The retrofit of respiratory isolation rooms for tuberculosis patients in Taiwan

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ABSTRACT

In order to effectively control nosocomial infection 12 respiratory isolation rooms for tuberculosis patients in four hospitals have been built by the Energy & Resources Laboratories, Industry Technology Research Institute in Taiwan. This project was funded by the Center of Disease Control of the Health Department. The performance of the air-conditioning and ventilation/exhaust system of respiratory isolation rooms has been tested and validated. The tested items include ventilation rate, static pressure, temperature, humidity and noise. All the measuring data have been proved to meet the regulation of the respiratory isolation room issued by the Health Department, Executive Yun in Taiwan.

The methods to retrofit the air-conditioning and ventilation/exhaust system of respiratory isolation rooms are illustrated in this paper in more detail. We propose a very effective and low cost methodology to improve the air-conditioning and ventilation/exhaust system of the respiratory isolation rooms and it is being used in Taiwan widely now.

INDEX TERMS

Tuberculosis; Respiratory isolation room; Air conditioning; Ventilation rate; Trace gas decay

INTRODUCTION

There are about 15 000 new cases of tuberculosis (TB) per year in Taiwan and 4000 TB victims transmit the disease to others. Around 1500 people die of TB every year. During recent years the newly registered tuberculosis case rate has been around 0.06% in Taiwan and its death rate per 100 000 population was 6.91 in 2000 (Health and Vital Statistics in Republic of China, 2002). Tuberculosis has long been recognized as disturbing to public health. The transmission of TB from patients who have infectious TB to other patients and health workers has been reported in hospitals in Taiwan. The increasing level of concern has aroused attention among government officers in the Center for Disease Control (CDC) of the Health Department and healthcare workers. Controlling the nosocomial infection of TB has become a very important mission in hospitals. The CDC in Taiwan has proposed a 10-year programme to sponsor more than 100 hospitals to set up respiratory isolation rooms in order to accommodate TB patients. Because many engineers working in the hospital have no experience setting up respiratory isolation rooms our laboratory's engineers have been invited to be consultants and are responsible to build 12 respiratory isolation rooms in four hospitals for demonstration.

TUBERCULOSIS NOSOCOMIAL INFECTION CONTROL PROGRAMME

The TB infectious control programme of the CDC includes two levels of control plans. The first level is the use of administrative management intended to reduce the risk of exposing uninfected persons to persons who have infectious TB. The second level is the use of engineering controls. This paper focuses on discussing the effective engineering controls to

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prevent the spread and reduce the concentration of TB droplet nuclei in respiratory isolation rooms.

The use of engineering controls is illustrated as follows:

- Negative pressure control is a process during which the amount of exhausted air from a room exceeds the amount of total supply air.
- Ventilation is a diluted process during which the concentration of TB droplet nuclei in a room can be reduced by supplying fresh air or exhausting the mixed room air.
- Air cleaning devices can be used. For example, the high efficiency particulate arresting filters (HEPA) and ultraviolet germicidal irradiation (UVGI) have been used to remove the TB droplet nuclei.

PROJECT OF THE RETROFIT OF RESPIRATORY ISOLATION ROOMS FOR TUBERCULOSIS PATIENTS IN FOUR HOSPITALS

The purpose of this project is to build up 12 respiratory isolation rooms whose performance will meet the regulation of the Health Department of Taiwan. The major works are summarized below:

1. Site Survey: Four site visit/reviews, space programming, existing design drawings reviews, and major mechanical, electrical and air conditioning components selection.
2. Schematic Design: Provision of design drawings, room data sheets and specifications with typical isolation room details for the required architectural, mechanical, electrical and air conditioning as well as ventilation/exhaust system.
3. Working Drawings: ERL personnel review the development of the Working Drawings by the builder.
4. Construction Services: Four construction site visits by ERL personnel to review the progress of project particularly related to air conditioning and ventilation/exhaust system design.
5. Performance Validation: ERL personnel provide the system validation activities such as testing, commissioning, training, protocol establishment and certification of respiratory isolation rooms.

