that a large supply air opening and low air velocity can be obtained for high air quality.

Meiss, et al. (2013) used the local mean age of air to calculate the room efficiency by focusing the difference of indoor-outdoor temperature in the room. The results showed that in the summer situation (inlet air temperature at 43 ºC and room temperature at 23 ºC), fresh air remained on the top of the room and cooled down to ambient temperature. Fresh air moved to the bottom room and flow out of the room. The jet flowed horizontally to the corner and deflects downward. The buoyancy force was opposed the flow. At the check point, the jet had maximum potential energy, then the jet came to check point, then the potential energy turned to kinetic energy as shown in Figure 2.8 and Figure 2.9. In the winter situation (inlet air temperature at 3 ºC and room temperature at 23 ºC), fresh air moved down quickly by buoyancy to the bottom of the room as shown in Figure 2.10 and Figure 2.11. In the isothermal situation (inlet air temperature was as same as the room temperature at 23 ºC), without the buoyancy and convective allowed the jet flow in a simply turbulence as shown in Figure 2.12 and Figure 2.13. The air change efficiency in summer was 46.84%, in winter was 48.32% and in isothermal situation was 48.53%.

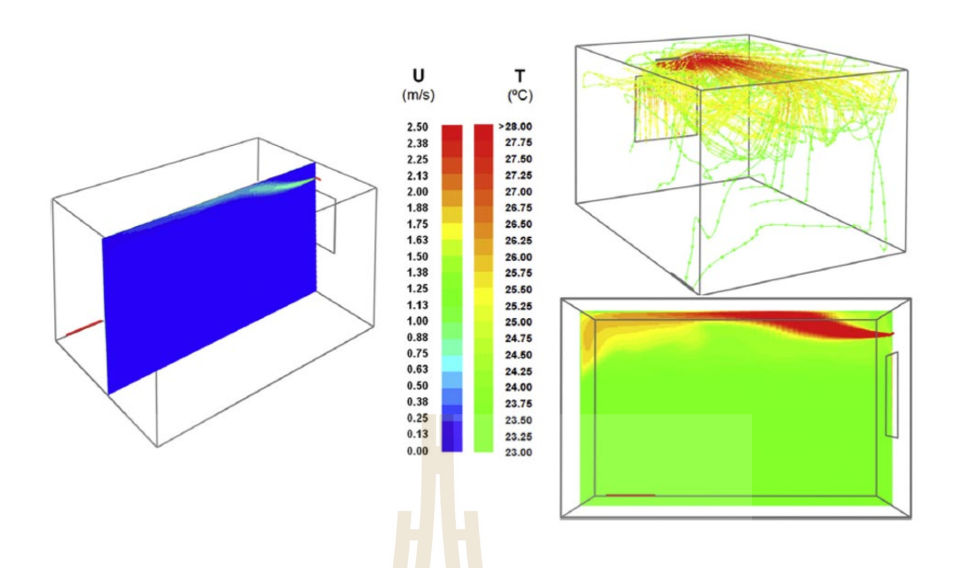

Figure 2.8 Path lines (temperature) in summer.

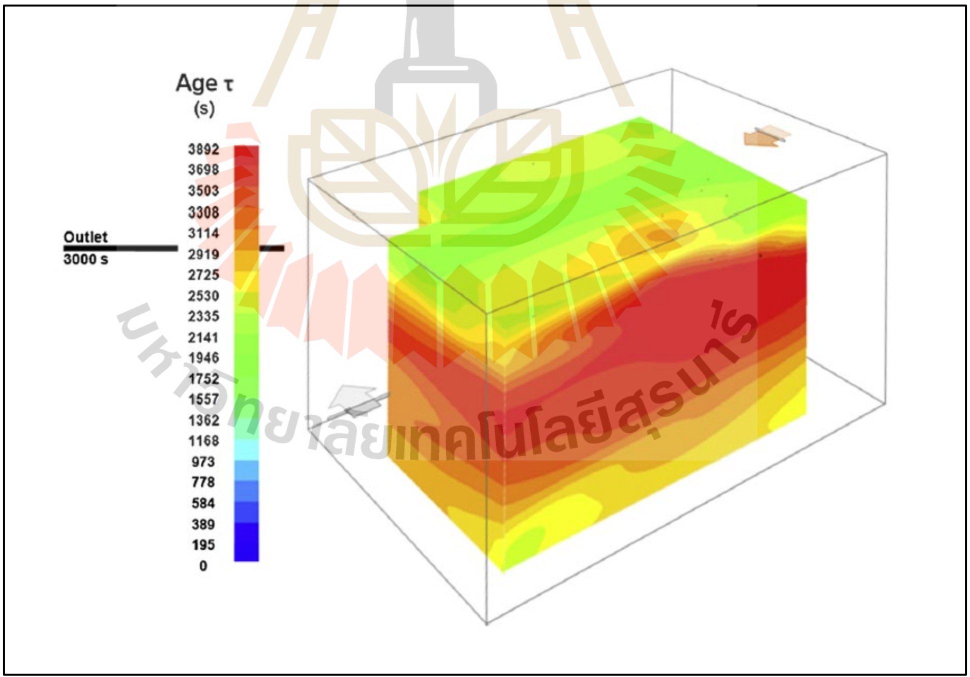

Figure 2.9 Age of air in the occupied area (T_{out} = 43 ºC).

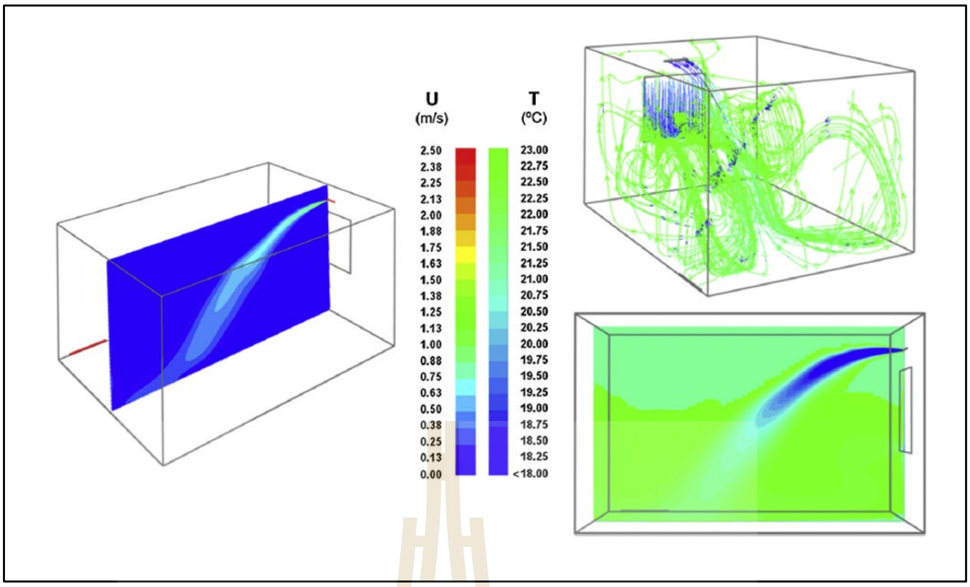

Figure 2.10 Path lines (temperature) in winter.

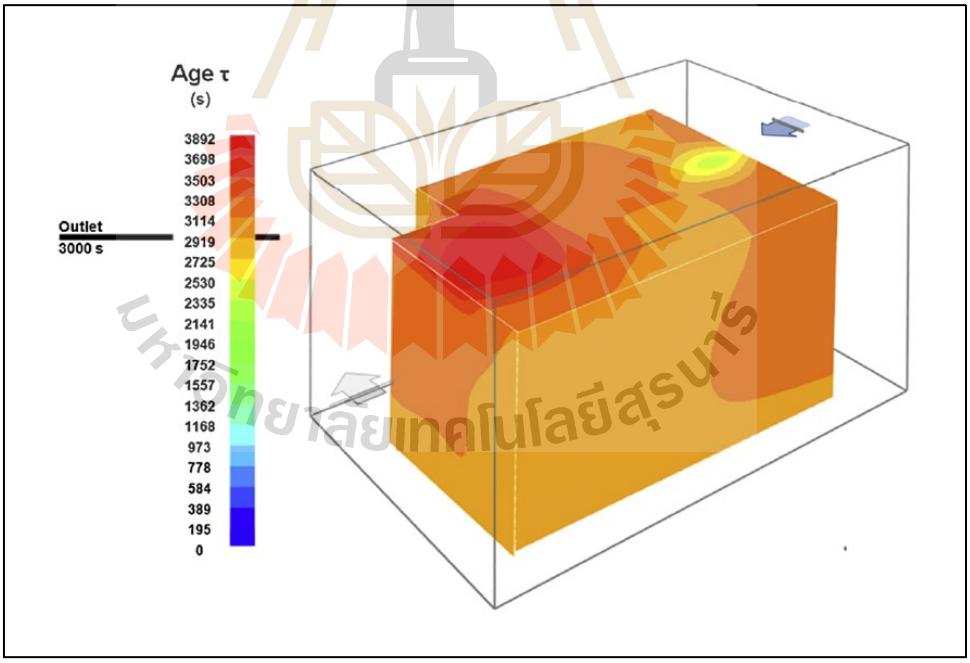

Figure 2.11 Age of air in the occupied area (T_{out} = 3 ºC).

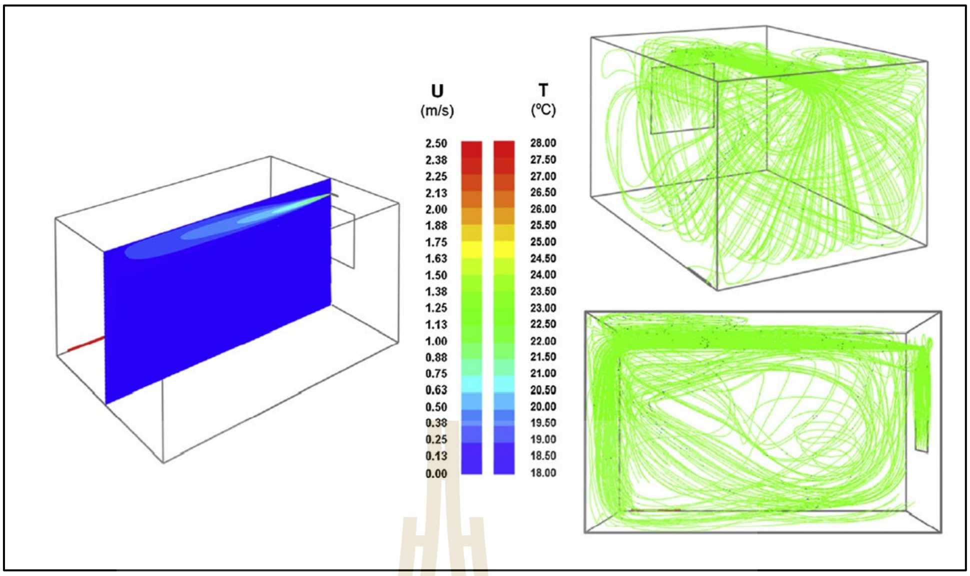

Figure 2.12 Path lines (temperature and velocity) in isothermal.

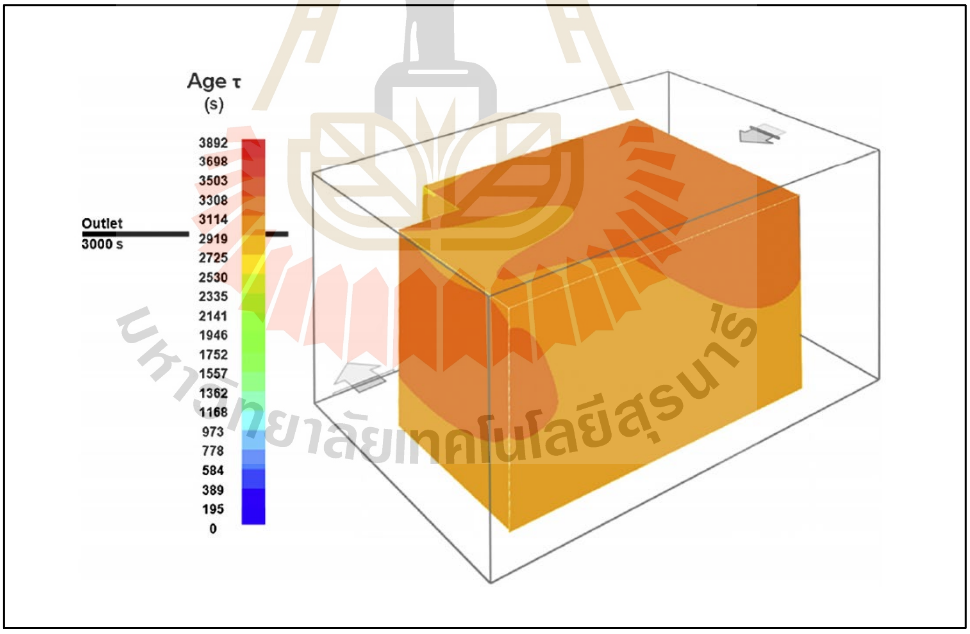

Figure 2.13 Age of air in the occupied area (T_{out} = isothermal).

Villafruela, et al. (2013) analyzed the influent of positioning the air inlets and air outlets by using the Computational Fluid Dynamics (CFD) technique. The results showed that the positions of air inlets on configuration 1 (air inlets at point 1,3 / air outlets at point 7,9) and 12 (air inlets at low position / air outlets at up position) obtained the best air change efficiency of 0.62 and 0.61, respectively as shown in Figure 2.14. In both configurations, the air entering to the room almost completely circulated before leaving out and the air flowed like a piston flow as shown in Figure 2.15.

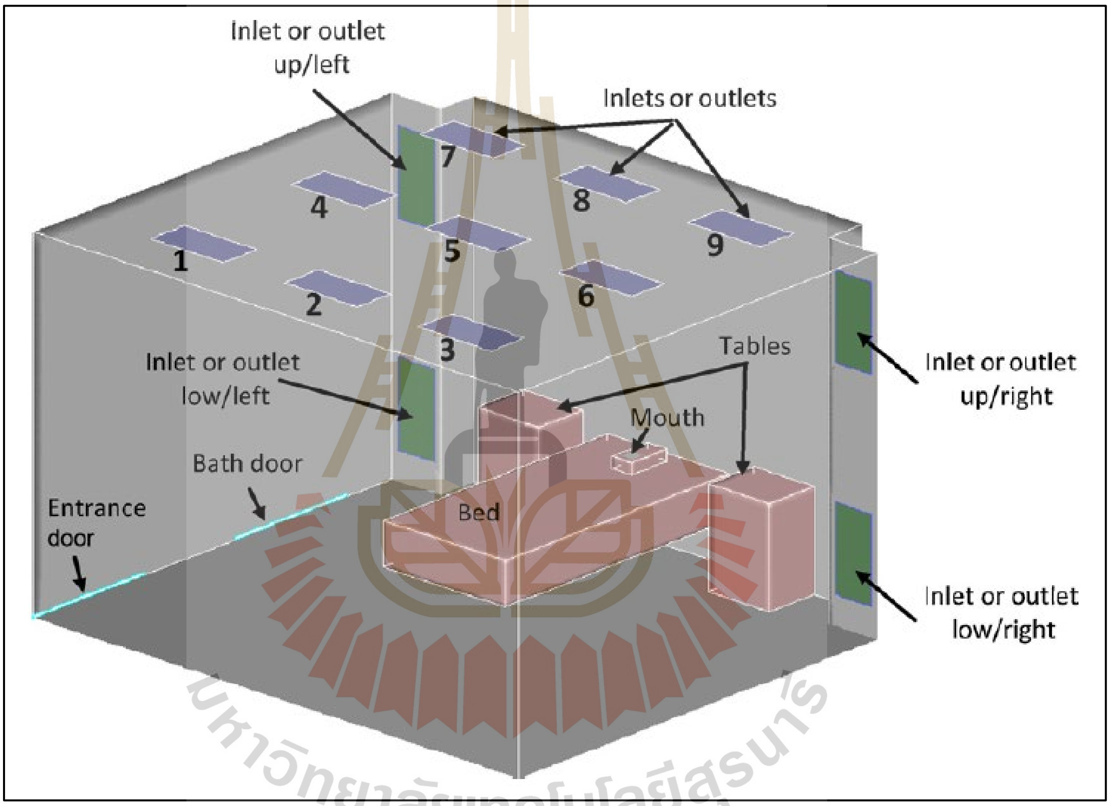

Figure 2.14 Isometric view of the room with the position of the air inlets and outlets.

Configurations 2 (air inlets at point 1,3 / air outlets at point 8) and 5 (air inlets at point 2 / air outlets at point 8) obtained the highest removal efficiency because the air outlets were in the position above the patient head, the air quickly eliminated out of the room as shown in Figure 2.15.

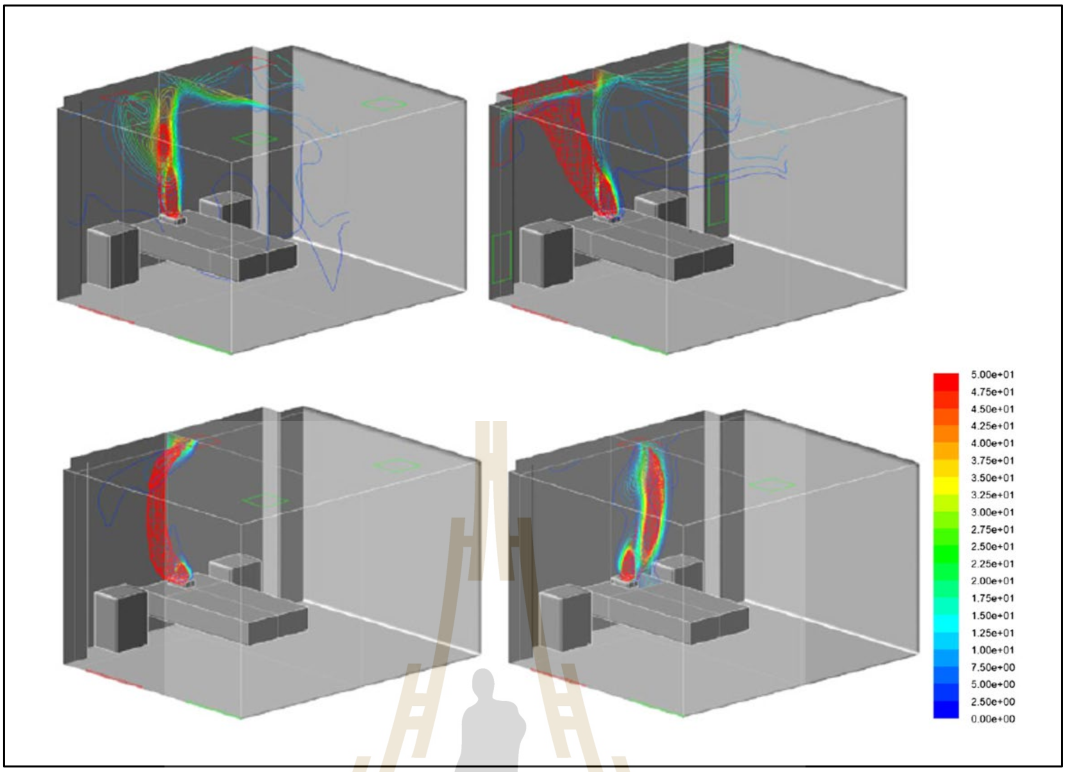

Figure 2.15 Isosurface of 50 quanta m^3 and quanta concentration in the planes x = 3 m and y = 2 m, for all the simulations with grille air supplies. Inlets are in green color and outlets are in red color (configuration 1 on the top left, configuration 12 on the top right, configuration 2 on the bottom left and configuration 5 on the bottom right).

Yang, et al. (2014) used Computational Fluid Dynamics (CFD) to analyze the air wind velocity, indoor temperature and air age of a bed room in summer. The results showed that the higher wind velocity obtained shorter air age and the air in a faraway area from the inlet air and outlet air obtained longer air age.

