ICIC Express Letters
Part B: Applications
Volume **15**, Number **4**, April **2024**

ICIC International ©2024 ISSN 2185-2766
pp. **417–424**

A STUDY OF IMPROVING THE RESPIRATORY INTENSIVE CARE UNIT (RCU) TO BE APPROPRIATED FOR COVID-19 SITUATIONS

Chattarika Uttachee[1], Ninnart Rachapradit[1,*], Chatchai Chanajon[1]
Ketsophon Pekkrue[1], Prayuth Poowarattanawiwit[2] and Kou Yamada[3]

[1]Department of Mechanical Engineering
Faculty of Engineering
[2]Department of Pharmacy Practice
Faculty of Pharmaceutical Sciences
Naresuan University
99 Moo 9, Thapo Sub-District, Muang District, Phitsanulok 65000, Thailand
{ chattarikau62; chatchaic62; ketsophonp62; prayuthp }@nu.ac.th
*Corresponding author: ninnartr@nu.ac.th

[3]Department of Mechanical Science and Technology
Gunma University
1-5-1 Tenjincho, Kiryu 376-8515, Japan
yamada@gunma-u.ac.jp

Received July 2023; accepted September 2023

Abstract. *This work presents a way to improve Respiratory Intensive Care Unit (RCU) to be appropriated for COVID-19 situations. The objectives of the study are to collect information, analyze the impacts, and study the design standards for improvement. The design standards are based on the guidelines of Centers for Disease Control and Prevention (CDC), World Health Organization (WHO), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), The Engineering Institute of Thailand Under H.M. The King's Patronage (EIT), and the relevant research articles. The medical personnel, engineers, and related agencies are involved in the planning and standardization process. Then analyze the area of Respiratory Intensive Care Unit, which needs to clearly divide the working area between medical staff and patients. After the improvement, the application of isolation room innovation was used to reduce the dangerous area and minimize the infection rate among medical staff. It also reduces excessive energy consumption.*
Keywords: COVID-19, Isolation room, The design standard for improvement and Respiratory Intensive Care Unit

1. **Introduction.** Currently, COVID-19 has spread worldwide, affecting many countries. This is due to the fact that COVID-19 has mutated extensively. The transmission of COVID-19 involves the principles of Droplet, Airborne, and Contact. While engaging in various activities such as breathing, talking, laughing, singing, exercising, as well as coughing and sneezing, if respiratory droplets containing COVID-19 are present, individuals in the same space can become infected through these airborne particles, even without close contact or direct contact with an infected person. This is referred to as airborne transmission [1]. The outbreak of SARS-CoV-2 has made us all think critically about hospital indoor air quality and the approaches to remove, dilute, and disinfect pathogenic organisms from the hospital environment [2].

In 2021, Naresuan University Hospital received funding to establish a Modified Airborne Infection Isolation Room (MAIIR) and it has been observed that efficient containment can be achieved even by using simple and inexpensive construction by considering pressure

DOI: 10.24507/icicelb.15.04.417

differential and air flow patterns [3] for patients with COVID-19. The design of MAIIR was led by Assistant Professor Dr. Ninnart Rachapadit and his research students. The purpose of the project was to prevent the spread of COVID-19 and treat infected patients effectively. However, the initial design of the negative pressure room resulted in energy waste and difficulty in controlling air exchange due to its large size. Additionally, no data was collected on the room's performance.

In 2022, the hospital received a donation for the construction of a new negative pressure room which was designed by Siam Cement Public Company Limited (SCG). To solve the problem of the previous design of MAIIR, the researchers focused on reducing the size of the room and ensuring easy access for medical personnel to reach patients. The main objectives of this research project were to study the strategies used to improve the Respiratory Intensive Care Unit (RCU) at Naresuan University Hospital to better manage COVID-19 and to collect data on the impact of these modifications. The study aimed to provide guidance for future improvements of isolation rooms for patients with airborne infections, especially in response to COVID-19.

The implementation of innovative isolation rooms in the Respiratory Intensive Care Unit has specified as positive outcomes. For example, 1) Medical personnel can have a clear view of the patients, allowing for better monitoring and observation; 2) It reduces the size of hazardous areas, enabling easier management and control of air quality; 3) It decreases the size of the space required for air exchange, leading to energy savings and minimizing unnecessary energy loss; 4) It enables better control of the spread of infectious diseases and the direction of airflow.