Design Considerations

Several items of considerations in the design of the respiratory isolation room are shown in Table 1.

Table 1 Items for considerations in design of respiratory isolation room

Items of consideration	
Anteroom installation	Yes
Independent ventilation/exhaust system	Yes
Negative pressure control	Yes
Ventilation rate	>6 air change per hour
Air recirculated within isolation room	No
Exhaust duct under negative pressure within building	Yes
Exhaust duct height	Higher than air recirculation zone
HEPA filter on exhaust	Optional

The key element for the isolation rooms should be a design having a minimum of six air changes per hour (ACH) based on the recommendation of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE, 1999). In order to prevent the escape of TB droplet nuclei the infectious isolation rooms should be operated and maintained under negative pressure for achieving unidirectional airflow (CDC, 1994).

Experimental Techniques and Methods for Performance Validation

The evaluation items include ventilation rate, static pressure, temperature and humidity. All the measuring data and results were checked in order to understand whether or not the performance of the air conditioning and ventilation/exhaust systems of the respiratory isolation rooms meet the regulation of CDC.

Negative pressure control

The purpose of the negative pressure is to control the direction of airflow between the respiratory isolation rooms and adjacent areas, thereby preventing contaminated air escaping from these rooms into other areas. The negative pressure achieved will depend on the difference between the exhaust and supply flows in the room. The differential pressure gauge is used to measure the pressure difference between the isolation room and the adjacent area. We suggest that the negative pressure should be maintained at 0.7 mmH_2O or higher to keep the unidirectional flow.

Ventilation rate and measurement

The ventilation of the isolation rooms maintains air quality by dilution and removal of airborne contaminants. The ventilation rate is expressed in air change rate (ACH). The number of ACH is expressed as the ratio of the volume of air entering the room per hour to the room volume and is equal to the exhaust airflow (Q) divided by the room volume (V) multiplied by 60, i.e. ACH = $(Q/V) \times 60$.

Tracer gas decay is a direct measurement of the air change rate. An inert gas that is easily detected at very low concentration is released and uniformly mixed within the isolation room. Assuming the gas does not react with the surrounding materials, the gas concentration will decrease as dilution air flows into room. The rate of decrease is proportional to the ventilation rate.

The air change rate is calculated using the following equation:

$$C = C_0^{-AT}$$

where C is the tracer gas concentration at time T, C_0 the tracer gas concentration at time $T = 0$, A the air change rate and T the time. This equation can be rearranged to yield the following expression:

$$A = (\ln C_0 - \ln C)/T$$

We use sulphur hexafluoride (SF_6) as a tracer gas. A multi-gas monitor is used to measure the concentration of SF_6 every minute. The principle of this instrument is based on the photoacoustic infra-red detection method (Instruction Manual, Vol. 1, Multi-gas Monitor Type 1302, Bruel & Kjir).

RESULTS AND DISCUSSION

From the point of view of preventing contaminated air escaping from an isolation room into other areas the three most important criteria to the respiration isolation rooms are static pressure, ventilation rate and anteroom. Table 2 lists the testing results of four hospitals.

Table 2 The testing results of four hospitals

Hospital	Isolation room	Pressure (mmH_2O)	ACH (h^{-1})	Temperature (°C)	Humidity (%)
A	2706	0.65	11.8	24.8	58
A	2707	0.40	9.40	23.0	58
A	2708	0.65	8.60	25.0	63
A	2709	0.40	9.50	25.0	65
B	0950	1.0	9.90	23.0	62
B	0951	1.1	11.3	23.8	60
B	ICU7	0.50	10.7	23.0	62
B	ICU8	0.50	13.1	23.6	59
C	8101	0.65	12.1	24.0	68
C	8132	0.80	9.60	23.7	69
D	ICU11	0.50	16	22.0	62
D	ICU12	0.80	13.6	22.0	62

The trace gas decay of one of the isolation room is shown in Figure 1 and its curve fitting is shown in Figure 2.

