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CFD Simulation for Air-Borne Infection Analysis in AII-Room

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***Abstract*—**The present study is a foundational study for performance improvements on isolation wards to prevent proliferation of secondary infection of infectious diseases such as SARS, H1N1, and MERS inside hospitals. Accordingly, the present study conducted an analysis of the effect of sealing mechanisms and filling of openings on ensuring air tightness performance in isolation wards as well as simulation on air currents in improved isolation wards. The study method is as follows. First, previous studies on aerial infection type and mechanism were reviewed, and the review results were utilized as basic data of analysis on simulation of air current. Second, national and international legislations and regulations in relation to isolation wards as well as case studies on developed nations were investigated in order to identify the problems in isolation wards in Korea and improvement plans. Third, construction and facility plans were compared and analyzed between general and isolation wards focusing on large general hospitals in Korea, thereby conducting comparison and analysis on the performance and effects of air-tightness of general and isolation wards through CFD simulations. The study results showed that isolation wards had better air-tightness performance than that of general wards.

***Keywords*—**AII Room, air-borne infection, CFD, computational fluid dynamics.

I. Introduction

A. Objectives of the Study

A remarkable damage has been inflicted on South Korea due to aerial infection such as severe acute respiratory syndrome (SARS) in 2003, H1N1 new influenza in 2009, and Middle East respiratory syndrome coronavirus (MERS-CoV) in 2015. In particular, MERS-CoV occurred in 2015 had 186 confirmed patients and 38 deaths [5], which was spread mainly by the secondary infection due to hospital acquired infections [13]. A ward that prevents such infectious spread is called isolation facility. An isolation hospital room refers to a ward where infectious carrier or patients with weak immunity are isolated to prevent virus poisons from being distributed or infected [12]. An isolation ward can be divided into positive and negative pressure wards. The mandatory requirements of isolation wards are various including building and facility plans [15], [16]. However, it is prerequisite to ensure air-tightness in wards essentially. Nonetheless, no related regulations are established in Korea, so performances and efficiencies of isolation wards are quite low. There have been several previous studies on aerial infection and isolation wards: aerial infection control using ultraviolet rays [6], infection control through hybrid setup of protective ventilation zone [2], analysis on infection path in hospitals utilizing gas tracer [11], current status in Korea according to infection management guidelines of other nations and proposal of improvement directions [9], and investigation on contaminant discharge according to human body movements and open and close of exit and entry doors [1]. However, few studies have been conducted about analysis on overall air-current in general and isolation wards based on real cases. Therefore, the present study aimed to compare and analyze air currents in general and isolation wards in order to determine a flow of overall air current in isolation wards. In addition, the present study analyzed a change in air current distribution inside wards according to locations of air supply and exhaust. The data in the present study are expected to be utilized in selection of location for air supply and exhaust inside wards and installation of isolation wards in the future.

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B. Study Method and Procedure

The study procedure of analysis on air current in isolation wards is as follows: First, we investigated the types and mechanisms of air infections and used them as the basic data for the simulation airflow analysis. Second, overall air current in isolation wards was analyzed through CFD simulation analysis. Third, air current inside wards according to locations of air supply and exhaust was analyzed. Finally, the effects of locations of air supply and exhaust and general and isolation wards were derived based on the above study procedure. The flow of the study is presented in Table I.

II. Literature Review

A. Aerial Infection

Aerial infection refers to spread and infection of virus floated in the air through skins or respiratory systems of others [7]. Sung [5], [8], [14] divided a path of spread largely as follows: contact, droplet, and airborne. In details, Sung divided a path into droplet infection spread and dropped by coughing and sneezing within 2-m distance, and droplet nuclei infection scattered and spread outside 2-m distance, thereby studying on droplet nuclei infection control according to air-conditioning system in hospitals. Lee [17] proposed a countermeasure against each infection path after dividing infection path into contact, droplets, and airborne. Catherine and Sleigh [3] performed a study on risk of aerial infection in hospitals probabilistically using the Wells-Reiley equation. Basically, risk of spreading contact and droplet infections becomes low if germ carriers are well managed and masks are well worn. On the other hand, it is difficult to prevent aerial infection (droplet nuclei infection) since it is floated and spread via a gap in buildings or air-conditioning systems [18].