To solve the problems from MAIIRs, we had to coordinate with hospital staff and relevant units involved, design principles and ideas for designing RCU, conduct a study and gather relevant standards, study and analyze the existing design before making improvements to identify problems in the current system, evaluate, inspection, and operation support, summarize and compile the study data to propose recommendations for improving and solving against COVID-19 outbreaks for further future.

This paper is organized as follows. In Section 2, we introduce the data source of this research which is held in Naresuan University Hospital and we divide it into 3 cases for improving the Respiratory Intensive Care Unit. Next, we introduced the isolation room by explaining the beneficial of this innovation and also the features of the AIIR and lastly on Section 2, is the methodology of this research. Section 3 gives the result of this research paper, the authors want to explain the procedure for improving the Respiratory Intensive Care Unit, before we analyze the area and pathway to solve the MAIIR problems. Section 4 presents the conclusion of this paper which we mainly talked about the implementation of the isolation room innovative, how it could solve the aforementioned problems.

2. Material and Methods.

2.1. **Data source.** Naresuan University Hospital is part of Naresuan University. This study focuses on this Respiratory Intensive Care Unit (RCU). The study is divided into 3 cases for improving Respiratory Intensive Care Unit: 1) Pre-improvement Respiratory Intensive Care Unit, 2) Strategies for new Respiratory Intensive Care Unit, and 3) Post-improvement Respiratory Intensive Care Unit.

2.2. **Isolation room.** A negative pressure room to be used during pandemic or extra need to patient. It offers a cost effective and practical solution, alternative to a permanent isolation installed in ER room, RCU ward and general wards. From Figure 1 which is a model from catalogue, it is shown the front side and back side of airborne isolation room, which is used in Respiratory Intensive Care Unit. The features of the airborne isolation room are

- It is made of transparent plastic materials;
- Convenient to support patient treatment;
- Ante-room to maintain constant negative air pressure;
- Airlock design.

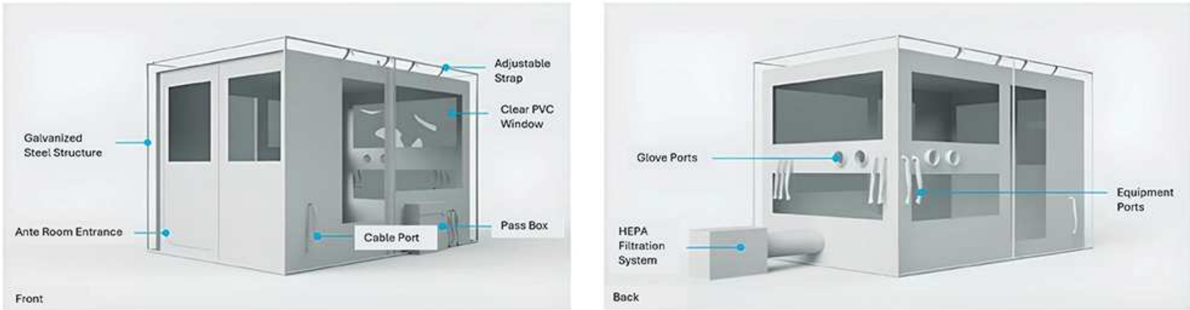

FIGURE 1. Isolation rooms

2.3. **Methodology.**

1) Coordinate with hospital staff and relevant units involved.
2) Design principles and ideas for designing RCU.
3) Conducte a study and gathered relevant standards.
4) Study and analyze the existing design before making improvements to identify problems in the current system.
5) Evaluate, inspection, and operation support.
6) Summarize and compile the study data to propose recommendations for improving and solving against COVID-19 outbreaks for further future.

3. **Results.**

3.1. **Procedure for improving the Respiratory Intensive Care Unit.**

3.1.1. *Coordination with hospital staff and relevant units involved in the air conditioning system.* Coordination with hospital staff and patients is crucial in terms of design concept and the use of space, allocation of utility space, and equipment placement. Therefore, planning should be based on various medical and system data, starting from the design phase to reduce any potential issues that may arise during or after construction. Moreover, it aims to facilitate medical personnel's work convenience. Initially, engineers are required to communicate their space requirements with hospital staff.