Bartak, et al. (2001) studied the differences in the results from the coarse grid (1,089 elements) with fine grid (24,300 elements) in CFD simulations compared with experimental results focused on the local mean age of air. The results showed that the coarse grid obtained the values closer from experimental result than the fine grid. Therefore, the coarse grid is enough for solving this purpose as the coarse grid values are higher than the fine grid for 4%.

CHAPTER III

RESEARCH METHODOLOGY

This research presents the predicting of air quality in the airborne infection isolation room. The installation positions of air channels are designed by using CFD simulation techniques to observe the air flow in the room. The CFD software is validated by investigating on the validating test cases. After ensuring the process of simulation, the real case is investigated to predict the air flow in the room to find the cause and leading to the guideline for improving the air quality.

3.1 Validation of CFD software

In this process, the CFD software has been investigated on the experiment results of Bartak el at (2001). The predicted results are compared with those of experiment results. The process of validation is described as follows.

3.1.1 Room geometry

Bartak et al (2001) studied the SVE-3 behaviors by using the experiment. The geometry of the room is shown in Figure 3.1. The room has constructed with the size of 4.2 × 3.6 × 3.0 m. It is included with one air inlet channel at the side of wall and one air outlet channel at the ceiling wall. Both have the side of 0.3 × 0.2 m.

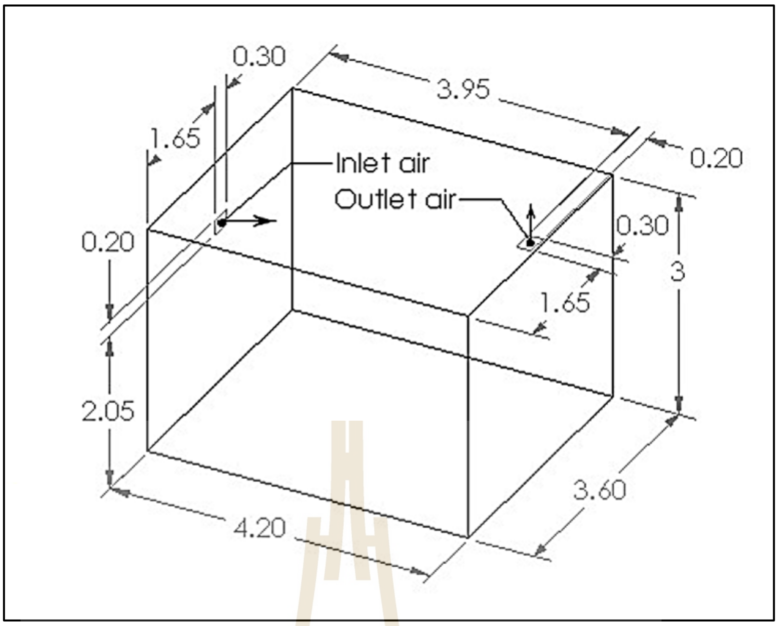

Figure 3.1 Schematic drawing of the test room (m.).

3.1.2 Specification of boundary conditions

The boundary conditions have been used to specify the boundary of the considered domain. In the software simulation, there are three types of the boundary condition that corresponding to those domain inlet, outlet and wall boundary condition. Each condition will be specified by the setting value as shown in Table 3.1.

Table 3.1 Boundary conditions for operation room.

Inlet velocity (m/s)	1.68
Air inlet temperature (^oC)	23
Turbulence kinetic energy of the inlet air (m^2/s^2)	1×10^{-4}
Turbulence dissipation rate of the inlet air (m^2/s^3)	1×10^{-4}
Outlet pressure (Pa)	0
Wall	No-slip

3.1.3 Turbulence model and meshing

In this study, the predicted results by using standard k-ε and RNG k-ε models are compared with experiment results. The meshing technique is constructed based on structured grid. Because this grid can be fitted on the shape of the room and interior objects, such as bed. In the predicting step, the residual convergence criteria are set with an order of 10^{-4}. The computation will stop as the residual of all equations decreases to 10^{-4}. The value of SVE-3 at the positions of lines x = 1.13, 2.20 and 3.20 m (see Figure 3.2) are used as the reference for comparing the data. The results show the percentage difference of SVE-3 from the experiment of Bartak et al (2001) and from the software prediction are shown in Figure 3.3.

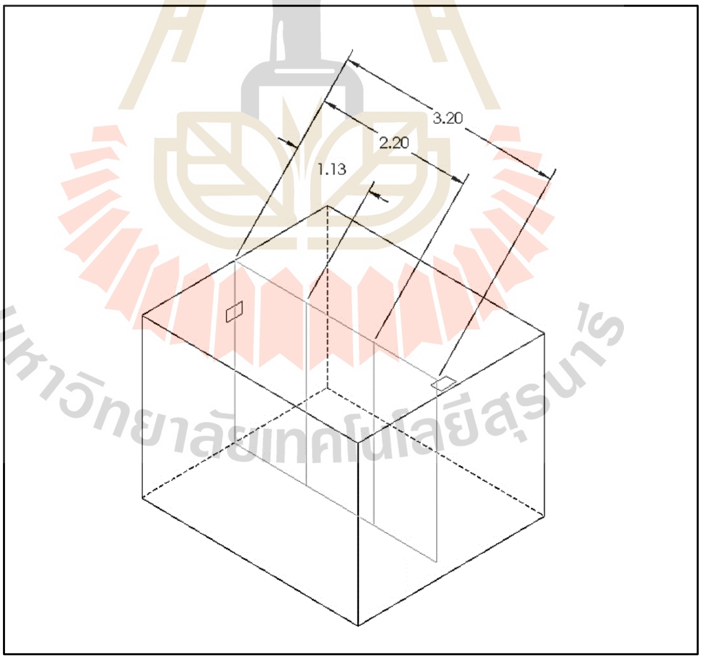

Figure 3.2 Positions for comparing the data.

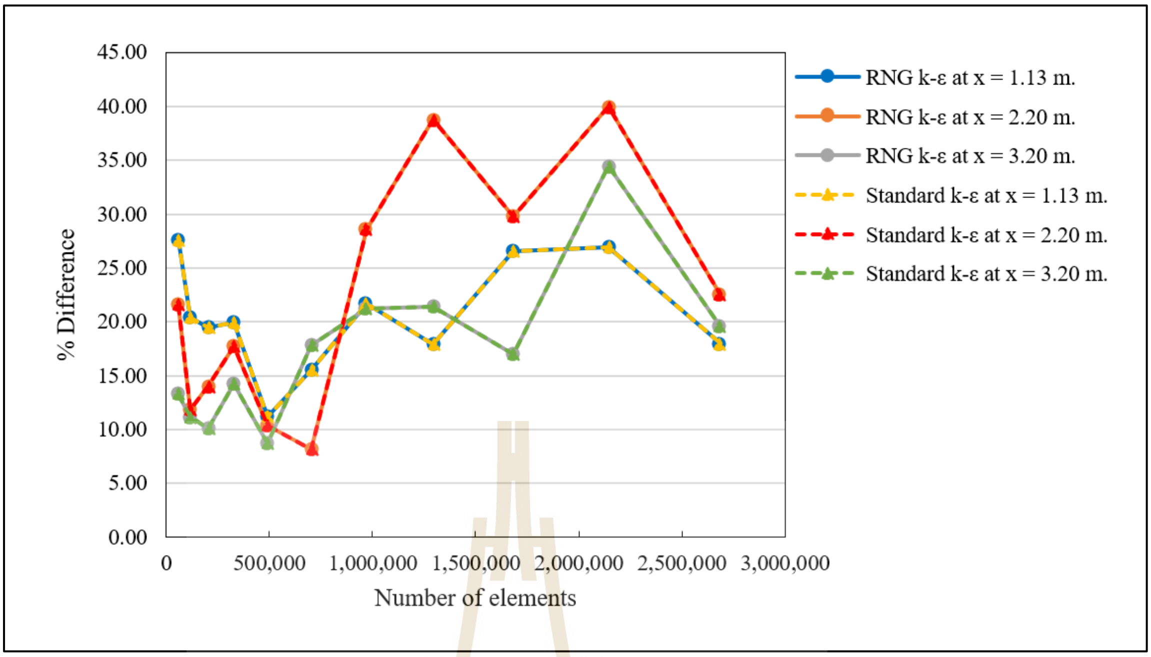

Figure 3.3 Percentage difference of SVE-3 between software prediction results and experiment results (Bartak et al 2001).

From Figure 3.3, it is found that both turbulence models give the same predicted value of SVE-3. However, in this study, the RNG k-ε turbulence model will be taken to be used. According to Rouaud and Havet's (2002) research, the RNG k- ε turbulence model provided more accurate than the standard k-ε model. Figure 3.3 shows that the element number of 492,800 gives the satisfactorily results close to the experiment results as the percentage difference about 10%.

3.2 Simulation of air flow in the airborne infection isolation room

After validation process, next step is to implement the software to predict the air flow behavior in the AIIR. The processes are shown in Figure 3.4.

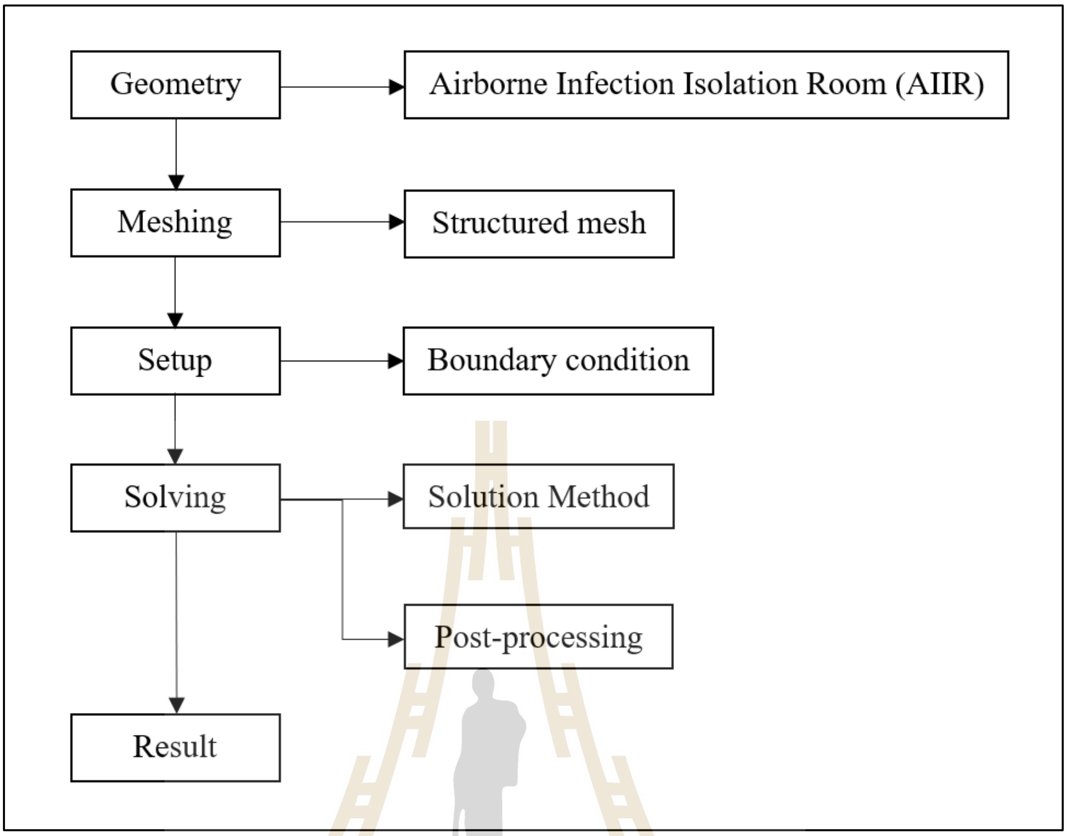

Figure 3.4 Diagram for simulation process.

3.2.1 Geometry

In this study, to compare the effect of room size on the air flow behavior, two room sizes are constructed as 3 × 6 × 3 m and 3.5 × 5.5 × 3 m. Fresh air is let into the anteroom through inlet air above the door and the gap under the door, then flow pass from anteroom to patient room through the air damper that is installed on the partition between both rooms. The size of inlet air and air damper are specified depending on the pressure in the patient room. The size of the air channel is the cause of pressure change in the room to control the pressure within the standard range.

In standard design, the room has divided to be two zones: the anteroom zone to prevent the air from patient room flowing back to the outdoor environment and the patient zone for treating patient to be treated. Both zones are separated with wall partition. In the anteroom, air conditioner has been installed on the wall. For patient room, bed and air outlet channels are fixed. The installation position of air inlet channel, air damper and air return channels are varied in order to study the air flow behavior. The air outlet channels are designed with the size of 0.3 × 0.3 m. They are located at the bed headboard at 0.15 m height above the floor. The air return channels are setup with the size of 0.3 × 0.3 m.

In this research, the study has been investigated based on four considered parameters: room size, position of the air inlet channel, air damper and air return channels. Details of each parameter are shown as follows.

3.2.1.1 Design of room size

Design of room size is considered based on two room. The study focused on the size of patient room. The first on is designed with the space of 3 × 6 × 3 m. The length of patient room is two times of the anteroom. The second one of room is designed with the size 3.5 × 5.5 × 3 m. It is shorter about 0.5 m but wider about 0.5 m compare with the first room. Both considered rooms are constructed as rectangular, Figure 3.5.

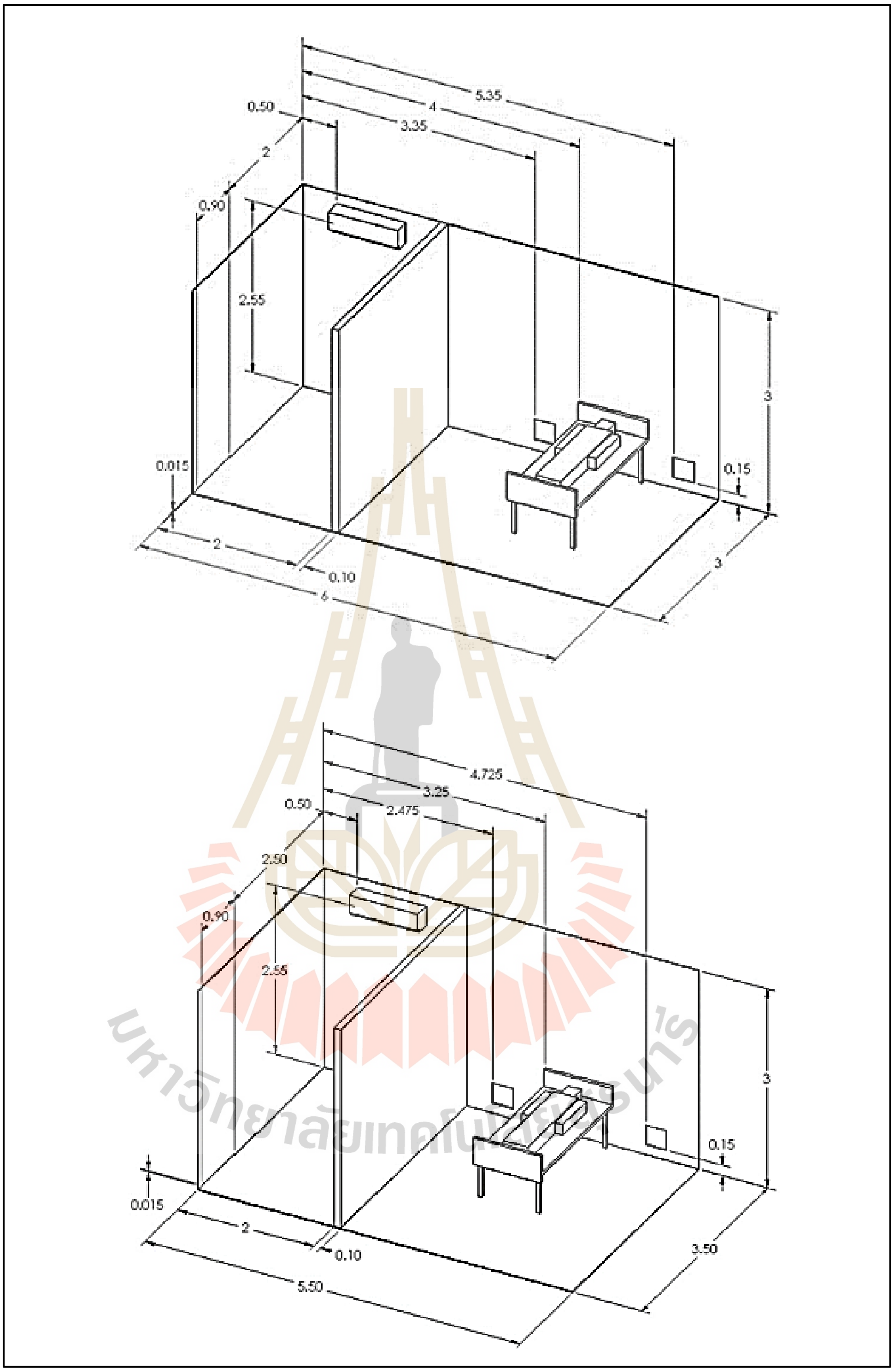

Figure 3.5 Geometry space of room type (top) 3 × 6 × 3 m (bottom) 3.5 × 5.5 × 3 m room size.

3.2.1.2 Design of air inlet channel and air damper positions

Air inlet channel and air damper positions are shown in Figure 3.6. There are two positions of the air inlet channels installed on the wall of the anteroom (position A and B). Two positions of air damper are installed on the wall partition between the patient room and the anteroom (position C and D). Generally, the AIIR is designed to have one channel of the air inlet. Because the air can sufficiently provide the air flowing into the room. In the room, the pressure must be controlled to give negative condition in order to prevent the airborne pathogen in the room flow outside without any treatment. The size of air inlet channel and air damper depended on controlling the pressure control in the patient room because the volume of the incoming air affects the pressure in the room. The positions of the air inlet channel and air damper are considered in four cases as shown in Table 3.2. The configurations of each cases are shown in Appendix A.

Table 3.2 The cases of inlet air channels and air damper.