TABLE I
FLOWCHART OF RESEARCH

Review of previous researches about types and mechanism of airborne infection and isolation ward
Comparison analysis of construction facilities plans in general ward and isolation ward
CFD (Computational Fluid Dynamics) analysis
Comparison analysis of air current in general ward and isolation ward
Airflow distribution according to air supply and exhaust location

B. Isoltion Ward

An isolation ward refers to a ward where infectious carrier or patients with weak immunity are isolated to prevent virus poisons from being distributed or infected [18]. An isolation ward can be divided into positive and negative pressure wards according to pressure inside the ward. Since patients whose immunity is degraded such as serious patients are vulnerable to the intrusion of germs, a positive pressure ward is suitable for them where inflow of external contaminants can be prevented. On the other hand, a negative pressure ward is suitable for germ carriers where aerial infection is concerned so that spreading germs externally can be prevented. Since a negative pressure ward is a specialized ward that aims to prevent spread of infection, it requires excellent air-tightness performance, a gap between sickbeds, high-performance filter, and all fresh air facilities basically. Fig. 1 shows a measure to form air-current in isolation wards proposed by the Centers for Disease Control (CDC) in the USA. Fig. 2 shows a drawing of isolation wards in general hospital in Korea. In an isolation ward, it is better to install air exhaust at the bed head side of patients to prevent spreading of virus into the ward via breathing of patients while the maximum negative pressure should be set by that in the toilet thereby preventing air from flowing into the hall.

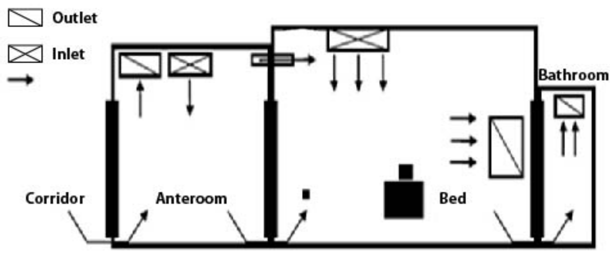


Fig. 1 Isolation room airflow

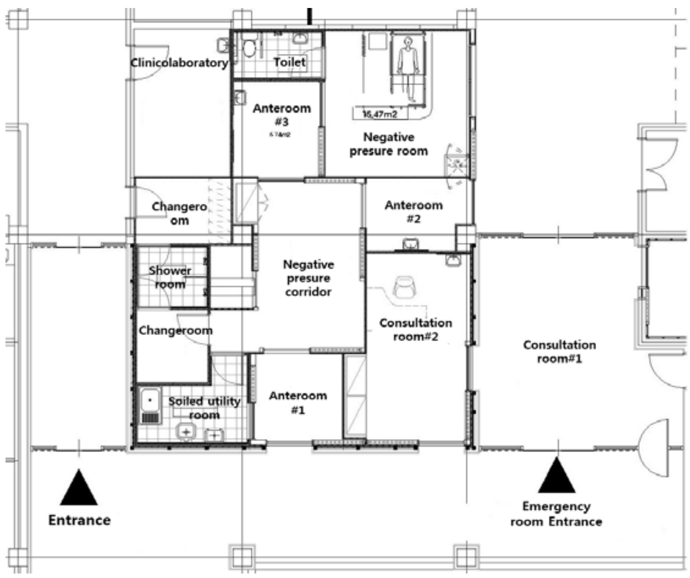


Fig. 2 Isolation ward floor plan

TABLE II
SUMMARY OF VENTILATION SPECIFICATIONS IN HOSPITAL

	PE Room	AII Room
Air Presure	> +2.5Pa	> -2.5Pa
Air Presure (ideal)	> +8Pa	> -2.5Pa
Room Air Change	≥ 12ACH	≥ 12ACH
Filtration Supply	99.97%++	90%
Recirculation	Yes	No

Table II presents criteria of positive and negative pressure wards recommended by the CDC in the USA. Positive and negative pressures refer to +2.5Pa or higher and –2.5Pa or lower, respectively, and 12 ACH or more of the number of ventilation is recommended. Air supply in the positive pressure ward should use 99.97% high-efficiency filter (HEPA), while a filter is not used in air exhaust. A negative pressure ward should employ 90% or higher efficiency of filter at air supply and 99.97% efficiency of filter at air exhaust [4].