Areas of coordination include

- Traffic routes for patients and staff;
- Separation of space for medical personnel and patients;
- Location of air intake and exhaust vents, and medical equipment;
- Safe and convenient access for patient and staff movement entrance and exit of the Respiratory Intensive Care Unit;
- Reduced risk of infection by separating spaces for medical personnel and patients;
- Easy maintenance and repair in the future.

3.1.2. *Design principles and ideas for designing Respiratory Intensive Care Unit.* The aim of improving the Respiratory Intensive Care Unit is to raise the level of safety and suitability for the COVID-19 pandemic situation. One of the important principles is to reduce the size of the room, increase air ventilation, and allow medical personnel to see the patients. In addition, the concept of Fresh Air has been applied to reducing the volume of air with contaminated particles. The recirculation of air is a measure for saving energy, but care must be taken, as it can transport airborne contaminants (including infectious viruses) from one space and distribute them to other spaces connected to the same system, potentially increasing the risk of airborne infection in areas that otherwise would not have been contaminated. This concern has been noted previously in regard to the possible recirculation of biological agents during terrorist attacks that have investigated the effectiveness of eliminating recirculation (e.g., providing 100% outside air to spaces and exhausting all of it) as a countermeasure following an indoor release of the agent [4]. The main idea for engineering the air conditioning system for the RCU is to create comfort for the patients, minimize environmental impact, and ensure stability and suitability for use. The system should be easy to maintain, able to meet the needs for future expansion and be cost-effective. Clear distinction of the advantages and disadvantages of different systems will lead to the most suitable choice of system. This design will serve as a guideline for personnel and organizations involved in the design process.

3.1.3. *Relevant laws and standards.* Engineers need to study the laws and regulations that control indoor air quality in buildings to ensure that the design complies with legal requirements. Additionally, they need to follow the appropriate standards and guidelines to ensure that the design meets the necessary safety and environmental standards. This may include standards set by international organizations such as ASHRAE or local regulations set by the government. Compliance with these laws and standards is crucial to ensure the health and safety of patients and medical personnel.

Table 7.1 Design Parameters—Inpatient SpacesHospital Spaces *(Continued)*

Function of Space (ad)	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Unoccupied Turndown	Minimum Filter Efficiencies (ab)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
Wound intensive care (burn unit)	NR	2	6	NR	No	Yes	8/14	40–60	70–75/21–24
INPATIENT NURSING									
AII anteroom (2.1–2.4.2.3) (u)	(e)	NR	10	Yes	No	Yes	8/14	NR	NR
AII room (2.1–2.4.2) (u)	Negative	2	12	Yes	No	Yes	8/14	Max 60	70–75/21–24
Combination AII/PE anteroom (2.2–2.2.4.5)	(e)	NR	10	Yes	No	No	8/14	NR	NR
Combination AII/PE room (2.2–2.2.4.5)	Positive	2	12	Yes	No	No	8/HEPA(ac)	Max 60	70-75/21-24
Continued care nursery (2.2–2.12.3.3)	N/R	2	6	N/R	No	Yes	8/14	30–60	72–78/22–26
Labor/delivery/recovery (LDR) (2.2–2.11.3) (s)	NR	2	6	NR	NR	Yes	8/14	Max 60	70–75/21–24
Labor/delivery/recovery/postpartum (LDRP) (2.2–2.11.3) (s)	NR	2	6	NR	NR	Yes	8/14	Max 60	70–75/21–24
Newborn nursery suite (2.2–2.12.3.1)	NR	2	6	NR	No	Yes	8/14	30–60	72–78/22–26
Nourishment area or room (2.1–2.6.7)	NR	NR	2	NR	NR	Yes	8/14	NR	NR
Nursery workroom (2.2–2.12.6.3)	NR	2	6	NR	No	Yes	8/14	Max 60	72–78/22–26
Patient care area corridor	NR	NR	2	NR	NR	Yes	8/14	NR	NR
Patient room (2.1–2.2)	NR	2	4 (y)	NR	NR	Yes	8/14	Max 60	70–75/21–24
Patient Ttoilet room (2.1–2.2.6)	Negative	NR	10	Yes	No	Yes (ae)	8/NR	NR	NR
PE anteroom (t)	(e)	NR	10	NR	No	No	8/14	NR	NR
Protective environment room (2.2–2.2.4.4) (t)	Positive	2	12	NR	No	No	8/HEPA(ac)	Max 60	70–75/21–24
Seclusion room (2.1–2.4.3)	NR	2	4 (y)	NR	NR	Yes	8/NR	Max 60	70–75/21–24
NURSING FACILITY									
Bathing room	Negative	NR	10	Yes	No			NR	70–75/21–24
Occupational therapy	NR	2	6	NR	NR			NR	70–75/21–24
Physical therapy	Negative	2	6	NR	NR			NR	70–75/21–24
Resident gathering/activity/dining	NR	4	4	NR	NR			NR	70–75/21–24