Case	Inlet air channel	Air damper channel
AC	A	C
AD	A	D
BC	B	C
BD	B	D

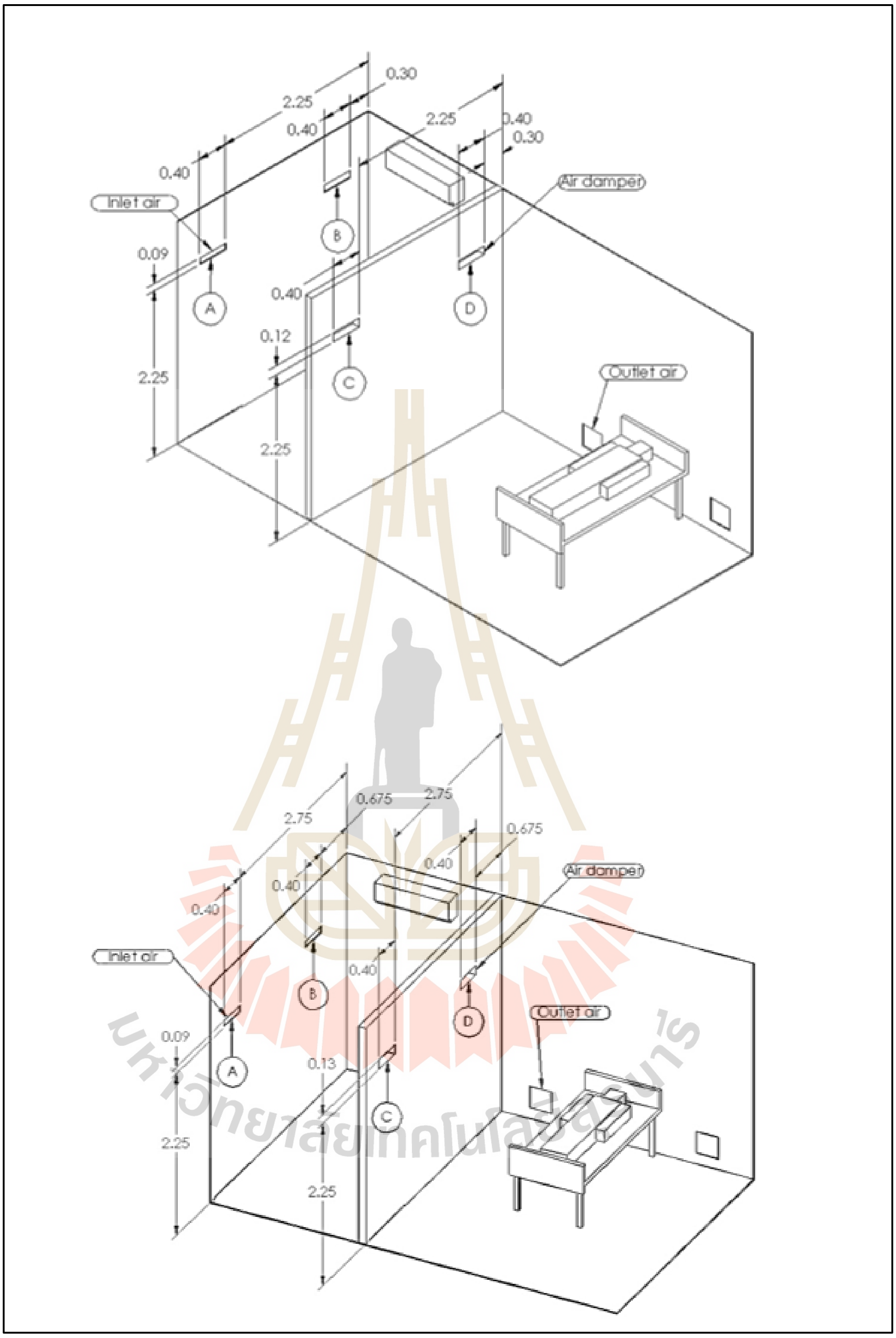

Figure 3.6 Position of air channel inlet and air damper for (top) 3 × 6 × 3 m (bottom) 3.5 × 5.5 × 3 m room size.

3.2.1.3 Design of air return channels

The patient room has affected by two air flow directions: air flow from the anteroom through the air damper and air flow from the air return channel that recovers inside air through the air conditioner. The positions for installing the air return channels are on the ceiling, wall and room partition. The installation of the air return channels at the back wall of the room will not be proper because it will make airborne pathogen flow through medical staff easily. In the study, the positions for installing the air return channels are considered with 12 positions as shown in Figure 3.7. Two positions are included to be the case study. Therefore, they are 6 cases to be considered here. The configurations of each case are shown in Appendix B.

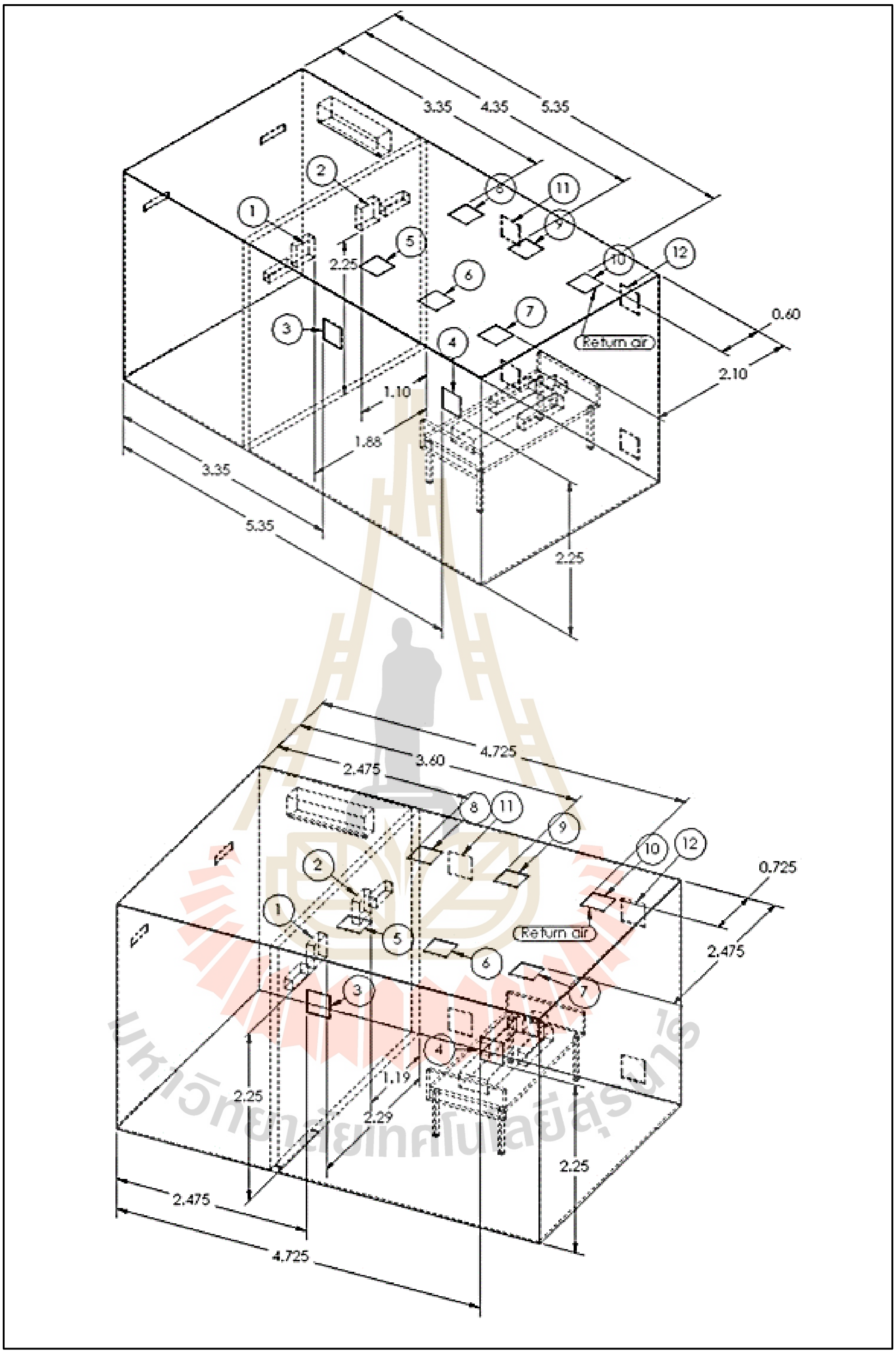

Figure 3.7 Varies position for installing the air return channels (top) 3 × 6 × 3 m (bottom) 3.5 × 5.5 × 3 m room size.

Table 3.3 The air return channels position on the room.

Position number	Location
1 - 2	Wall partition
3 - 4	Front side wall
11 - 12	Rear side wall
5 – 10	Ceiling wall

3.2.2 Meshing and grid independence

In this research, the structured grid has been used in the simulation process. This grid can be placed and fitted to the shape of the room. In this process, the grid will be constructed with small size near wall zone. Furthermore, at the position where the flow will change too much in its behavior, such as the position of inlet/outlet channel, the grid will be constructed with high density as well.

In the process of grid independence testing, the grid elements have been created with varied number. The prediction of SVE-3 values has been used as the validation parameter. If any of two grid levels provides the similar results of SVE-3, the lower grid level will be taken as the grid to use in computation. In this study, the independence grid level is generated for 2 sets corresponding to the size of room.

The 3 × 6 × 3 m room size has been investigated on the grid number of 96,000, 175,000, 288,000, 441,000, 640,000 and 891,000 elements while the 3.5 × 5.5 × 3 m room size has been performed with 117,000, 206,250, 331,500, 498,750, 714,000 and 983,250 elements. The results of predicted SVE-3 on each grid level are shown in Figure 3.8. It is found that the grid level with the number of 441,100 and

206,250 elements for the 3 × 6 × 3 m and 3.5 × 5.5 × 3 m room size are satisfied with the grid independence condition. The configuration of grid for those room size cases are shown in Figure 3.9.

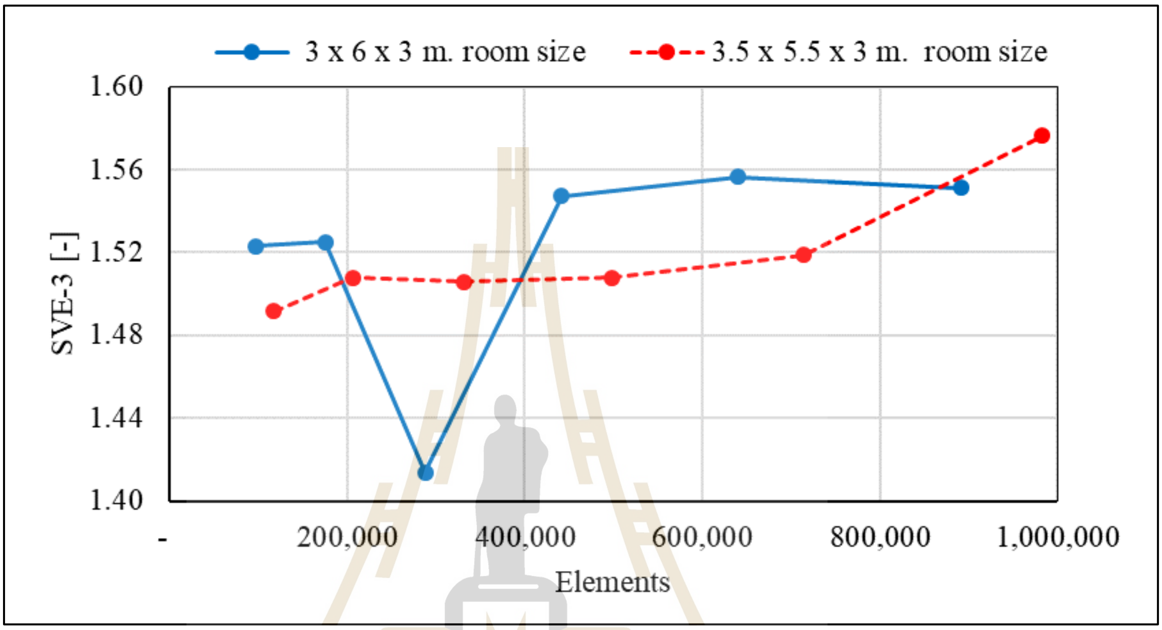

Figure 3.8 The results of SVE-3 based on each grid levels.

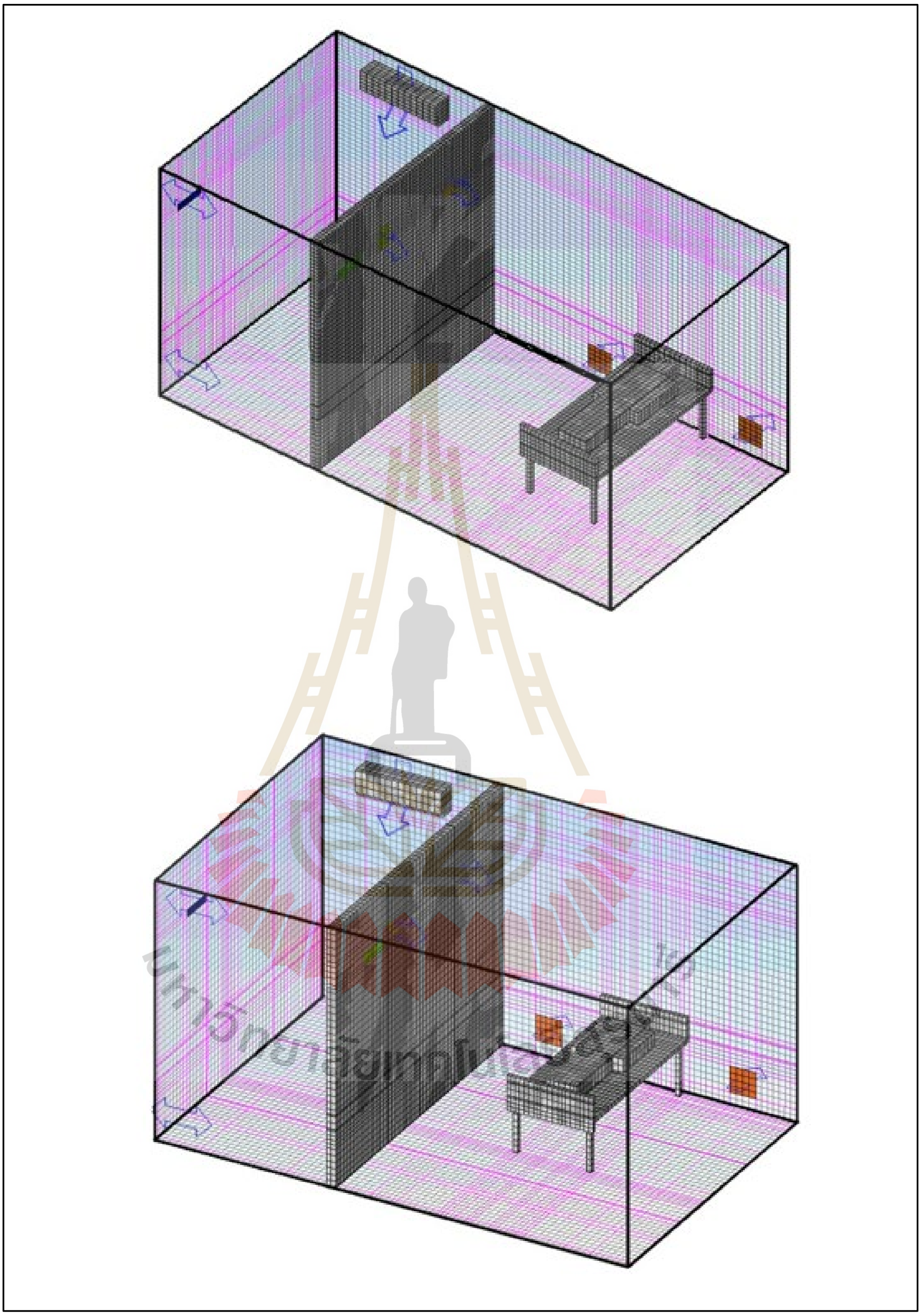

Figure 3.9 Grid configuration for (top) 3 × 6 × 3 m (bottom) 3.5 × 5.5 × 3 m room size.

3.2.3 Setup

3.2.3.1 Boundary conditions

In this study, the actual inlet air velocity is set to be unknown. The environment inside the room, however, the relative pressure in the room must be lower than outside the room (negative room pressure), in which at least -2.5 Pa for the anteroom and -5 Pa for the patient room. The required negative pressure conditions as previous state can be provided by suctioning the air out of the room. The air will be driven by the negative pressure effect and then flows from outside into the room through inlet air channel. The pressure at the inlet air channel will be set at 0 Pa equal to the outside pressure. Therefore, in order to drive the pressure to be negative, the air flow at the air outlet channels must be specified with suitable value. In this study, outflow air velocity has been adjusted until the pressure condition in the anteroom and the patient room are found to be -2.5 Pa and -5 Pa, respectively. The boundary conditions for this simulation are shown in Table 3.3.

Table 3.3 The boundary conditions for simulation of air flow.

Flow field	Incompressible flow	
	Steady-state	
Flow model	RNG $K-\varepsilon$ turbulence model	
Inlet	Inlet pressure	$0 Pa$
	Turbulence kinetic energy	$1\times10^{-4} m^2/s^2$
	Turbulence dissipation rate	$1\times10^{-4} m^2/s^3$
	Temperature	$30^{\circ}C$
Outlet	Outlet velocity	$1.6 m/s$
	Temperature	$24^{\circ}C$

Table 3.3 The boundary conditions for simulation of air flow. (Continued)

Air conditioner	Supply air velocity	$2m/s$
	Supply air temperature	$24^{\circ}C$
	Turbulence kinetic energy	$1\times10^{-4}m^2/s^2$
	Turbulence dissipation rate	$1\times10^{-4}m^2/s^3$
	Air return conditioner velocity	$0.87m/s$
	Air return conditioner temperature	$25^{\circ}C$
Return air	Inlet velocity	$1m/s$
	Turbulence kinetic energy	$1\times10^{-4}m^2/s^2$
	Turbulence dissipation rate	$1\times10^{-4}m^2/s^3$
	Temperature	$24^{\circ}C$
Wall	No-slip	
	Convection heat transfer coefficient	$200kJ/kg^{\circ}C$

The PC at Shibaura Institute of Technology was used to simulate the air flow with CPU core of i7-4790K 4.00 GHz, and RAM with 8.00 GB. The average time to simulate was approximated to 10 minutes.

3.3 Method to maintain the pressure in the room

In order to tuning the pressure in the room to satisfied the needing conditions, the changing of air channel sizes have been performed as follows.

1. Determine (assuming) the size of air inlet channel of 0.4 × 0.3 m and air damper of 0.4 × 0.3 m.

2. Determine the air velocity of 1.6 m/s at the air outlet channel and 1.0 m/s at the air return channels.

3. Run the case until all equations are convergence.

4. Check the pressure in the room that both in the anteroom and patient room is in the standard range or not. The pressure in the anteroom is -2.5 Pa and in the patient is -5.0 Pa.

4.1 If pressure in the anteroom is higher than -2.5 Pa, the tuning can be done by decreasing the size of air inlet channel.

4.2 If pressure in the anteroom is lower than -2.5 Pa, the tuning can be done by increasing the size of air inlet channel.

4.3 If pressure in the patient room is higher than -5.0 Pa, the tuning can be done by decreasing the size of air damper.

4.4 If pressure in the patient room is lower than -5.0 Pa, the tuning can be done by increasing the size of air damper.

5. Repeat step 3. and 4. until the pressure in the room satisfy the standard range.

CHAPTER IV

RESULTS AND DISCUSSION

The main objective of this research is to study the behavior of air flow, air change rate, temperature, pressure and humidity in the AIIR. Two room sizes of 3 × 6 × 3 m and 3.5 × 5.5 × 3 m have been investigated by using CFD methodology to simulate the air flow. The positions of the air inlet channel, air damper and the air return channels are to find the suitable positions for providing the good condition of air quality.

Based on the air flow prediction on AIIR, the values of air quality (SVE-3), temperature, velocity, and pressure are obtained. The relative humidity and the air change rate are calculated from Eq 2.1 and Eq 2.4, respectively. The values of the considered parameters are shown in Table 4.1 and Table 4.2.

Table 4.1 Results for 3 × 6 × 3 m room size.