C. Related Legislation

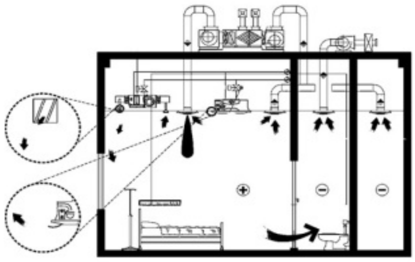
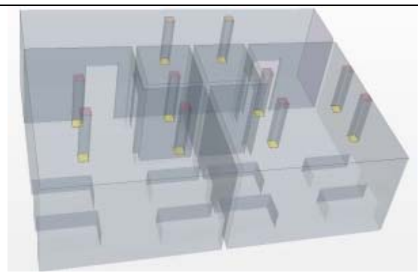
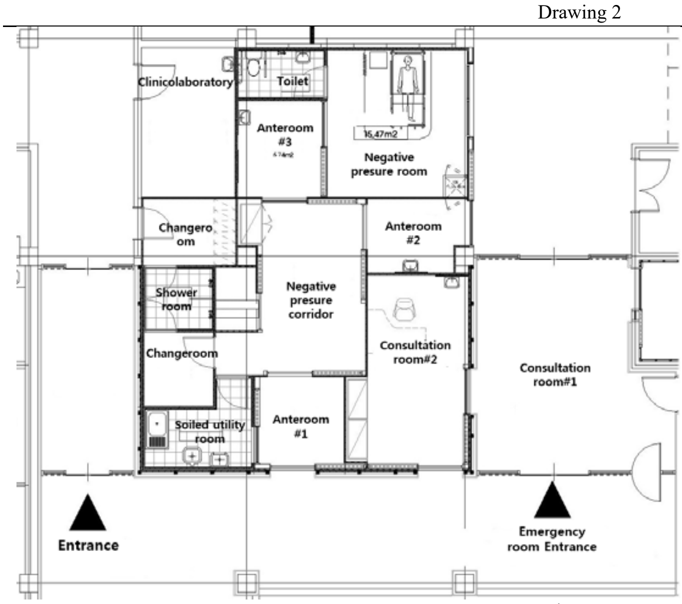
The Korea Centers for Disease Control and Prevention have simple recommendations about isolation wards only based on the criteria of the CDC in the USA through the Operation and Management of Sickbeds for Nationally Designated Inpatient

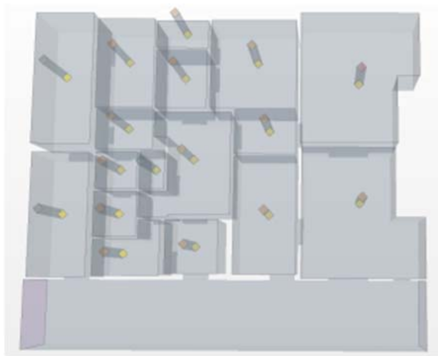
Treatment [10]. Accordingly, the Ministry of Health and Welfare in Korea announced mandatory regulations regarding installation of isolation wards such as negative pressure isolation wards and ensuring a sufficient area of operation room and intensive care center as well as distance between sickbeds on July 27 in 2016. The details are presented in Table III where improvements on facility standards of medical institutions are enforced such as installation of isolation wards including negative pressure isolation wards and ensuring sufficient area of sickbeds in operating room and intensive care center and gap between sickbeds to prevent and manage infections in medical institutions. Japan has also designs and management guidelines of facilities in hospitals published by the Hospital Facility Association applied to hospitals and other medical and welfare facilities according to the Medical Act. Among them, indoor air quality is dealt with in the Heating, Ventilation, and Air Conditioning Facility Section (HEAS – 02).