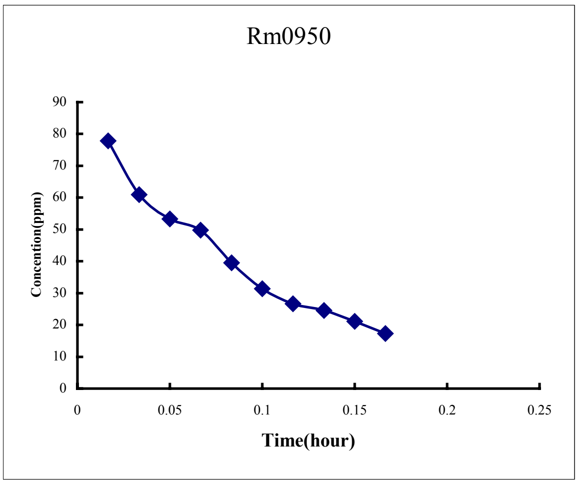

Figure 1 Trace gas decay (ppm vs. hour).

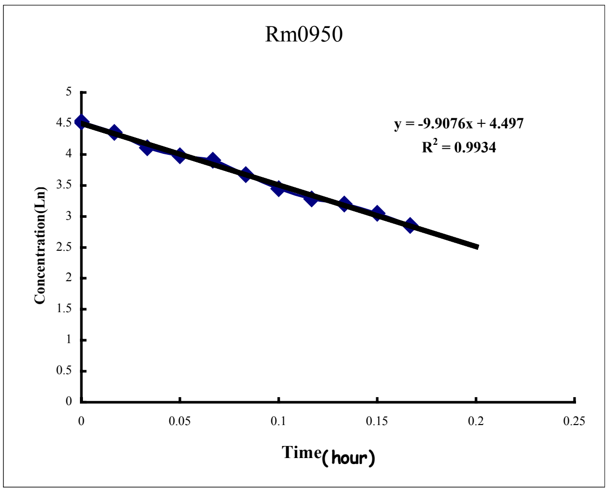

Figure 2 Curve fitting of trace gas decay (Ln vs. hour).

It is very difficult to retrofit the air conditioning and ventilation/exhaust system for renovating the existing hospital facilities into respiration isolation rooms that need special ventilation characteristics for the purposes of isolation. In order to use the existing facilities and minimize the cost of renovation, engineers should consider many items, for example (a) whether or not to use the existing fan coil; (b) anteroom location; (c) negative pressure control; (d) ventilation rate; (e) airflow pattern; (f) exhaust flow treatment; (g) building sealing; (h) temperature and humidity control; (i) monitoring instruments; (j) repair and maintenance.

CONCLUSIONS AND RECOMMENDATIONS

The ERL's engineers recommended a design drawing of the air conditioning and ventilation/exhaust system for infectious isolation rooms shown in Figure 3. In a special case we use a fan coil unit to supply fresh air to the isolation room because of the space limitation of the building. The concept of the design drawing is shown in Figure 4.