Case	Pressure in anteroom [Pa]	Pressure in patient room [Pa]	Temperature in anteroom [ºC]	Temperature in patient room [ºC]	Humidity in anteroom [%RH]	Humidity in patient room [%RH]	Velocity in patient room [m/s]	Air change rate [ACH]	Velocity at inlet air [m/s]	Intake air rate [ACH]	SVE-3 in patient room [-]	SVE-3 at bed [-]
AC (1-2)	-3.03	-5.81	25.66	25.91	49.12	48.40	0.187	19.20	1.5	9.00	1.547	1.555
AC (3-4)	-3.05	-5.87	25.53	25.28	49.51	50.24	0.181	19.20	1.505	9.03	1.38	1.414
AC (5-7)	-3.07	-5.37	25.59	25.47	49.33	49.68	0.169	19.20	1.522	9.13	1.554	1.416
AC (6-9)	-3.05	-6.03	25.62	25.12	49.24	50.73	0.157	19.20	1.495	8.97	1.391	0.913
AC (8-10)	-3.04	-5.84	25.65	26.34	49.15	47.19	0.158	19.20	1.53	9.18	1.903	1.768
AC (11-12)	-3.06	-6.2	25.67	24.96	49.10	51.21	0.147	19.20	1.517	9.10	1.112	1.187
AD (1-2)	-2.89	-6.33	26.31	24.56	47.27	52.45	0.181	19.20	1.468	8.81	1.222	1.285
AD (3-4)	-3.17	-6.83	26.37	24.77	47.10	51.79	0.161	19.20	1.532	9.19	1.354	1.27
AD (5-7)	-2.95	-6.5	26.18	24.67	47.64	52.11	0.19	19.20	1.482	8.89	1.247	1.469
AD (6-9)	-3.15	-6.82	26.25	24.75	47.44	51.86	0.173	19.20	1.536	9.22	1.405	1.191
AD (8-10)	-3.05	-6.75	26.25	24.81	47.44	51.67	0.169	19.20	1.51	9.06	1.396	1.255
AD (11-12)	-3.15	-6.83	26.26	24.82	47.41	51.64	0.197	19.20	1.565	9.39	1.447	1.609
BC (1-2)	-3.03	-6.72	25.87	25.22	48.52	50.42	0.193	19.20	1.569	9.41	1.522	1.484
BC (3-4)	-2.9	-6.43	25.91	24.9	48.40	51.39	0.181	19.20	1.538	9.23	1.527	1.507
BC (5-7)	-2.9	-6.43	25.97	24.9	48.23	51.39	0.164	19.20	1.537	9.22	1.582	1.334
BC (6-9)	-2.91	-6.52	25.98	24.95	48.20	51.24	0.165	19.20	1.54	9.24	1.427	1.006
BC (8-10)	-2.9	-6.42	25.95	25.08	48.29	50.85	0.161	19.20	1.54	9.24	1.708	1.666
BC (11-12)	-2.9	-6.42	25.93	24.79	48.34	51.73	0.153	19.20	1.537	9.22	1.391	1.54
BD (1-2)	-2.9	-6.71	26.14	24.66	47.75	52.14	0.183	19.20	1.541	9.25	1.232	1.313
BD (3-4)	-2.93	-8.74	26.11	24.81	47.83	51.67	0.186	19.20	1.551	9.31	1.229	1.29
BD (5-7)	-2.9	-6.59	26.12	24.84	47.80	51.58	0.176	19.20	1.536	9.22	1.267	1.4
BD (6-9)	-2.91	-6.69	26.11	24.91	47.83	51.36	0.172	19.20	1.536	9.22	1.416	1.154
BD (8-10)	-2.91	-6.7	26.15	24.94	47.72	51.27	0.179	19.20	1.551	9.31	1.47	1.315
BD (11-12)	-2.93	-8.72	26.1	24.81	47.86	51.67	0.194	19.20	1.552	9.31	1.263	1.346

Table 4.2 Results for 3.5 × 5.5 × 3 m room size.

Case	Pressure in anteroom [Pa]	Pressure in patient room [Pa]	Temperature in anteroom [ºC]	Temperature in patient room [ºC]	Humidity in anteroom [%RH]	Humidity in patient room [%RH]	Velocity in patient room [m/s]	Air change rate [ACH]	Velocity at inlet air [m/s]	Intake air rate [ACH]	SVE-3 in patient room [-]	SVE-3 at bed [-]
AC (1-2)	-2.54	-5.58	25.13	25.11	50.70	50.76	0.16	17.95	1.315	7.38	1.463	1.477
AC (3-4)	-3.04	-6.19	25.31	24.57	50.16	52.42	0.172	17.95	1.282	7.19	1.443	1.446
AC (5-7)	-3.05	-5.77	25.31	24.75	50.16	51.86	0.166	17.95	0.928	5.21	1.424	1.501
AC (6-9)	-2.53	-5.09	25.32	24.34	50.13	53.15	0.136	17.95	1.322	7.42	1.365	0.989
AC (8-10)	-3.28	-5.3	24.97	26.05	51.18	48.00	0.131	17.95	1.286	7.21	1.843	1.829
AC (11-12)	-3.05	-5.56	25.19	24.7	50.52	52.01	0.155	17.95	1.17	6.56	1.284	1.489
AD (1-2)	-2.51	-5.78	25.35	24.4	50.04	52.95	0.171	17.95	1.289	7.23	1.145	1.398
AD (3-4)	-3.05	-5.84	25.36	24.58	50.01	52.39	0.162	17.95	1.275	7.15	1.192	1.352
AD (5-7)	-3.05	-5.83	25.47	24.73	49.68	51.92	0.162	17.95	0.923	5.18	1.335	1.624
AD (6-9)	-2.53	-5.87	25.18	24.41	50.55	52.92	0.151	17.95	1.334	7.48	1.305	1.004
AD (8-10)	-3.26	-6.24	25.44	24.61	49.77	52.29	0.163	17.95	1.28	7.18	1.323	1.128
AD (11-12)	-3.05	-5.86	25.42	24.7	49.83	52.01	0.176	17.95	1.29	7.24	1.171	1.324
BC (1-2)	-2.82	-5.83	25.75	24.85	48.86	51.55	0.167	17.95	1.312	7.36	1.545	1.565
BC (3-4)	-2.93	-6.09	25.79	24.68	48.75	52.07	0.173	17.95	1.308	7.34	1.57	1.483
BC (5-7)	-2.92	-6.08	25.81	24.73	48.69	51.92	0.165	17.95	1.029	5.77	1.466	1.58
BC (6-9)	-2.77	-5.6	25.59	24.5	49.33	52.64	0.146	17.95	1.343	7.53	1.337	0.922
BC (8-10)	-2.93	-6.11	25.82	25.01	48.66	51.06	0.136	17.95	1.309	7.34	1.905	2.113
BC (11-12)	-2.93	-6.07	25.79	24.55	48.75	52.48	0.166	17.95	1.298	7.28	1.32	1.539
BD (1-2)	-2.51	-5.46	25.54	24.34	49.48	53.15	0.174	17.95	1.438	8.07	1.092	1.297
BD (3-4)	-2.6	-5.51	25.65	24.55	49.15	52.48	0.159	17.95	1.436	8.06	1.21	1.414
BD (5-7)	-2.6	-5.52	25.68	24.65	49.07	52.17	0.164	17.95	1.015	5.69	1.279	1.496
BD (6-9)	-2.56	-5.6	25.29	24.34	50.22	53.15	0.145	17.95	1.488	8.35	1.35	1.031
BD (8-10)	-2.8	-5.92	25.7	24.57	49.01	52.42	0.169	17.95	1.436	8.06	1.326	1.11
BD (11-12)	-2.6	-5.51	25.67	24.6	49.10	52.32	0.179	17.95	1.315	7.38	1.216	1.423

4.1 Air change rate

The standard value of air change rate for the considered room must not less than 12 ACH (The Engineering Institute of Thailand under H.M. the King's Patronage). From Table 4.1 and Table 4.2, the results show that the air change rate of all cases are equal to 19.20 ACH and 17.95 ACH for 3 × 6 × 3 m and 3.5 × 5.5 × 3 m room size, respectively.

Although this room has the appropriate air change rate, it is still undefined whether the room has good air quality or not. Therefore, the SVE-3 (Scale Ventilation Efficiency) has been taken to be used as the indicator of the air quality. The small value of SVE-3 indicates that in this area has good air quality and the fresh air is quickly replaced in.

The SVE-3 in the patient room is used to analyze the overall air quality of the room. This can use to identify the areas that have good air quality or not. The average of SVE-3 at the patient bed is analyzed for air quality in the area where patient stays. This is very important area because, if the air quality is poor, it can be the cause of patient to receive poor treatment

From Table 4.1 and Table 4.2, the results can be divided into two cases: for the room size of 3 × 6 × 3 m and 3.5 × 5.5 × 3 m. The study considers the effect of air inlet, air damper and return air channel position. The positions of each air channels are shown Chapter III. In consideration, the SVE-3 value at the bed zone will be controlled to be lower than 1.0. The less value of SVE-3 is the better quality of the air. The results of SVE-3 are considered in the case studies as follow.

4.1.1 SVE-3 predicted results for the 3 × 6 × 3 m room size

From Table 4.1, the distribution of SVE-3 in the patient room and the bed zone area are shown in Figure 4.1. Name of each case refers to positions of air inlet channel, air damper and air return channels. For example, AC (1-2) means air inlets at channel A, air damper at position C and air return at channel 1 and 2.

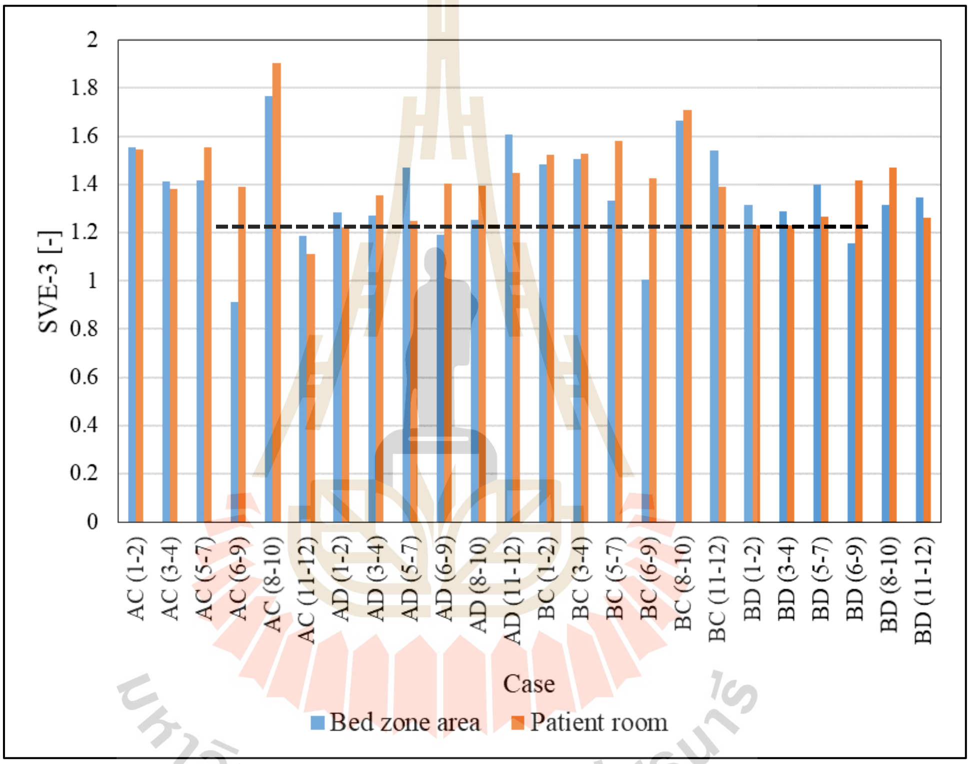

Figure 4.1 The predicted SVE-3 values for the 3 × 6 × 3 m room size.

Figure 4.1 shows that the predicted SVE-3 value at the bed zone area of the case AC (6-9) and case BC (6-9) are less than 1. The position of both air channels can provide the suitable condition for the rehabilitation of the patient. However, the best result of SVE-3 is the case AC (6-9) because it gives the lower value of SVE-3 than case BC (6-9). The streamlines if that case is shown in Figure 4.2.

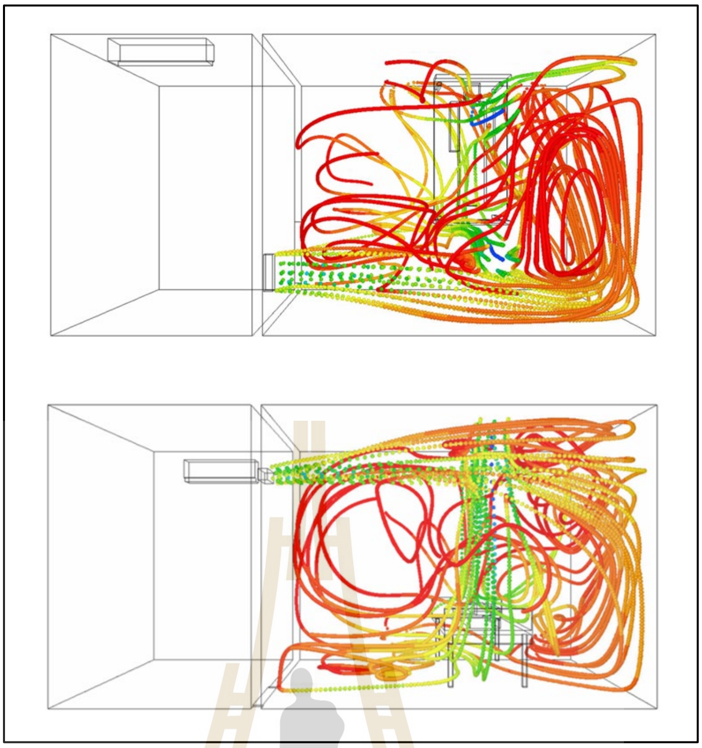

Figure 4.2 The predicted SVE-3 distribution along the flow direction for case AC (6-9) (top) top view and (bottom) front view.

Figure 4.2 illustrates the predicted SVE-3 distribution along the flow direction of the air from air damper and air return channels through the patient bed. Most of air has been immediately sucked out at the air outlet channels beside the patient's headboard. In this area, therefore, the SVE-3 seems to be stayed with the low value. Air flow from damper has mixed with the air flow from return channel and passes to the side wall of the room before sucked out of the room. The non-sucked air will diffuse to the middle and top zones of the room as shown in Figure 4.3. Because of there is no air inlet channel to fill the fresh air in. So, the air in this area come to be longer suspension than the rest of areas. As a result, the results of SVE-3 values in the patient room is higher than 1.0.

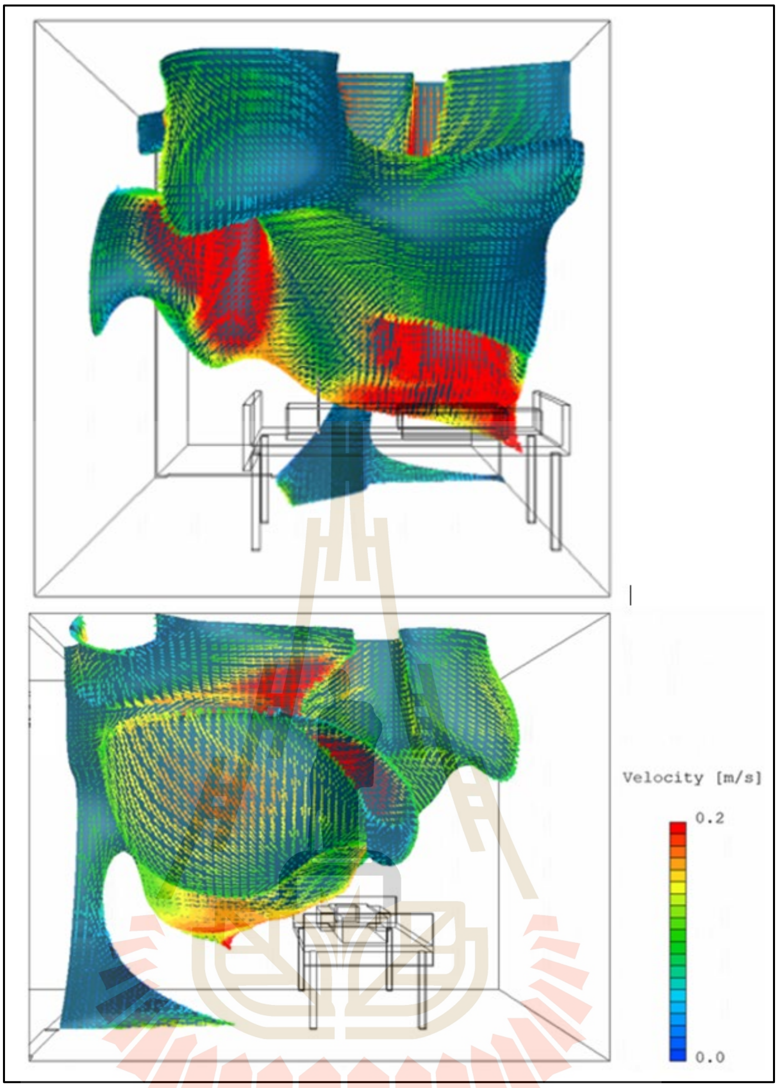

Figure 4.3 Stationary zone of SVE-3 for case AC (6-9) (top) side view and (bottom) front view.

Figure 4.3 shows the stationary zone where the value of predicted SVE-3 is higher than 1.5 in the patient room. For the case that provides the best predicted SVE-3 is case AC (11-12). The streamlines and distribution are revealed in Figure 4.4.

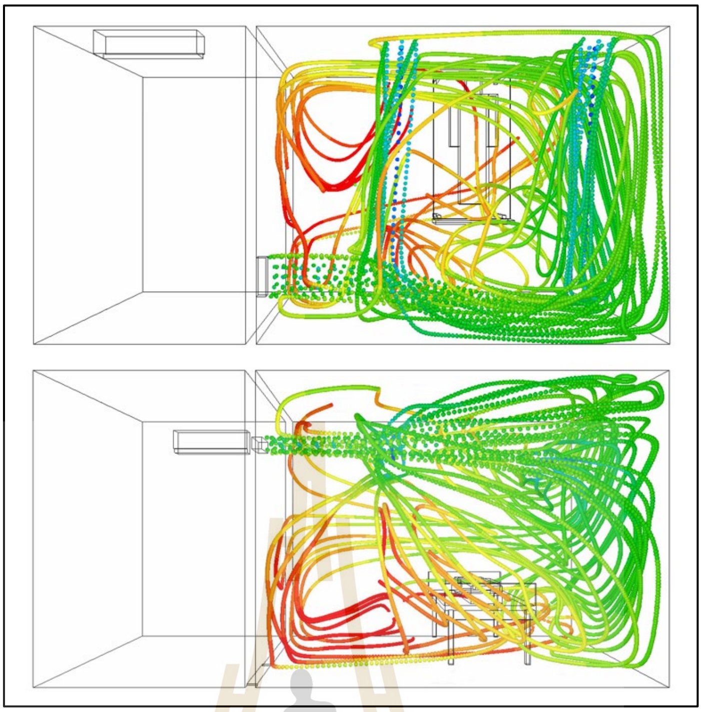

Figure 4.4 The predicted SVE-3 distribution along the flow direction for case AC (11-12) (top) top view and (bottom) front view.

From Figure 4.4, it is found that the air flow from air return channel 11 and 12 give more distribution of the flow compare woth the case AC (6-9) which is let the flow from channel 6 and 9. This is because the room width is longer than its longitudinal side. This makes the air distribution better than those of other cases. In addition, the flow of air from damper at the position C has also mixed with the air flow from the return channel. This allows the flow of air pass to the side of the room. Most of the air has sucked out from the room at the outlet channels located at the right side of the bed position. The non-sucked air in the room will be laydown at lower zone of the room floor and some parts are attached to the room wall partition as shown in Figure 4.5.