TABLE III
ENFORCEMENT REGULATIONS OF MEDICAL FACILITIES SPECIFICATIONS (PLAN, MINISTRY OF HEALTH AND WELFARE)

	Applicable Object	Current Standard	New building & Extended Building	Duty to improve of Existing Building
AII Room (1per-son)	General Hospital (≥ 300 Beds)	None	Equivalent level of Government designated beds	1 per 300 beds
AII Room	None	None	1 per 10 beds (AII Room: minimum 1)	1 per 10 beds (AII Room: minimum 1)

TABLE IV
OVERVIEW OF THE MODELING OF GENERAL AND ISOLATION ROOM

<table>
<tr><th>Room</th><th>Contents
Drawing 1</th></tr>
<tr><td>General</td><td> 
Positive pressure
Spread indoor air to outside
Infection diffusion of patients with infectious respiratory disease</td></tr>
<tr><td></td><td>Drawing 2</td></tr>
<tr><td>Isolation</td><td>


Negative pressure
Prevention of diffusion of contaminated air
Arrange anteroom between corridor and isolation room
Installation of HEPA filters</td></tr>
</table>

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III. Overview of the Simulation and Evaluation Methods

A. Overview of General and Isolation Wards

The drawings of wards used in the present study were modeled with isolation wards in medical facilities whose number of sickbeds in general hospitals in Daejeon was 100 or more. They were compared and analyzed via simulations. The analysis was conducted with three viewpoints largely. First, formation of air current in general and isolation wards was analyzed. Second, formation of air current in the wards according to installation of air supply and exhaust was compared and analyzed. In Table IV, a space in general wards was configured similar to general wards in Korea (6 m x 6 m, ward+toilet plan). In addition, comparison was conducted according to locations of air supply and exhaust based on general wards (twin beds) in order to analyze air current inside wards according to locations of air supply and exhaust. The floor area of the ward was 7,000 mm horizontally and 3,300 mm vertically. In Drawing 1 in Table IV, air supply was set at the entry side while air exhaust was set at the inside of the ward. In Drawing 2 in Table IV, air supply was set at the inside of the ward, while air exhaust was set at the entry side. Additionally, air supply was installed at the entry side, and air exhaust was installed each over the sickbed in the analysis. The analysis was assumed that there was 5 mm of a gap in the lower end when the opening was closed. Furthermore, outlet shapes, induction action, and cold draft were excluded in order to simply analyze spread and movements of air current only.

TABLE V
OVERVIEW OF THE SIMULATION

Mesh	Polyhedral Mesh	
Mesh Size	0.05 m	
Inlet	Stagnation Inlet Velocity Inlet	
Outlet	Pressure Outlet	
Physics	Cell Quality Remediation Constant Density Gas Gradients	K-Epsilon Turbulence Realizable K-Epsilon Two-Layer Segregated Flow Three Dimensional

TABLE VI
INDOOR SETTING CONDITION

Item	Factor
Velocity	1m/s
Negative Pressure	Anteroom: -2.5 Pa AII Room: -8 Pa Toilet: -8 Pa
Distance of beds	1.5 m, 2 m, 2.5 m

B. Overview of the Analysis on Air Current Using Simulation

CFD simulation analysis using the standard k-ε model, which was proposed by Launder and Spalding for the first time, was conducted to analyze the air current in each ward. The used program was Star-CCM+(ver.9.06) from CD-Adapco, and Table V summarizes the basic setup conditions for the CFD simulation. A type of mesh used was polyhedral mesh whose cross-section was hexagonal polyhedron mesh and a size of mesh was set to 0.05 m. The indoor temperature was set at 26 °C, and stagnation inlets were used in the hall, so air introduced without generating air current was treated as a stagnated cross-section at the both ends in the hall to check the inflow and outflow of the air in the ward. Around 1.0 m/s of discharge air was generated using a velocity inlet for air supply. A pressure outlet was applied to air exhaust to set a negative pressure for each zone. Air supply and exhaust were set equivalently in general and isolation wards. For isolation ward, pressures of front room, isolation room, and toilet were set to –8 Pa, –10 Pa, and –12 Pa, respectively to form a positive pressure at the general wards.