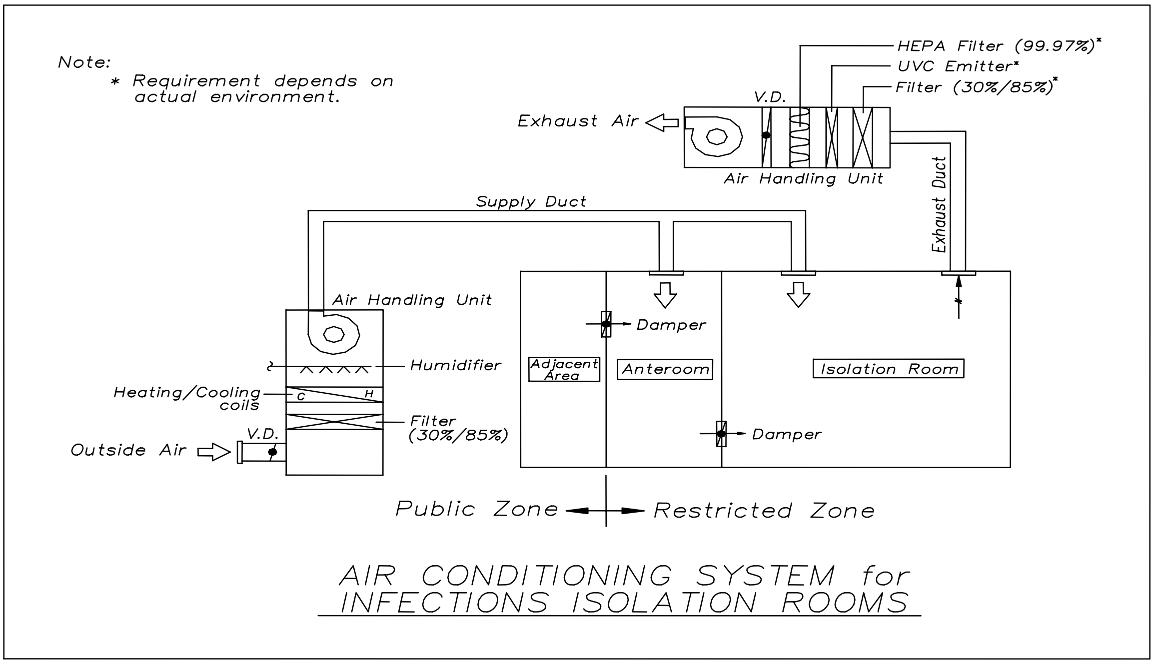

Figure 3 Typical design drawing of the air conditioning and ventilation/exhaust system for infectious isolation room.

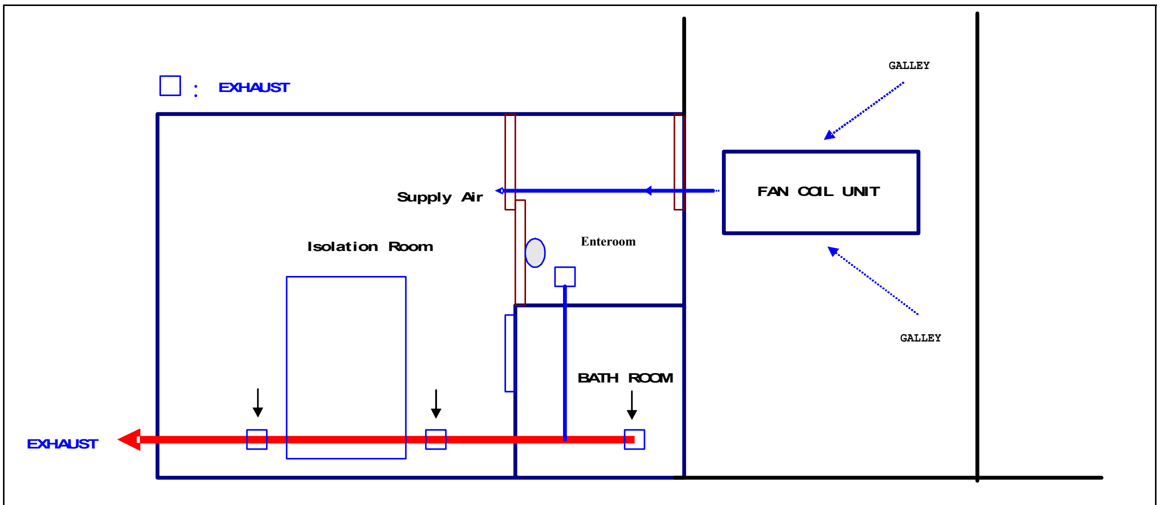

Figure 4. Alternative Air Conditioning System For Isolation Rooms

Considering the habits of technicians in Taiwan's hospital the ERL's engineers also proposed some criteria for designing the respiration isolation rooms. All the criteria listed as follows:

- anteroom,
- negative air pressure relative to the corridor and the surrounding areas,
- at least supply rate of six air changes per hour,
- no air recirculation in isolation room,
- sealed room, door grille for controlled airflow,

- independent exhaust system,
- duplicate exhaust fan to provide airflow in the event of fan failure,
- optional HEPA filter on exhaust,
- pressure gauge and alarm system,
- visible labelling,
- grouping isolation rooms together in one area of the building,
- shared anteroom if isolation rooms grouped.

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