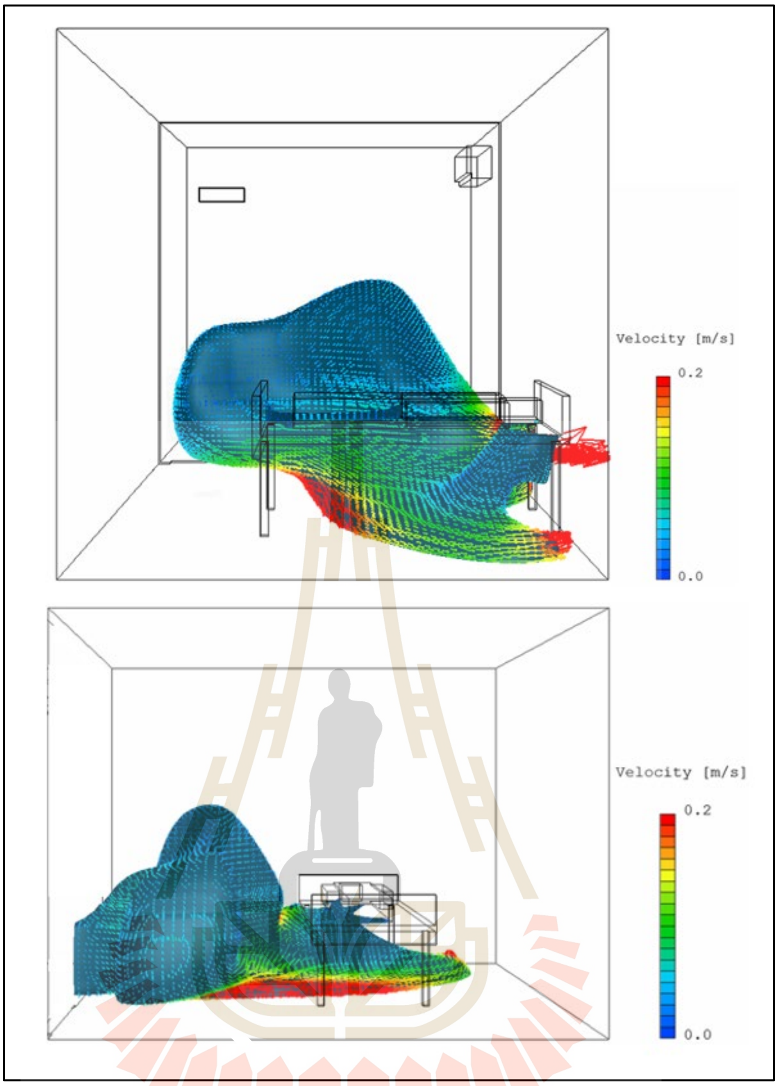

Figure 4.5 Stationary zone of SVE-3 for the case AC (11-12)

(top) side view and (bottom) front view.

4.1.2 The predicted SVE-3 results for the 3.5 × 5.5 × 3 m room size

From Table 4.2, the predicted SVE-3 value in the patient room and bed area zone are shown in Figure 4.6.

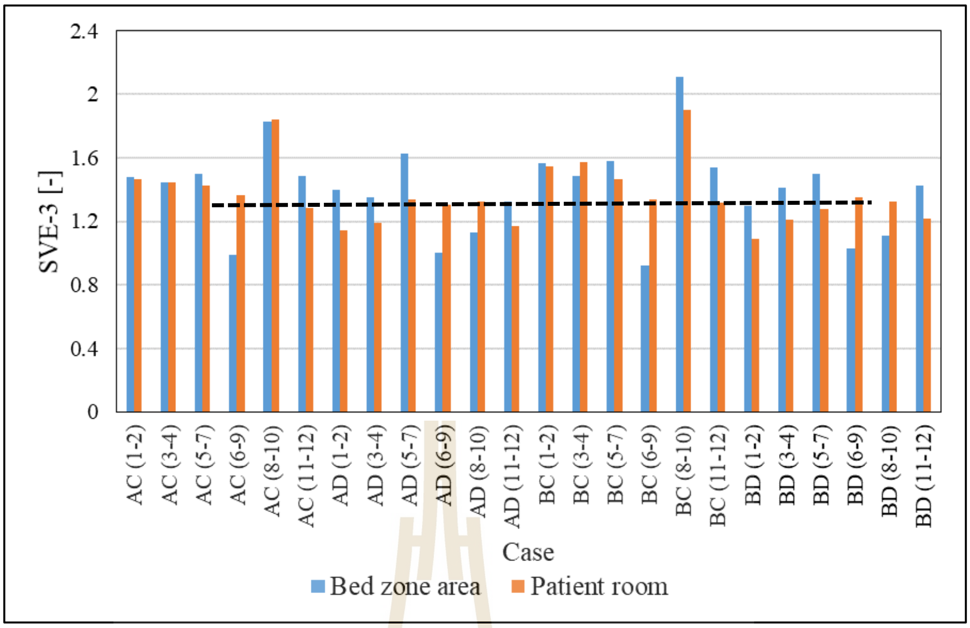

Figure 4.6 The predicted SVE-3 values for the 3.5 × 5.5 × 3 m room size.

From Figure 4.6, it states that there are three cases with the SVE-3 value less than 1 around the bed zone area. The position of both air channels can provide the suitable condition for the rehabilitation of the patient. The case that gives the best result of minimum SVE-3 value as same as 3 × 6 × 3 m room size is case BC (6-9). The streamline is shown in Figure 4.7.

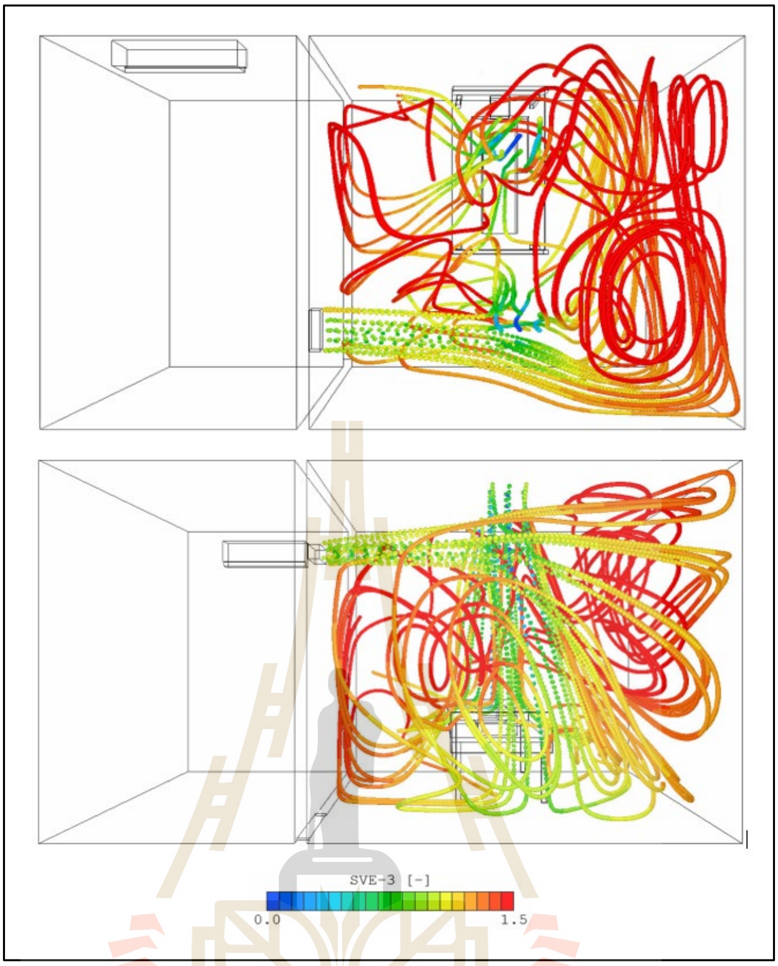

Figure 4.7 The predicted SVE-3 distribution along the flow direction for case BC (11-12) (top) top view and (bottom) front view.

Figure 4.7 illustrates the SVE-3 distribution along the flow direction from the air return channels along the patient bed. Then, most of air has immediately sucks out at the patient's headboard as shown in Figure 4.8. Partial non-sucked air from the air damper arises at the middle and top of the room as shown in Figure 4.9. Because there is no any air channel to fill the fresh air in this zone. As the result, the air in this area has longer age than the other areas. Partial air from the air damper is mixed with air from the air return channels and flows down to the floor before releasing out of the room. Therefore, the result of SVE-3 values in the patient room is higher than 1.0.

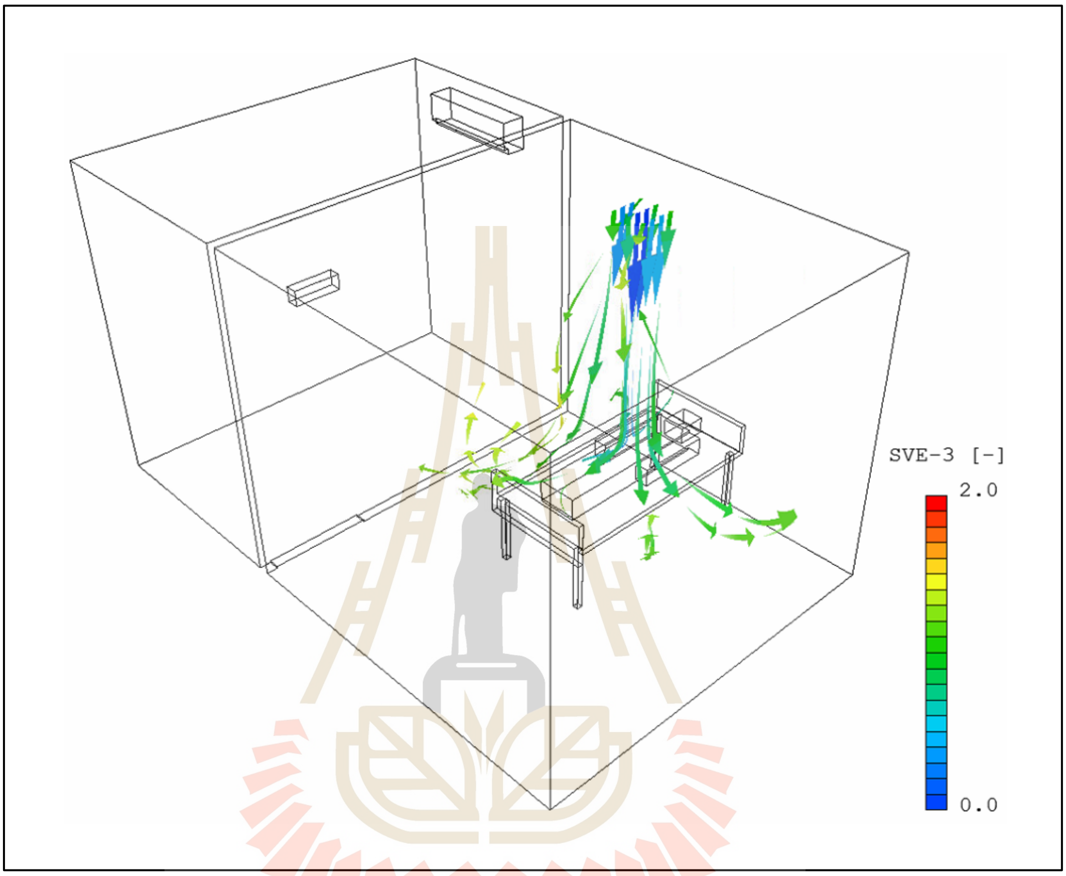

Figure 4.8 The predicted SVE-3 distribution from air return channels in case BC (6-9).

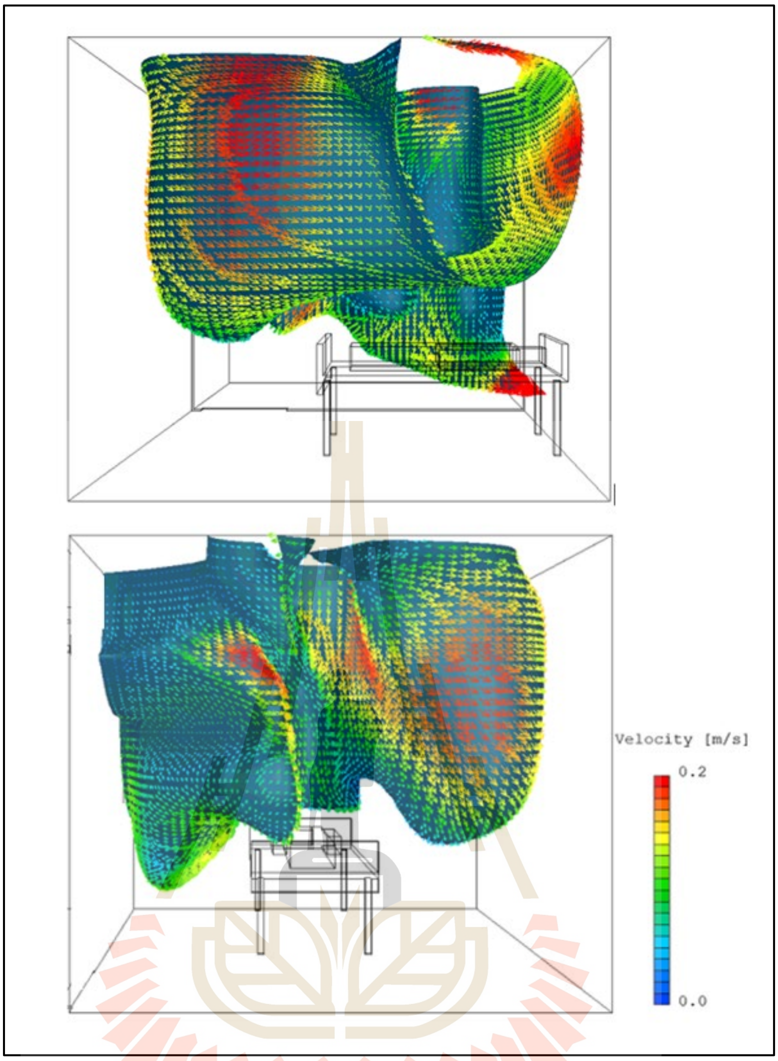

Figure 4.9 Stationary zone of SVE-3 for case BC (6-9) (top) side view and (bottom) front view.

From Figure 4.9, it is found that the non-flow air exists at partition because partial air flows to this area and cannot be transferred out. Generally, most of the air flows to bed and immediately sucks out of the room. Figure 4.9 shows the stationary zone where the SVE-3 value is higher than 1.5 in the patient room. In contrast, the best case that provides the minimum SVE-3 value is the case BD (1-2) as the air flow direction shown in Figure 4.10.

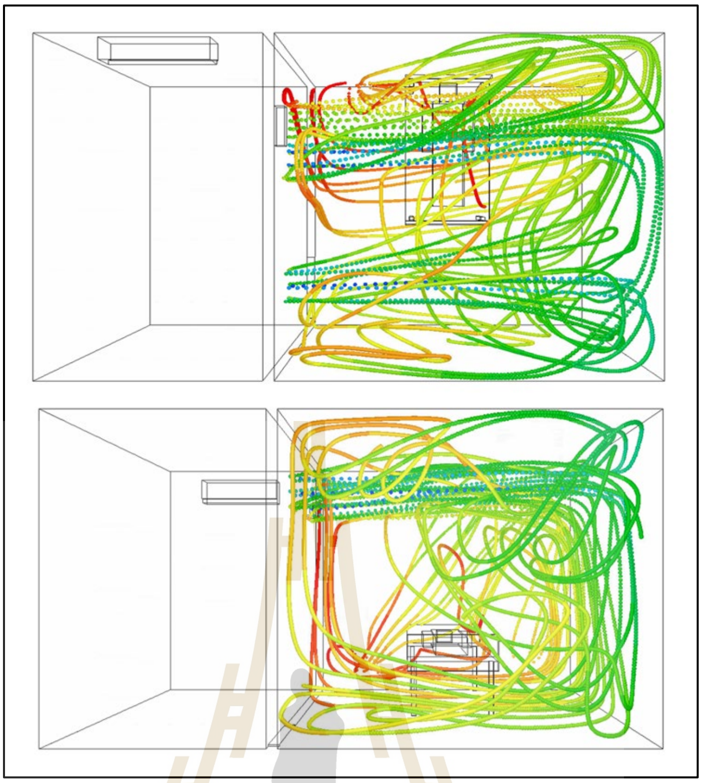

Figure 4.10 The predicted SVE-3 distribution along the flow direction for case BD (1-2) (top) top view and (bottom) front view.

From Figure 4.10 it is found that the air that flows from channel 1 and 2 give the appropriate air distribution towards all rooms because the room width is equal to the longitudined side. In addition, the flow from air damper at the position D has also mixed with the air flow from the air return channel and let the air flow in the same direction. This phenomenon allows the air flow to the side of the room, flow down to the floor, then sucked out of the room at the air outlet channels at the right side of the be. The non-sucked air at the corner of the room with partition floats at lower layer above the floor and then sucked out immediately as shown in Figure 4.11 so there is no any fresh air remaining in this area.

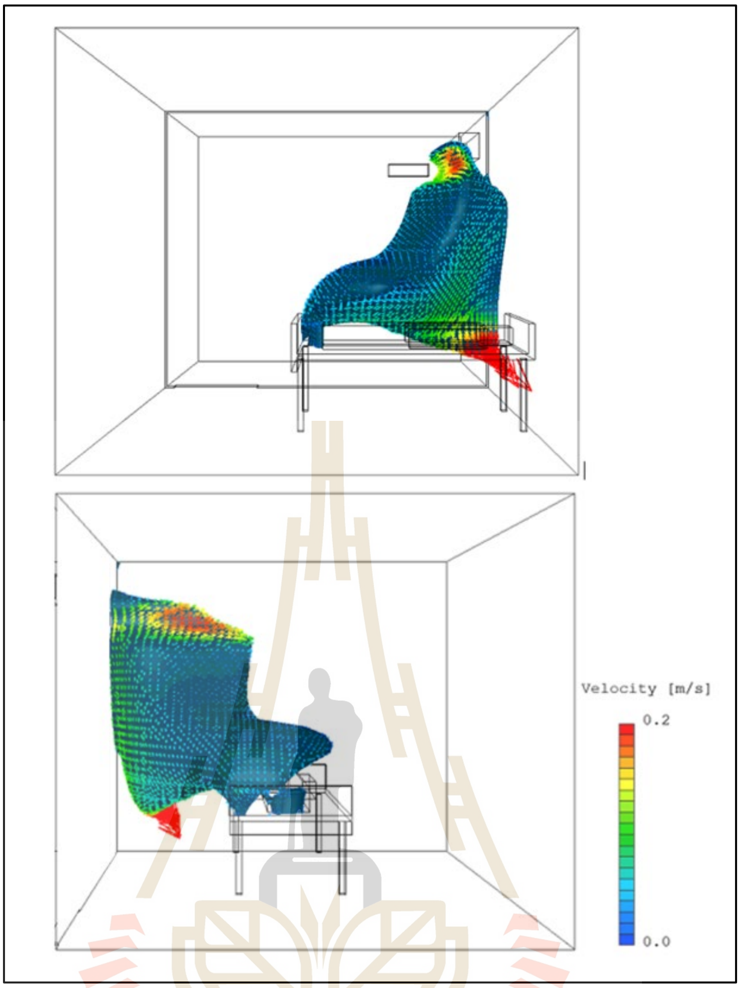

Figure 4.11 Stationary zone of SVE-3 for case BD (1-2) (top) side view and (bottom) front view.

4.1.3 Effect of air channels position

In this research, the influence of the air channels position on the flow come from three parts; inlet channel, air damper and return channel as described follow:

4.1.3.1 Effect of inlet channel

From Table 4.1 and Table 4.2, when the position of the inlet channel has changed while the position of air damper and the return channel are fixed. It is found that the SVE-3 values are similar. For example, the predicted SVE-3 value is 1.391 for the 3 × 6 × 3 m room size in case AC (6-9) and value is 1.472 for case BC (6-9). For the 3.5 × 5.5 × 3 m room size, the predicted SVE-3 is 1.365 for case AC (6-9) and is 1.337 for case BC (6-9).

The result depicted is Figure 4.12 shows the similar SVE-3 value for both cases. The air flowed through the damper at the same position. The contour of the SVE-3 values at difference position of the inlet channel. Above one is that the air inlet channel alignment with the damper position (case AC). Bottom is the difference alignment position (case BC).