Note: NR = no requirement

ANSI/ASHRAE/ASHE Addendum p to ANSI/ASHRAE/ASHE Standard 170-2017

FIGURE 2. Design parameters – Inpatient spaces

3.1.4. *Evaluation, inspection, and operation support.* The evaluation, inspection, and operation support aim to ensure that the systems or machinery can operate efficiently, closely matching their initial performance. This is done to ensure that the systems function as intended, meet the required specifications, and are energy-efficient.

3.2. **The Respiratory Intensive Care Unit analysis.** The analysis of issues and problem-solving approaches in the critical care respiratory unit's interior space can be divided into several parts. The analysis and management begin with assessing the working

Figure 3. Indoor air quality assessment in isolation rooms

and utilization areas of medical personnel and patients. Apart from providing clear delineation of workspaces, this also restricts the patient's infectious spread, allowing for easier management and control of air. The key principle is to direct airflow from the cleanest area to the most contaminated area and subsequently exhaust the contaminated air out of the building.

The spaces can be categorized as follows:

- Contaminate Zone (red): Areas with potential pathogen contamination.
- Buffer Zone (light red): Areas separating contaminated and surrounding zones.
- Service Zone (pink): Areas dedicated to providing necessary services.
- Clean Zone (green): Areas maintained as free from contamination.

Originally, the utilization of the Respiratory Intensive Care Unit was designated for patient rest and observation. Medical personnel would enter this area to observe patients and perform various activities within the room. The primary route for medical personnel to access this area and carry out their duties was through the left side, as illustrated in Figure 5. They would then proceed to the central room where patients were stationed. This involved sharing the same space and air between medical personnel and patients

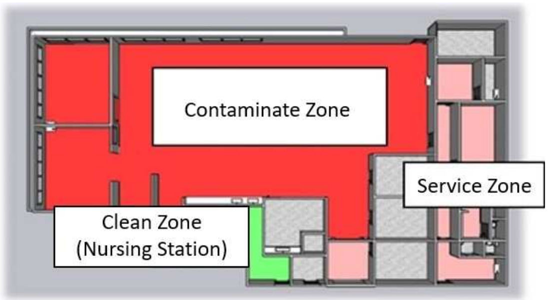

Figure 4. The area of pre-improvement Respiratory Intensive Care Unit

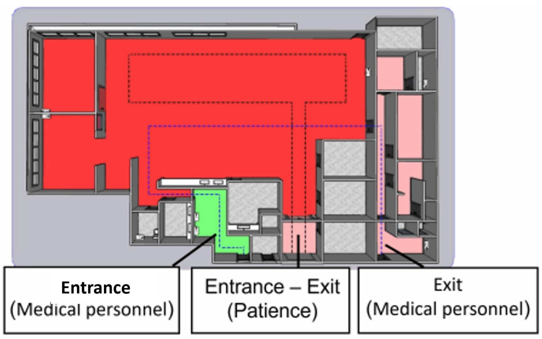

Figure 5. Pathway of pre-improvement Respiratory Intensive Care Unit

within the central room. Patients would be transported through the entrance door and placed in the central room, resulting in the central room becoming a contaminated zone due to various patient activities such as coughing, sneezing, breathing, and daily routines [5]. This situation posed a risk of infection and danger to the medical personnel working in the area. Once the observation and tasks were completed, medical personnel would exit through exit for medical personnel on the right side shown in Figure 5. From the aforementioned figure, it can be observed that the safe area for medical personnel was limited to only the entrance hallway, which was significantly smaller compared to the entire space within the Respiratory Intensive Care Unit. In normal circumstances, this room could be utilized and accommodate patients. However, in the context of the COVID-19 pandemic with increased risks and hazards, this room should be improved. Due to the airborne transmission nature of COVID-19, the shared air between medical personnel and patients is considered an initial and significant risk factor that could lead to personnel acquiring the infection.