IV. Result

A. Comparison and Analysis of General and Isolation Wards

A mean wind speed in general wards was around 0.1 m/s, showing air spread to the hall and around 0.24 m/s air current was flown at the lower part of the room. On the contrary, since isolation room was set as a negative pressure in the isolation ward, air current in the room was not flown to the hall but passed through air exhaust. A wind speed of air current inside the isolation ward was very fast around 1 m/s higher than that in the general ward.

B. Simulation Result According to Locations of Air Supply and Exhaust

Table VII presents simulation results in which paths of air current movements were identified with cross section mode to determine the paths inside the ward according to locations of air supply and exhaust. The analysis results according to locations of air supply and exhaust showed that air outflow to the external area of the ward was smaller when air supply was installed at the inside rather than at the entry side of the room. Furthermore, the parallel sickbed arrangement showed smaller air spread effect to other sickbeds than that in the serial sickbed arrangement. The air exhaust installed over each sickbed showed that air current over each sickbed was discharged through the air exhaust over the sickbed, indicating a low air spread. A mean speed of air current in the sickbed was around 0.06 m/s, and the maximum and minimum speeds were 2.28 m/s and 0.00016 m/s

V. Conclusion

The present study conducted comparison of air current between general and isolation wards, and analysis on air current according to locations of air supply and exhaust inside the room.

(1) A negative pressure was formed at the isolation ward, resulting in low air spread possibility to the outside and showing a low risk of aerial infection spread probabilistically.
(2) Risk of aerial infection was low in the air supply and exhaust. An air outflow to the external area of the ward was smaller when air supply was installed at the inside rather than at the entry side of the room.

Based on the above results, it is helpful to prevent spread of airborne bio contaminants by hospitalizing suspicious patients in isolation wards. An air outflow to the external area of the ward was smaller when air supply was installed at the inside rather than at the entry side of the room. The data in the present study were generated based on CFD simulation results. In order to have more accurate study results, actual measurements at clinical fields are needed in the future, and the data can be utilized as reference for installation and improvements of isolation facilities in the future.

TABLE VII
SECTIONAL VIEW OF THE SIMULATION

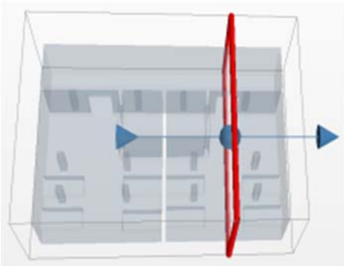
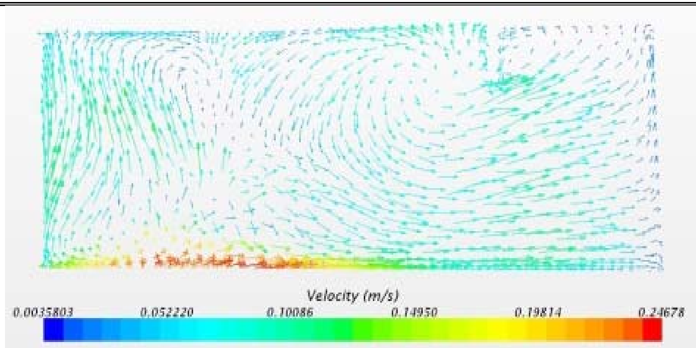
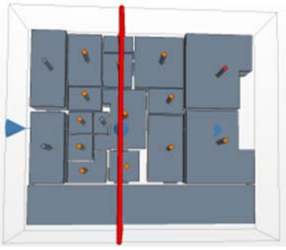
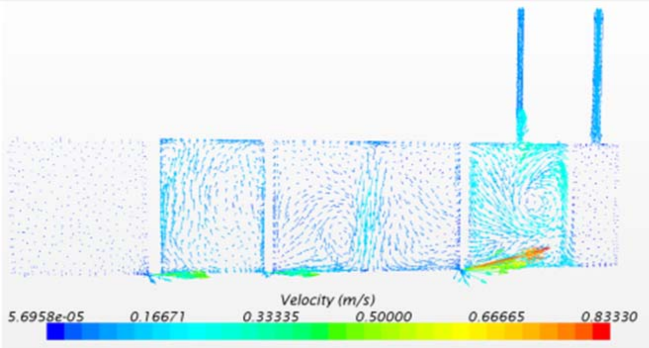
General room 	
Isolation room 	