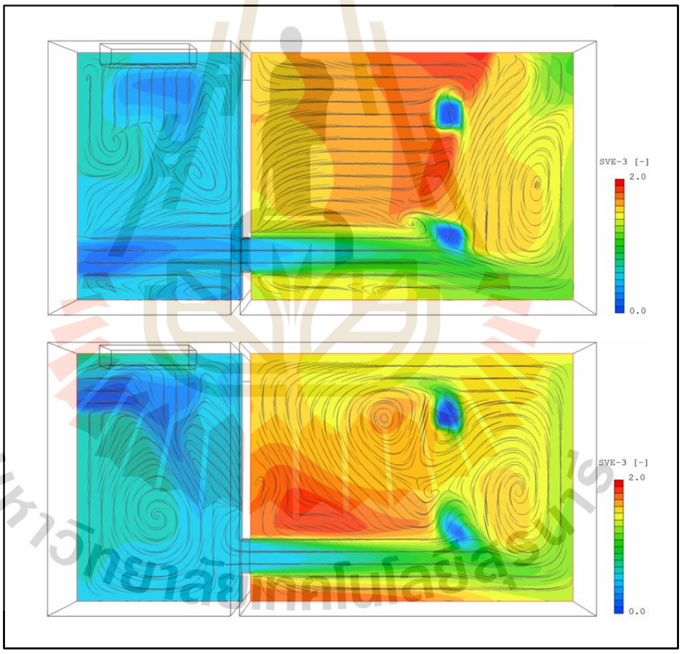

Figure 4.12 Contour of SVE-3 and streamline for 3 × 6 × 3 m room size (top) case AC (6-9) and (bottom) case BC (6-9).

4.1.3.2 Effect of air damper and air return channel positions

The effect of air damper and air return channel to the flow depend on the alignment position. The most effective result appears where the position of inlet channel and air damper are installed at position 8 and 10, respectively. If both channels are not in lined alignment such as position C, the result will give the worst condition of the air quality. Since the air from return channels does not mix with the air in the rest area. It will immediately flow out of the room. The air from the air damper also flows to the room's right-side wall and flows out at the outlet channels on the right side of the bed (see Figure 4.13).

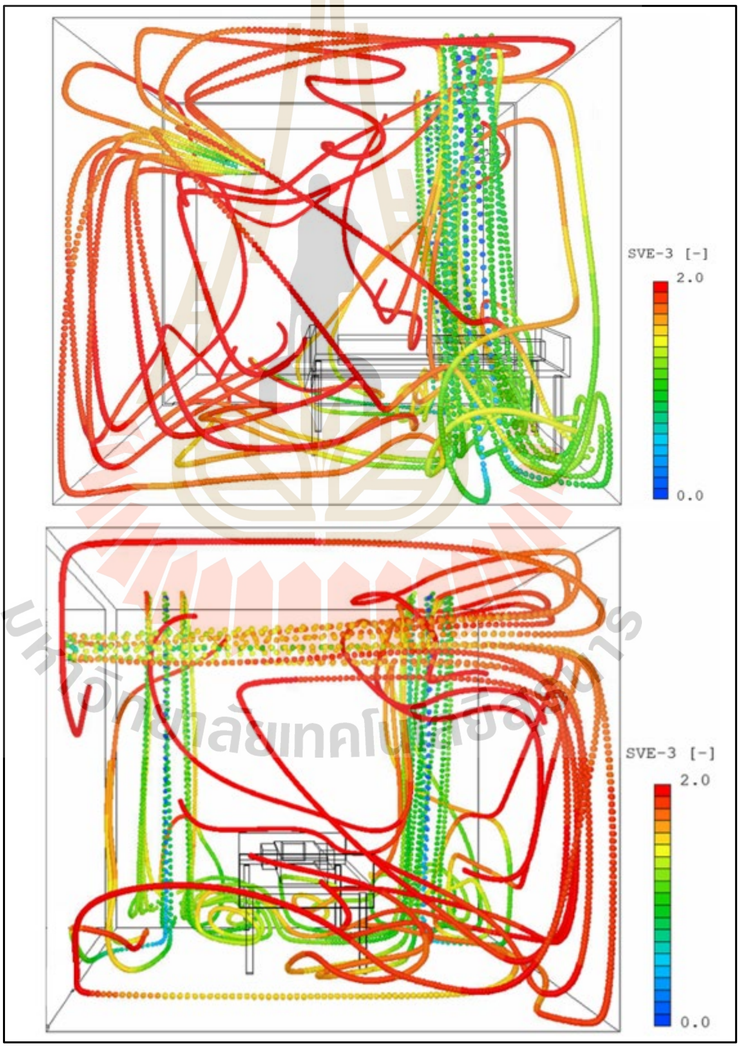

Figure 4.13 Path line of air flow of case BC (8-10) for 3.5 × 5.5 × 3 m room size (top) side view and (bottom) front view.

In case of the damper located at the position D and return channel located at the position 8 and 10. It is found that the obtained values of SVE-3 are similar like the damper located at the position C. This is because the flow of air from damper has mixed with the flow of air from return channels. This condition provides the good behavior of air distribution in the room as shown in Figure 4.14.

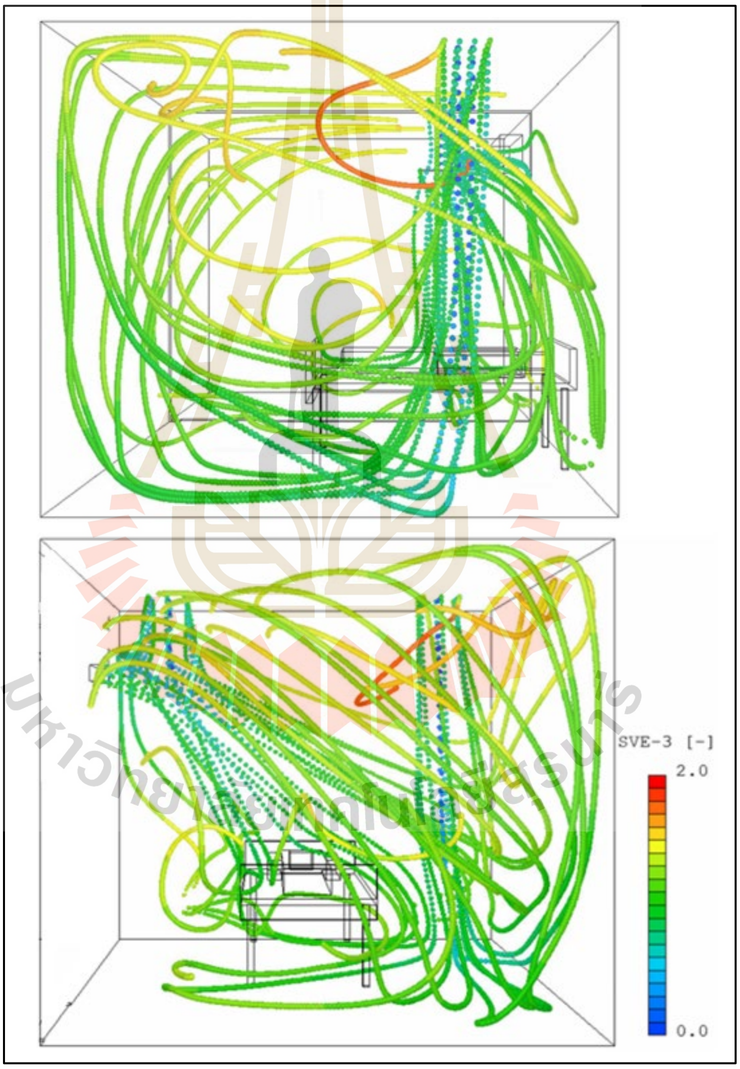

Figure 4.14 Path line of air flow of case BD (8-10) for 3.5 × 5.5 × 3 m room size (top) side view and (bottom) front view.

4.2 Pressure

From Table 4.1 and Table 4.2, the predicted pressure in the anteroom and the patient room are in the standard requirement. In the simulation, the pressure can be changed by adjusting the size of inlet channel, damper and the magnitude of air velocity at the outlet channels. From the predicted results of air flow in the room, it can be seen that the pressure in the anteroom is higher than in the patient room due to the flow has been sucked out at the outlet channels that installed in the patient room as shown in Figure 4.14.

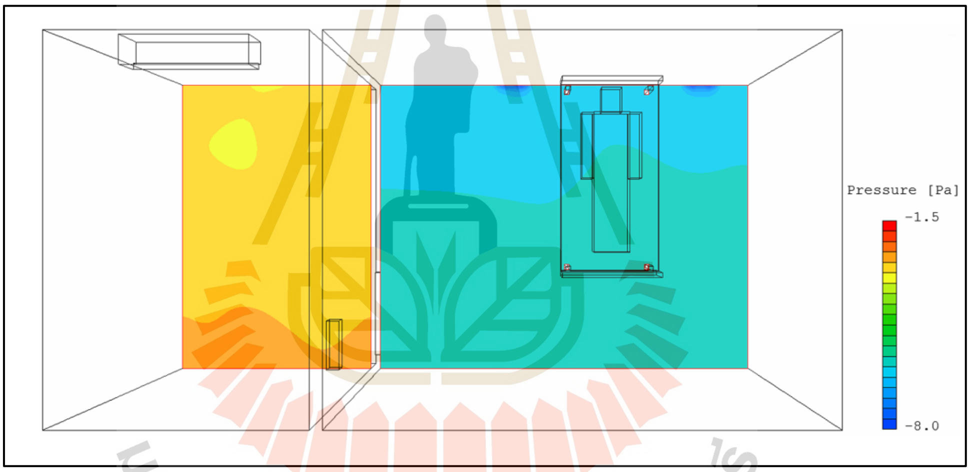

Figure 4.15 Contour of pressure for case AC (6-9) of 3 × 6 × 3 m room size.

4.3 Humidity

The relative humidity in the room is calculated by using equation 2.1. It depends on the pressure and temperature inside the room. When the pressure increases, the relative humidity increases. In contrast, when the temperature decreases, the relative humidity also decreases as well. If the moisture in the air is in the same condition, the higher air temperature will lower the relative humidity. Equation 2.1 for Table 4.1 and

Table 4.2 seems that relative humidity is about 51.07 %RH and 52.09 %RH, respectively and they are in the standard range of the room. Therefore, it is suitable for rehabilitation of patients. If the relative humidity becomes less or more than stated, the pathogens in the room will increase and grow inside the room.

4.4 Temperature

The temperature and air velocity are variables that can alter the air flow behavior in the room. The results show that the average temperature in the patient room is in the standard range approximated to 24 - 26 °C. For the average air velocity, the result is approximated to 0.13 – 0.20 m/s which is in the range that makes human feel comfortable and not be disturbed.

CHAPTER V

CONCLUSIONS

This research presents the use of CFD software designing the positions of the inlet channel, damper and return channels in the AIIR. The positions of the bed and outlet channels are fixed. The study focuses on the air quality in the room based on standard conditions. The RNG k– ε turbulence model has been investigated for predicting the flow based on steady flow assumption. The effect of the air channel installation positions on the air flow behavior has been considered. The conclusions of the study are described as follows.

5.1 Conclusions

The results from the air flow prediction are found that the air exchange rate, pressure, temperature and relative humidity are satisfied the standard requirement. That is mean that the purposed conditions can be implemented to the room.

The best case of the air quality around the bed zone is the case where position of the return channel and the damper provide the air flow in the direction through the bed. In this case, the return channels are installed at the middle zone of the room and above the bed. For damper, the location where alignment with the end of the bed is recommended.

The best case of the air quality in the patient room is the case that the installation position of the return channel and the damper provide the flow that gives the higher distribution of air in the room. For the damper and return channels position, they are depended on the room size. For 3 × 6 × 3 m room size, damper should be installed at the position that is aligned with the end of the bed and the return channel should be installed on the wall at bed headboard. For the room size of 3.5 × 5.5 × 3 m, the air damper must be installed at the position that is aligned with the headboard of the bed and the return air channels should be installed on the wall partition.

The effect of inlet channel on SVE-3 found that with fixed the position of damper and return channels, there are no difference in changing the position of the inlet channel. The air may have slightly changed properties such as air velocity and temperature.

Consider the effect of damper and return channels on the flow. It is found that, if the position of return channels has fixed on the ceiling above the center of the bed, changing of damper position give too much influence to the air flow in the room. For the other rest cases, if the air damper position has fixed while the return channels are changed, or both are fixed, the SVE-3 predicted becomes similar obtained results.

Increasing the air velocity and changing the size of the inlet channel and damper trend to give most influent to the pressure changing in the room.

As the pressure increases, the relative humidity will increase. As the temperature decreases, relative humidity will also decrease.

5.2 Recommendation for future work

In the simulation of an air flow, the thermal effect on human skin should be included because this can be affected to the flow behavior.

Actually, medical staff may come to work in this room which let the changing in air flow behavior. In order to require more accuracy of an air flow simulation results while in operation, medical staff should be located in the room.

In order to know where the air has accumulated and the direction of air flow is more accurate, it may change the simulation to the transient simulation.

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APPENDIX A

Position of air inlet channel and air damper

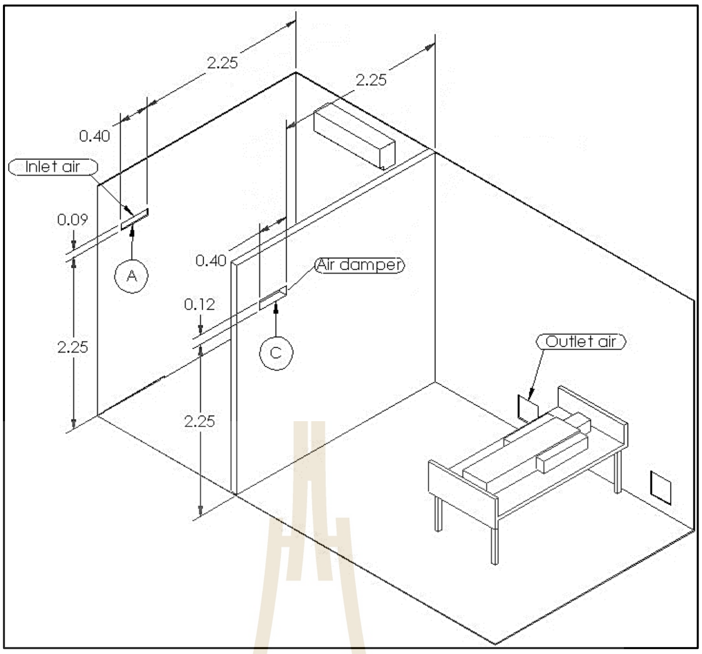

Figure A.1 Case AC for 3 × 6 × 3 m room size.

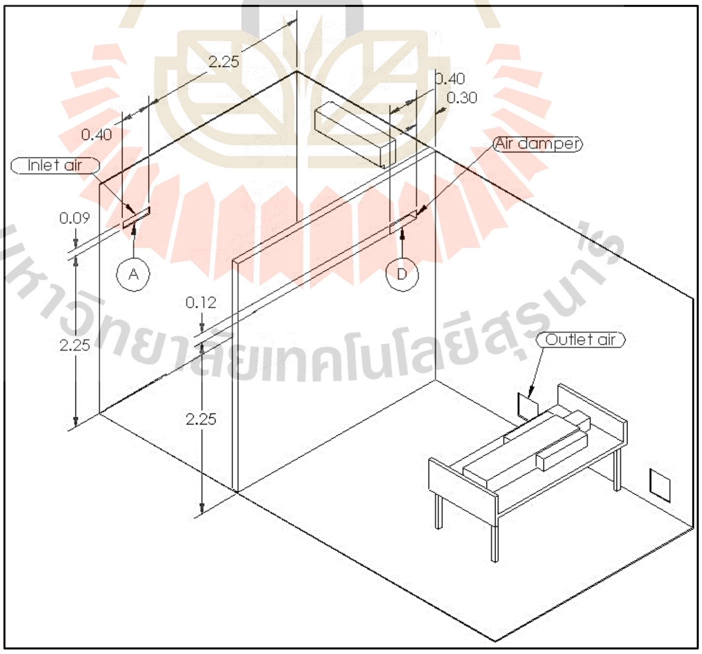

Figure A.2 Case AD for 3 × 6 × 3 m room size.

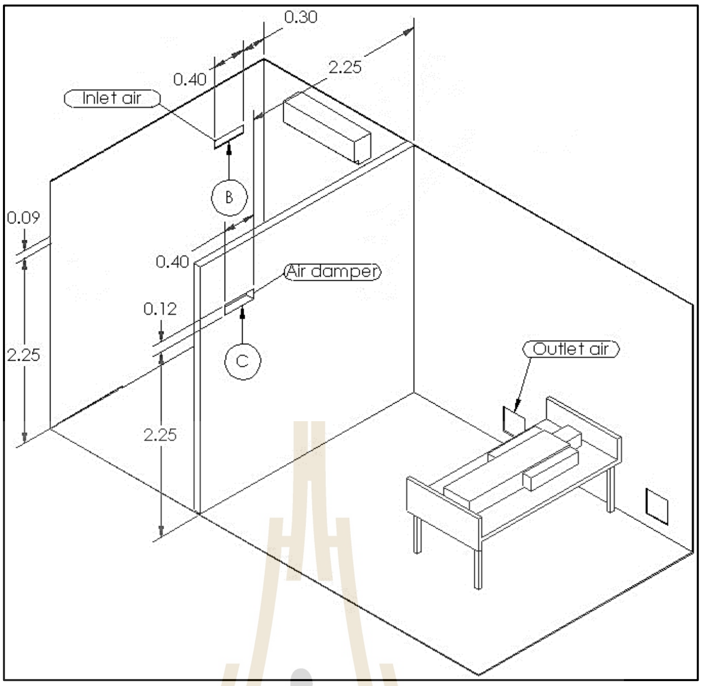

Figure A.3 Case BC for 3 × 6 × 3 m room size.

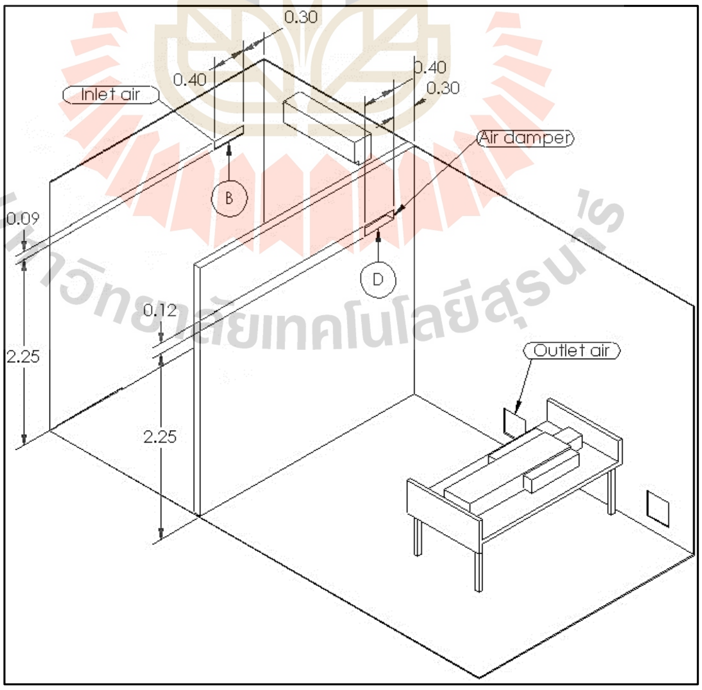

Figure A.4 Case BD for 3 × 6 × 3 m room size.

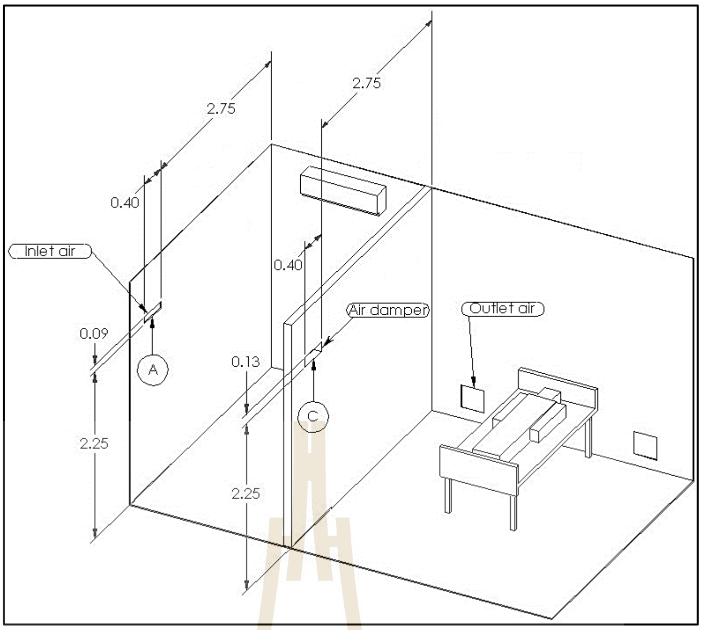

Figure A.5 Case AC for 3.5 × 5.5 × 3 m room size.