Figure 6 illustrates the need for more than just upgrading the Respiratory Intensive Care Unit room to meet safety standards. Incorporating airborne infection isolation room standards is necessary for enhanced safety. A new pathway for healthcare providers is introduced. In Figure 7, with a designated "Clean Zone" for medical personnel, improving safety within the Respiratory Intensive Care Unit. However, the challenge of managing contaminated air outside the medical personnel room still exists.

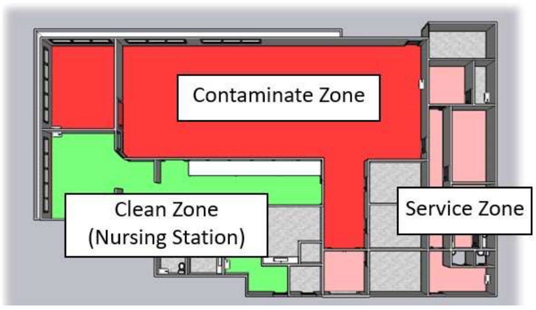

Figure 6. The area of strategies for new Respiratory Intensive Care Unit

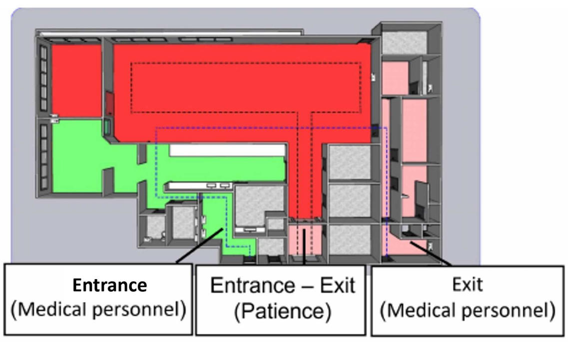

Figure 7. Pathway of strategies for new Respiratory Intensive Care Unit

After the improvement, the Respiratory Intensive Care Unit (RCU) has been modified by incorporating an isolation room, also known as a negative pressure room, to help reduce the occupied space. The risk assessment and zoning of each area and pathway can be evaluated according to Figure 8 and Figure 9. In this case, the central area has been upgraded by utilizing the isolation room to accommodate the mentioned patients, effectively reducing the space utilized by patients. Consequently, the area with the highest risk and patient occupancy is limited solely to the isolation room or the reduced Contaminate Zone.

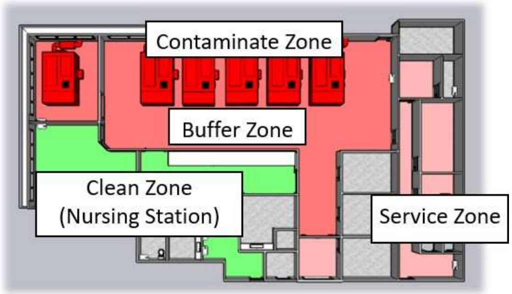

Figure 8. The area of post-improvement Respiratory Intensive Care Unit

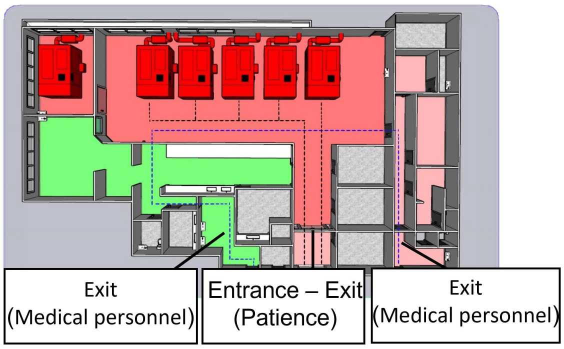

Figure 9. Pathway of post-improvement Respiratory Intensive Care Unit

However, the Centers for Disease Control and Prevention (CDC) in the United States has provided guidelines stating that it takes a certain amount of time for the air to dilute and reduce the concentration of contaminants by 99% and 99.9% through air exchange per hour [6]. By following these recommendations, healthcare professionals can use the central area safely. After completing their tasks, they should exit the room following the blue line indicated in Figure 9, without returning to the original path. This prevents unintentional transmission of potential pathogens that may adhere to their clothing or remain on their bodies from entering the nursing area.