TABLE VIII
SIMULATION RESULT ACCORDING TO DIFFERENCE OF EXHAUST VENT (VERTICAL SECTION)

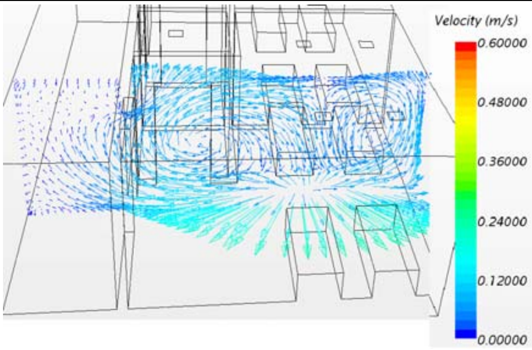
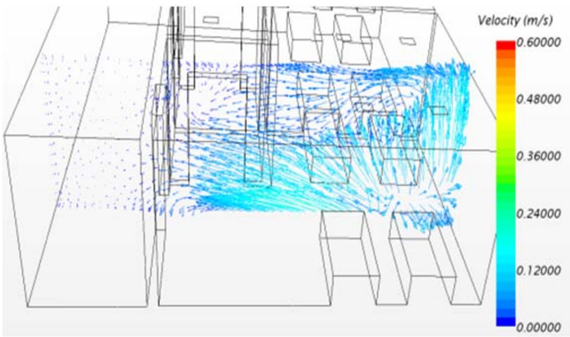
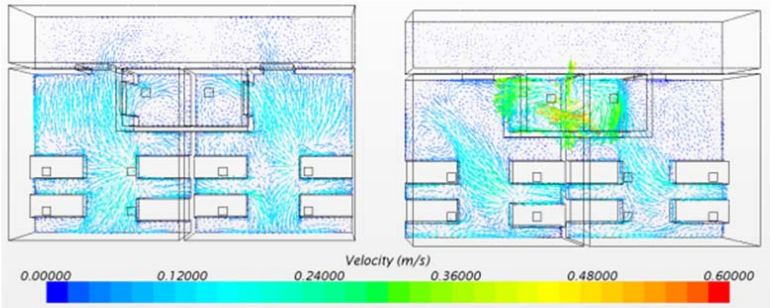
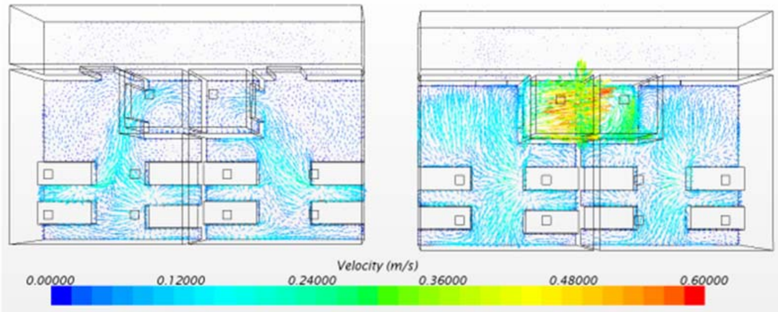
Entry side much out-flow	
Inside less out-flow	

TABLE IX
SIMULATION RESULT ACCORDING TO DIFFERENCE OF EXHAUST VENT (HORIZONTAL SECTION)

Entry side	
Inside	

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