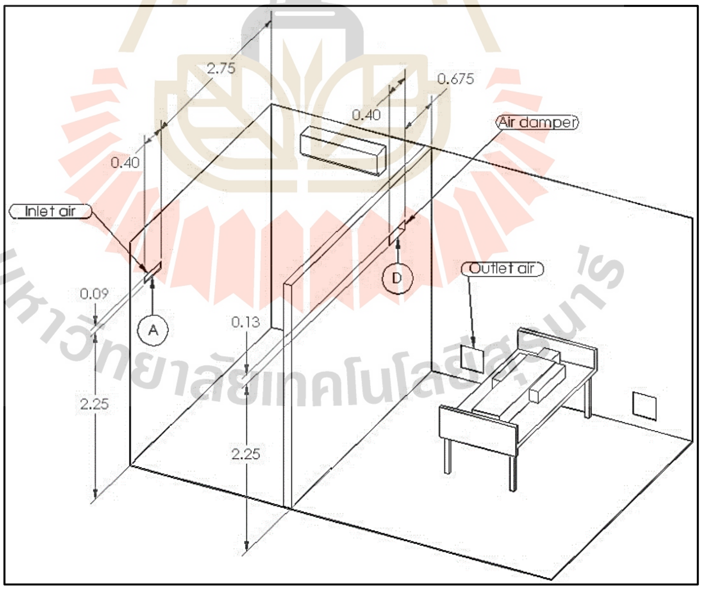

Figure A.6 Case AD for 3.5 × 5.5 × 3 m room size.

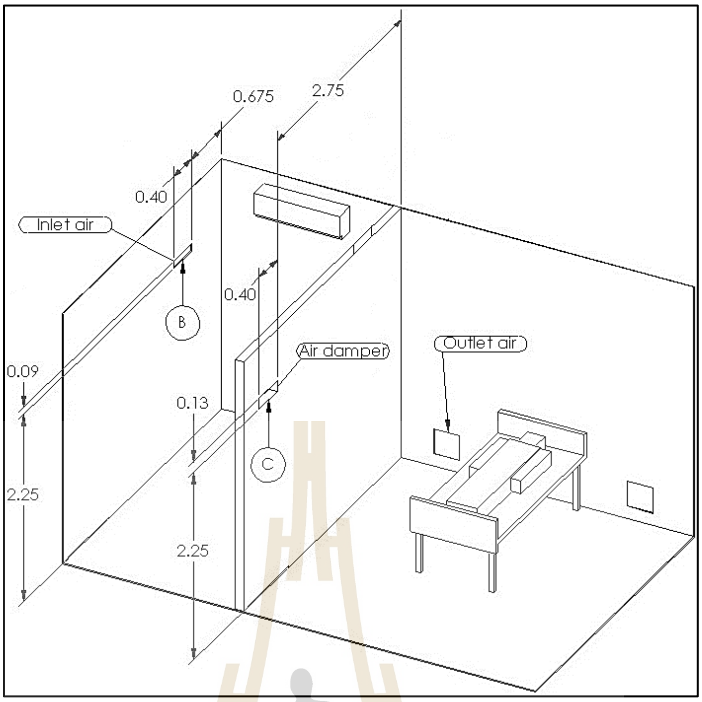

Figure A.7 Case BC for 3.5 × 5.5 × 3 m room size.

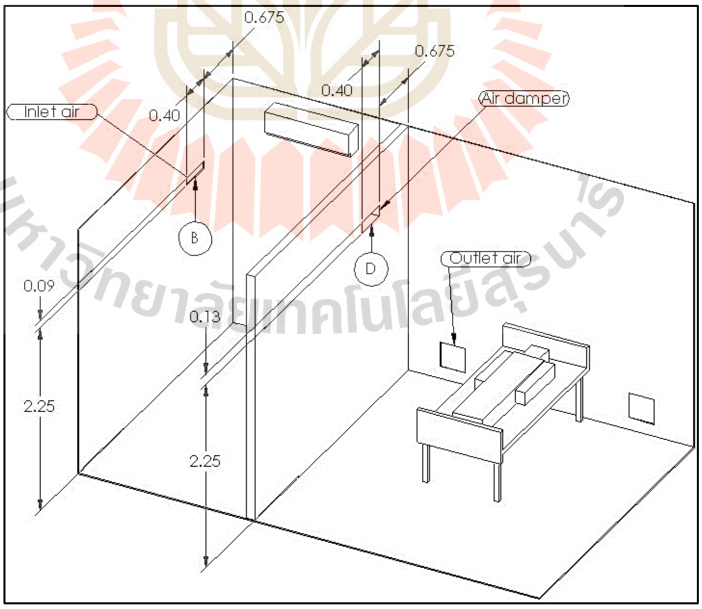

Figure A.8 Case BD for 3.5 × 5.5 × 3 m room size.

APPENDIX B

Position of air return channels

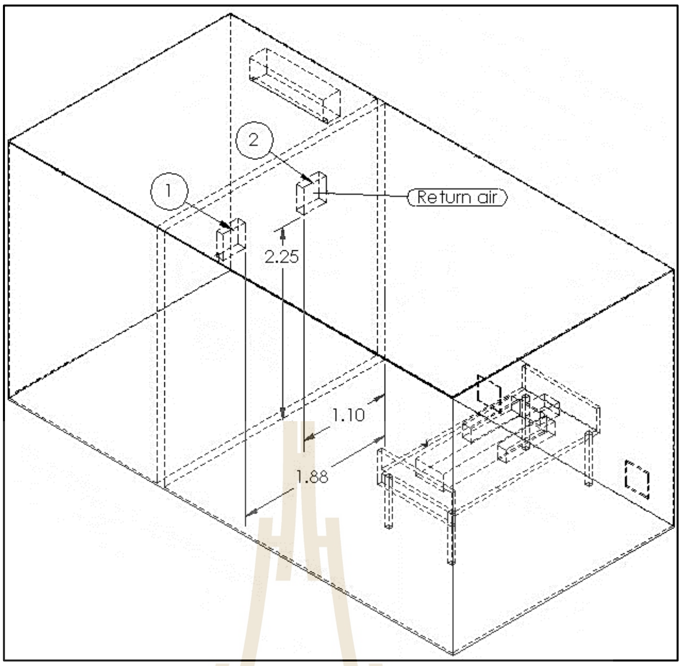

Figure B.1 Case of air return channel 1-2 for 3 × 6 × 3 m room size.

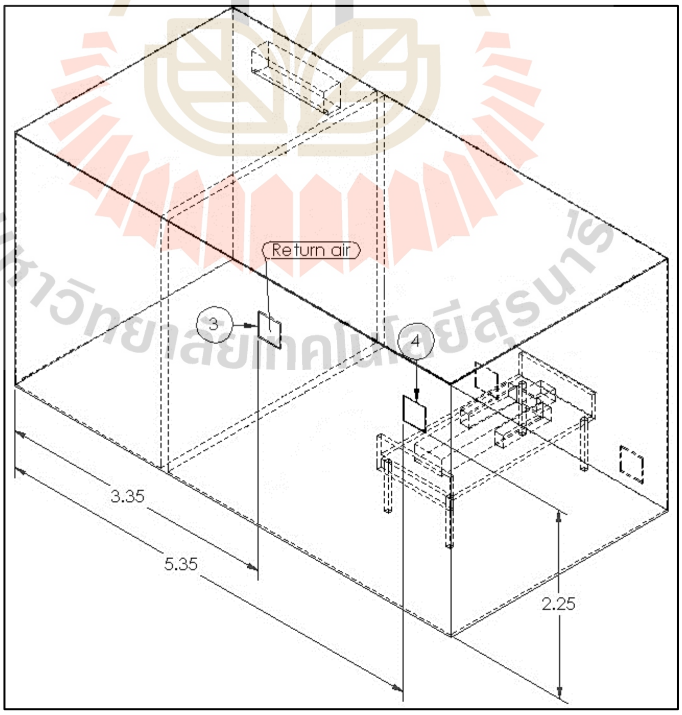

Figure B.2 Case of air return channel 3-4 for 3 × 6 × 3 m room size.

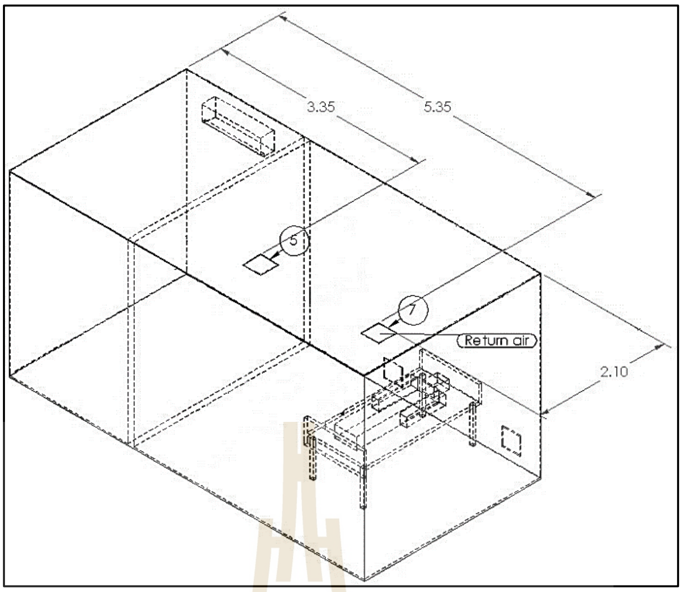

Figure B.3 Case of air return channel 5-7 for 3 × 6 × 3 m room size.

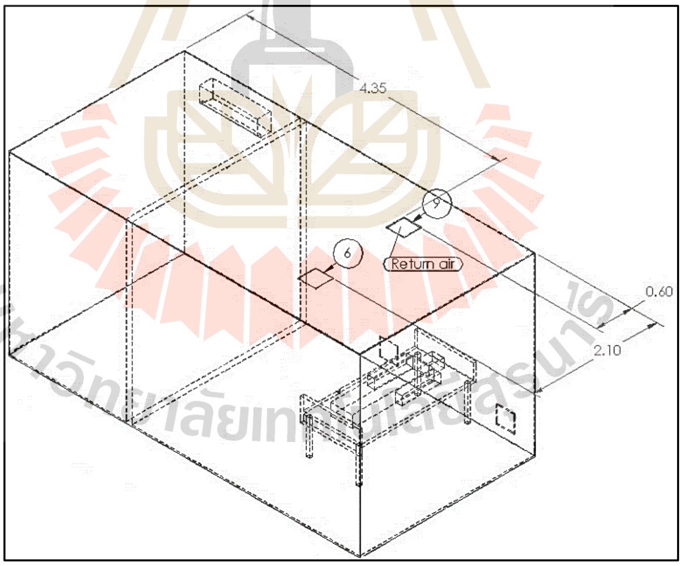

Figure B.4 Case of air return channel 6-9 for 3 × 6 × 3 m room size.

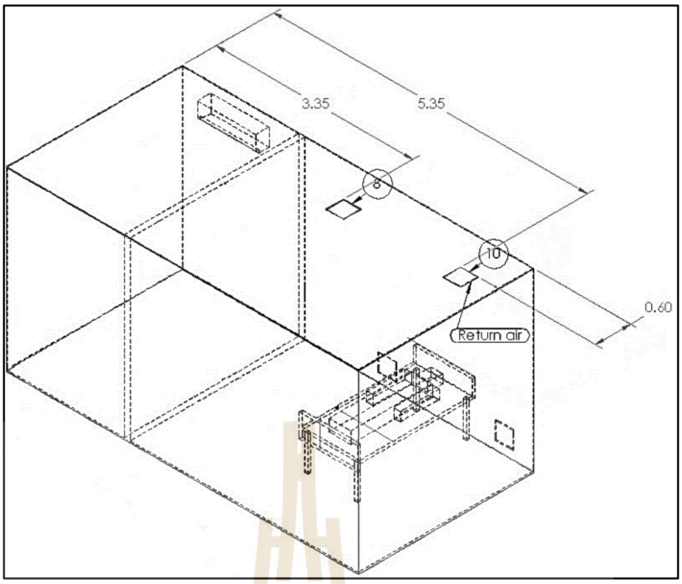

Figure B.5 Case of air return channel 8-9 for 3 × 6 × 3 m room size.

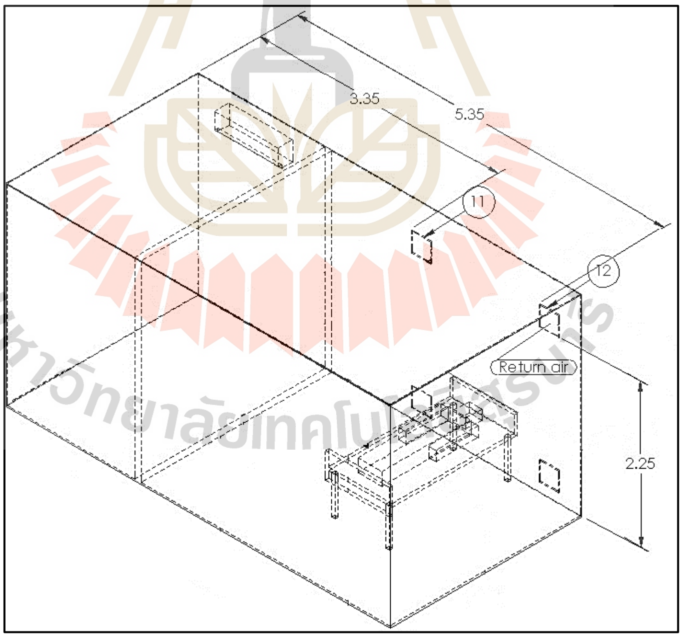

Figure B.6 Case of air return channel 11-12 for 3 × 6 × 3 m room size.

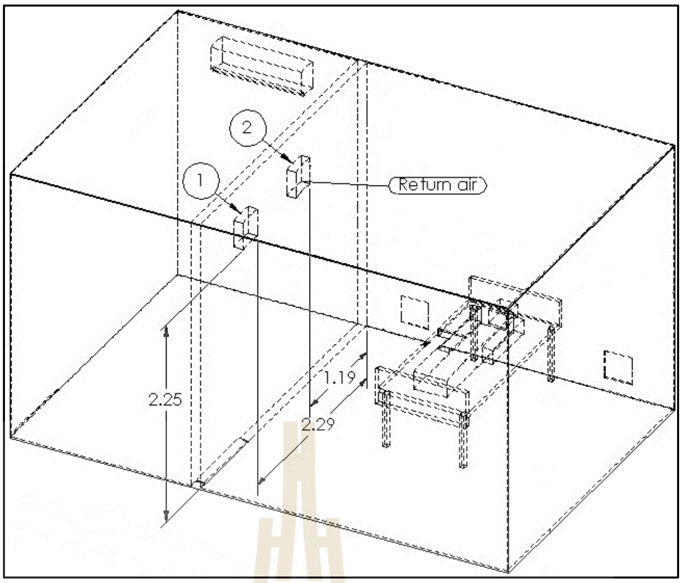

Figure B.7 Case of air return channel 1-2 for 3.5 × 5.5 × 3 m room size.

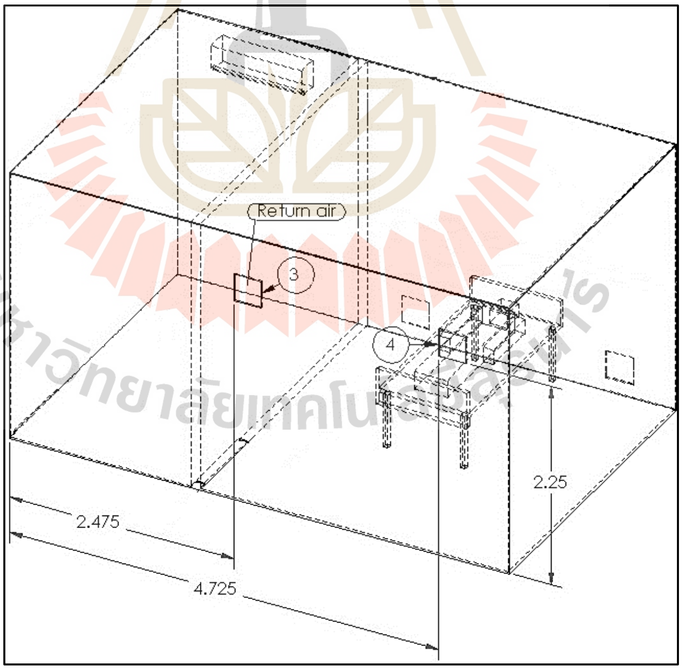

Figure B.8 Case of air return channel 3-4 for 3.5 × 5.5 × 3 m room size.

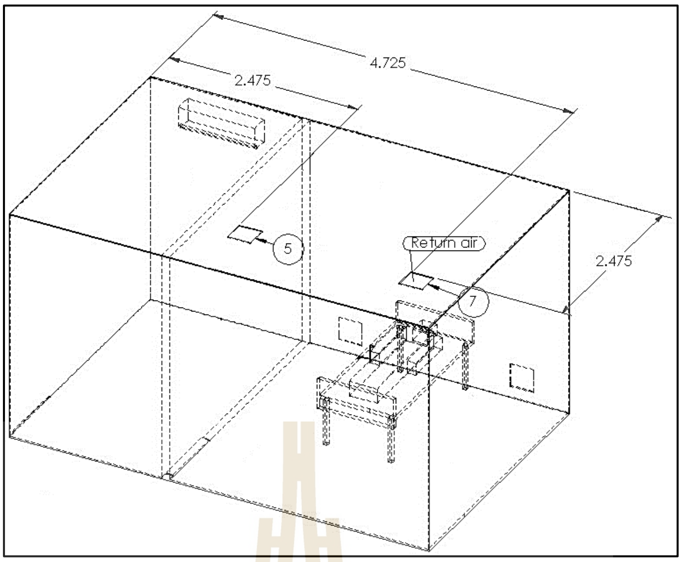

Figure B.9 Case of air return channel 5-7 for 3.5 × 5.5 × 3 m room size.

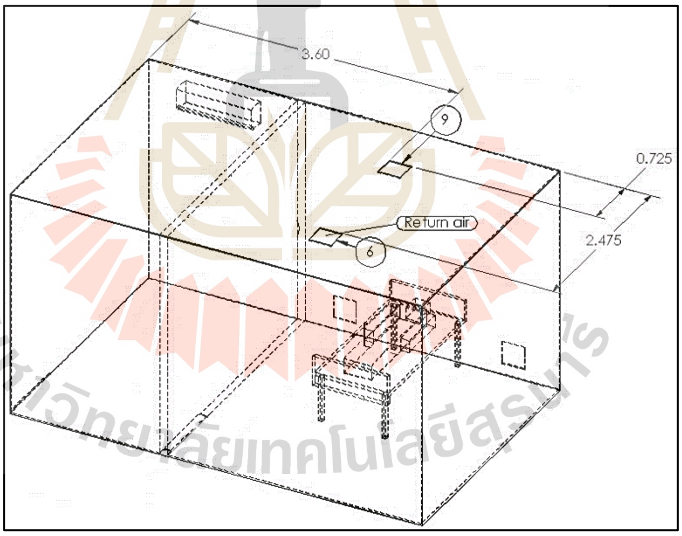

Figure B.10 Case of air return channel 6-9 for 3.5 × 5.5 × 3 m room size.