4. **Conclusions.** Based on the study on improving the critical care ward of the respiratory system and literature review, it was found that the improvement process should begin with coordination among engineers, physicians, nurses, and relevant departments to reach a mutual agreement on the work process, space allocation, ideas, and necessary standards. Prior to implementation, clear delineation of the designated areas for doctors and patients is essential. The theory of airflow control must be considered to enhance safety. The implementation of the isolation room innovative in the Respiratory Intensive Care Unit has resulted in the following outcomes.

Medical personnel can have a clear view of the patients, allowing for better monitoring and observation.

1) It reduces the size of hazardous areas, enabling easier management and control of air quality.
2) It decreases the size of the space required for air exchange, leading to energy savings and minimizing unnecessary energy loss.
3) It enables better control of the spread of infectious diseases and the direction of airflow.

Overall, the use of this innovation in the Respiratory Intensive Care Unit has improved patient care, enhanced safety measures, and optimized resource utilization.

Acknowledgment. The study of Improving the Respiratory Intensive Care Unit (RCU) to be Appropriated for COVID-19 Situations can be successfully accomplished thanks to the understanding and support of many personnel.

REFERENCES

[1] WHO (World Health Organization), *Modes of Transmission of Virus Causing COVID-19: Implications for IPC Precaution Recommendations*, https://www.who.int/news-room/commentaries/detail/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations, 2020.

[2] E. S. Mousavi, N. Kananizadeh, R. A. Martinello and J. D. Sherman, COVID-19 outbreak and hospital air quality: A systematic review of evidence on air filtration and recirculation, *Environmental Science & Technology*, 2020.

[3] M. Hyttinen, A. Rautio, P. Pasanen et al., Airborne infection isolation rooms – A review of experimental studies, *Indoor and Built Environment*, vol.20, no.6, pp.584-590, 2011.

[4] A. K. Persily, R. E. Chapman, S. J. Emmerich et al., *Building Retrofits for Increased Protection against Airborne Chemical and Biological Releases*, NIST Interagency/Internal Report (NISTIR), National Institute of Standards and Technology, Gaithersburg, MD, 2007.

[5] Centers for Disease Control and Prevention, *COVID-19 Prevention Actions*, CDC, https://www.cdc.gov/infectioncontrol/basics/transmission-based-precautions.html, 2021.

[6] L. Sehulster and R. Y. W. Chinn, *Guidelines for Environmental Infection Control in Health-Care Facilities*, Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC), 2003.

[7] A. M. Elsaid and M. S. Ahmed, Indoor air quality strategies for air-conditioning and ventilation systems with the spread of the global coronavirus (COVID-19) epidemic: Improvements and recommendations, *Environmental Research*, DOI: 10.1016/j.envres.2021.111314, 2021.

[8] C. Y. Chen, P. H. Chen, J. K. Chen and T. C. Su, Recommendations for ventilation of indoor spaces to reduce COVID-19 transmission, *Journal of the Formosan Medical Association*, vol.120, no.12, 2055, 2021.

[9] C.-C. Jung, P.-C. Wu, C.-H. Tseng and H.-J. Su, Indoor air quality varies with ventilation types and working areas in hospitals, *Building and Environment*, vol.85, pp.190-195, 2015.

[10] M. D. Nembhard, D. J. Burton and J. M. Cohen, Ventilation use in nonmedical settings during COVID-19: Cleaning protocol, maintenance, and recommendations, *Toxicology and Industrial Health*, vol.36, no.9, pp.644-653, 2020.

[11] Q. Zhou, Z. Lyu, H. Qian, J. Song and V. C. Möbs, Field-measurement of CO_2 level in general hospital wards in Nanjing, *Procedia Engineering*, vol.121, pp.52-58, 2015.