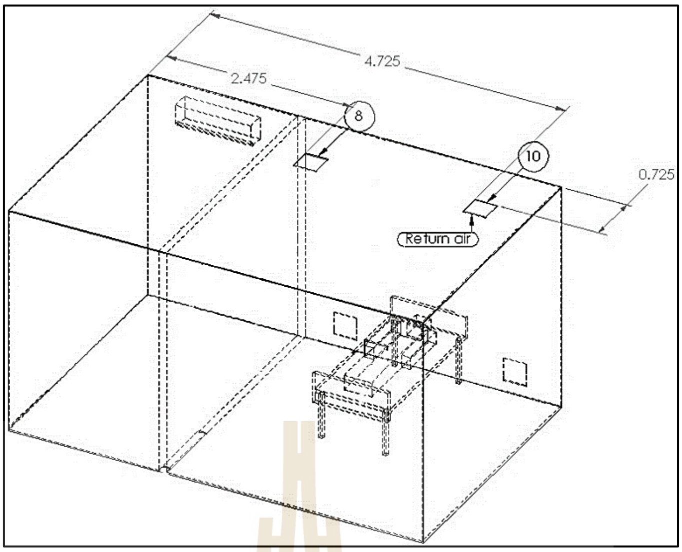

Figure B.11 Case of air return channel 8-10 for 3.5 × 5.5 × 3 m room size.

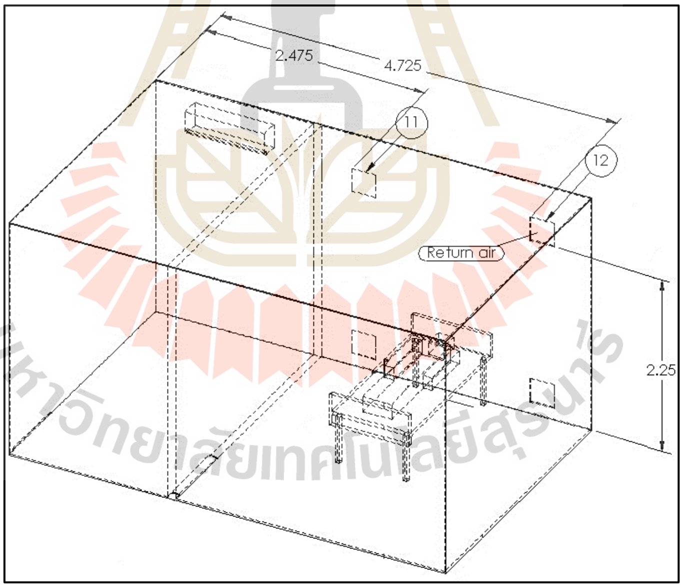

Figure B.12 Case of air return channel 11-12 for 3.5 × 5.5 × 3 m room size.

APPENDIX C

Sizing of facilities

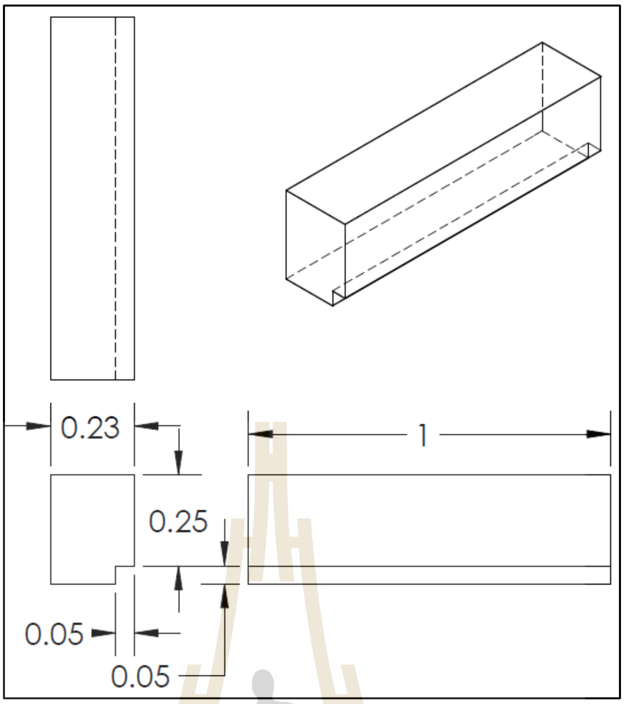

Figure C.1 Drawing of air conditioner [m].

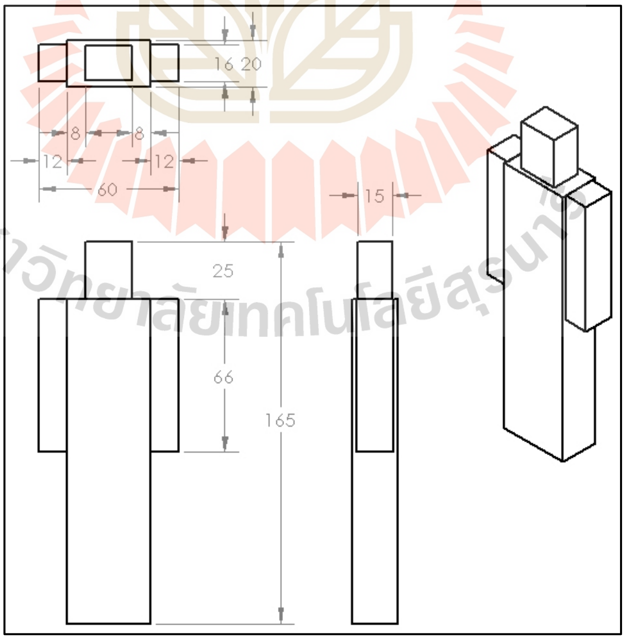

Figure C.2 Drawing of the patient body [cm].

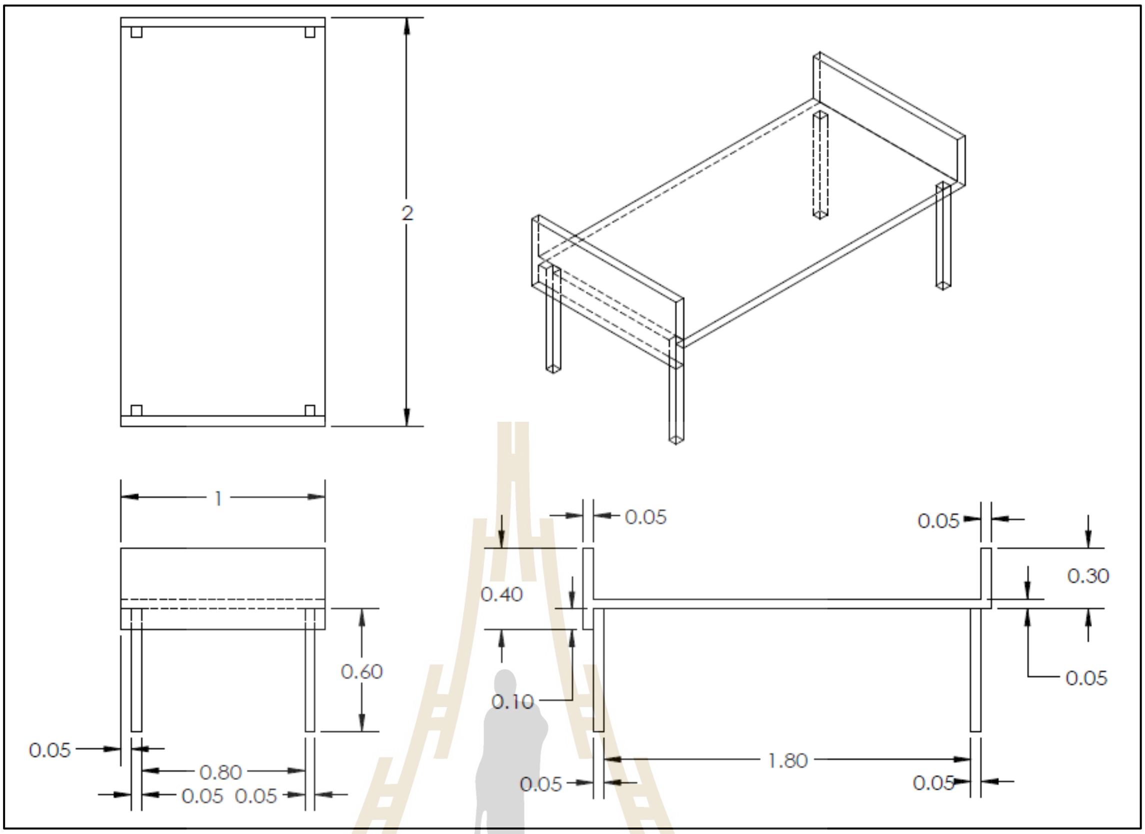

Figure C.3 Drawing of the patient bed [m].

APPENDIX D

List of Publications

List of Publication

Sarapat P., Suluksna K. and Suwa Y. (2018). CFD Simulation Aimed at Improving the Air Quality of the Patient's Room in the Hospital. In Proceeding of The 35th Annual Meeting and Symposium on Aerosol Science and Technology. Nagoya, Japan.

第 35 回
エアロゾル科学・技術研究討論会

THE 35th ANNUAL MEETING AND SYMPOSIUM ON AEROSOL SCIENCE AND TECHNOLOGY

2018 年 7 月 31 日(火)～ 8 月 2 日(木)
名古屋大学　東山キャンパス(愛知県名古屋市千種区不老町)
July 31 –　August 2, 2018
Nagoya University, Aichi, Japan

主催
日本エアロゾル学会

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Shimotachiuri-dori, Kamigyo-ku, Kyoto, 602-8048, Japan

共催

・静電気学会	・The Institute of Electrostatics Japan
・日本気象学会	・The Meteorological Society of Japan
・日本空気清浄協会	・Japan Air Cleaning Association
・日本大気電気学会	・Society of Atmospheric Electricity of Japan
・日本粉体工業技術協会	・The Association of Powder Process Industry and Engineering, Japan
・粉体工学会	・The Society of Powder Technology, Japan
・日本保健物理学会	・Japan Health Physics Society

協賛

・応用物理学会	・The Japan Society of Applied Physics
・化学工学会	・The Society of Chemical Engineers, Japan
・空気調和・衛生工学会	・The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan
・室内環境学会	・Society of Indoor Environment, Japan
・大気環境学会	・Japan Society for Atmospheric Environment
・日本産業衛生学会	・Japan Association of Industrial Health
・日本防菌防黴学会	・The Society for Antibacterial and Antifungal Agents, Japan

後援

・名古屋大学大学院環境学研究科	・Graduate School of Environmental Studies, Nagoya University

3rd day **Thursday, August 2, 2018**

Room B – Conference room #1, 3F

09:00 – 11:33 Application of Aerosols, Cleanrooms, Indoor Aerosols, etc.

[Room B] Chaired by: N. Namiki, S. Ikawa, and Y. Suwa

B301 **Development of the evaluation method for the risk of fission products release to the environment during severe accident in nuclear power plant (1) Outline and develop state of source term PRD which can evaluates fission products release to the environment**

K. Nakamura[1], Y. Yamane[2], T. Kanai[1], K. Murata[2]
[1]*CRIEPI*, [2]*Advancesoft Corporation*

B302 **Development of the evaluation method for the risk of fission products release to the environment during severe accident in nuclear power plant (2) Development of the evaluation module for fission product aerosol behavior in source term PRD**

Y. Yamane[1], K. Nakamura[2], K. Murata[1], T. Kanai[2]
[1]*Advancesoft Corporation*, [2]*CRIEPI*

B303 **Fabrication of ternary nanocomposite film by PECVD process with simultaneous feeding of gaseous and solid raw materials**

I. Shimada, M. Kubo, M. Shimada
Hiroshima Univ.

B304 **Characterization of air quality in smoking spaces and its improvement by air flow control**

N. Namiki[1], S. Katagiri[1], R. Nakayama[1], N. Kagi[2]
[1]*Kogakuin Univ.*, [2]*Tokyo Inst. of Technol.*

B305 **CFD Simulation aimed at improving the air quality of the patient's room in the hospital**

P. Sarapat[1,2], Y. Suwa[1], K. Suluksna[1]
[1]*Suranaree Univ. of Technol.* [2]*Shibaura Inst. of Technol.*

B306 **Examination for designs of the instruments using the fluid simulation**

S. Ikawa
Sibata Scientific Technology LTD.

B307 **A study on non-isothermal characteristics of the coanda effect caused by indoor air using CFD simulations**

T. Nogami, Y. Suwa
Suranaree Univ. of Technol.

B308 **Natural ventilated slab cooling system using double skin**

S. Yukizane, Y. Suwa
Suranaree Univ. of Technol.

B309 **Study of airflow distribution performance for duct by Swirling flow**

T. Nagai, Y. Suwa
Suranaree Univ. of Technol.

3rd day **Thursday, August 2, 2018**

Atrium / Foyer

13:30 – 16:00 Aerosol Studies Basic Courses

[Atrium / Floyer] Chaired by: N. Hama

B305

病室の空気質向上を目的とした CFD シミュレーション
CFD Simulation aimed at Improving the Air Quality of the Patient's Room in the Hospital

○Panudet Sarapat (Suranaree University of Technology and Shibaura Institute of Technology)
Yoshihide Suwa (Shibaura Institute of Technology)
Keerati Suluksna (Suranaree University of Technology)

ABSTRACT

Hospital in Thailand commonly supply outside air from the anteroom to the patient's room through a damper installed between these 2 rooms. In this study, the distribution of airflow was analyzed using CFD simulation. The design method to realize the indoor environment which provides less infection possibility to patients was discussed.

INTRODUCTION

Infection in the hospital is a very important problem which is happening all around the world. Particularly, infections from the airborne pathogens such as *Mycobacterium tuberculosis*. Thailand has 723 community hospitals (2009) with an average of one Airborne Infection Isolation Room (AIIR). Due to climate condition in Thailand, patients always feel discomfort and hot in the AIIR room. One solution is to set an air conditioning unit in the room, however, this will lead to higher dispersion of pathogens in the room. In order to increase the air quality and patient thermal comfort inside the room, we conduct a numerical simulation of an anteroom connected with patient's room with different air-conditioner, bed and outlet air arrangement.

1. Simulation and Evaluation method

1.1 Computational domain

Figure 1 shows the model of an AIIR. This room was separated into 2 room including the anteroom and the patient room. Air will flow through the inlet air and the gap under the door due to the pressure difference between outside and inside the room. Then the air will flow from the anteroom through the damper and the gap under the door to the patient's room. Air conditioner was installed in the wall and the outlet air was installed under the patient's bed. In the study, the CFD simulation was used to simulate and evaluate indoor environment by using the numerical simulation based on finite volume method in the STREAM CRADLE V.12 software. We analyzed using the RNG k–ε model. The room dimension was 6 x 3 x 3 m^3. The boundary conditions were set as follow: the pressure inlet was 0 Pa at 30 degree Celsius, the supply air conditioner was 2 m/s at 24 degree Celsius, the return air conditioner was 0.89 m/s at 25 degree Celsius and the velocity outlet was 2 m/s at 25 degree Celsius. In the simulation, the position of the air conditioner, the position of the patient's bed and the outlet air were changed (Figure2). In this evaluation the initial conditions were assume to be the same in every case.

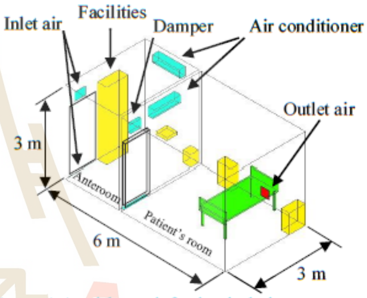

Figure 1 An airborne infection isolation room model

1.2 SVE-3

In this study, "age of air" and SVE-3 were used to evaluate the air quality in the room. "Age of air" is defined as the elapsed time passed after a unit of air is supplied to an arbitrary position. A zone where "age of air" shows a large value has less ventilation performance and therefore a higher possibility of contamination. On the other hand, SVE-3 is the normalized "age of air" with nominal ventilation time when a uniformly distributed source of contaminant is assumed. SVE-3 is advantageous when analyzing airflow pattern in a room. An ensemble averaged-value of the <SVE-3> is used in the following sections.

1.3 PMV

The human thermal comfort (HTC) is defined as the state of mind which expresses satisfaction with the surrounding thermal environment (One of methods that were used to evaluate HTC is the predicted mean vote (PMV)). PMV was used to assess the thermal sensation in the human base on the Fanger's equation's which presented in the ASHRAE thermal sensation scale in 1967. Variables that affecting human thermal comfort such as temperature, air velocity, mean radiant temperature, humidity, metabolic rate and clothing insulation was considered as parameter in PMV calculation. PMV scale is set in the range of cold (-3) to hot (+3) and with the value of comfort at 0. In this study, PMV was analyzed only at the vicinity of the patient's bed space because that will provide accurate result compared to whole room.

2. Result and Discussion

2.1 Air quality

The results of <SVE-3> and <PMV> are shown in figure 3. For all cases <SVE-3> less than 1.5 were obtained and A-2 and A-3 cases show the lowest value of 0.99 as shown in figure 4. However, for A-3 a stagnation region of SVE-3 = 1.5 was observed at the corner of the patient's room. This is because, the supply air from the air conditioner and from the inlet air is not flows in the same direction and mixing process occurring at the center of the room. So, the air cannot flow to the corner of the room and the airborne pathogens will not flow out from the patient's room. It is very dangerous for the patient and staff when the patient's room operated.

2.2 Human thermal comfort

For the thermal comfort, A-2 showed as the best case at PMV value of -0.35 (close to neutral), due to a good balance position of air conditioner from the patient's bed. B-4 showed the worst PMV value, which the air conditioner was installed above the head of the patient's bed. Air velocity relatively serve as a bigger factor compare to temperature. Based on our result, when air velocity increases while temperature remain about the same value, PMV showed larger change toward smaller value. Therefore, human thermal comfort can be provided by decreasing the air velocity.

3. Conclusion

The SVE-3 and PMV were analyzed to investigate the air quality and human comfort in an AIIR, respectively. The different installation position of the air conditioner and the outlet are affecting the air flow pattern inside a room. The arrangement that have same direction of air flow by the air conditioner and the damper were found to be the best case, because direct flow of cold air toward to patient can be prevented, while keeping the room cool and also making the good air quality. However when the air flows are at different directions, air will not circulate all whole room, which make the worst case. In this study was simulated in the basic flow. By the way, in the future, the generation of particle will be analyzed to improve the accuracy of the results.

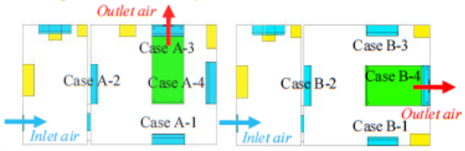

Figure 2 An AIIR: (a) case A, (b) case B

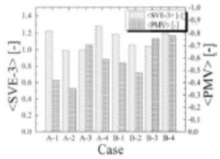

Figure 3 SVE-3 value and PMV value

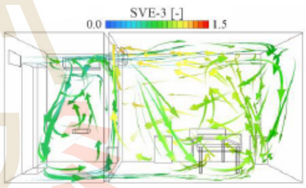

Figure 4 The airflow in the Case A-2

4. Reference

ASHRAE Ventilation for Acceptable Indoor Air Quality, Atlanta GA, American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE Standard 62-2004), 2004.

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5. Acknowledgement

This work was perform as a cooperative research between Shibaura Institute of Technology and Suranaree University of Technology.

BIOGRAPHY

Mr. Panudet Sarapat was born on June 18, 1993 in Mueang District, Roi Et Province, Thailand. In 2012, he began his bachelor's degree at School of Mechanical Engineering, Institute of Engineering at Suranaree University of Technology, Nakhon Ratchasima Province. After graduating bachelor's degree, he continued for a master's degree at the School of Mechanical Engineering, Institute of Engineering, Suranaree University of Technology.