Building and Environment 81 (2014) 81–91

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Experimental analysis of the transport of airborne contaminants between adjacent rooms at different pressure due to the door opening

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ARTICLE INFO

Article history:
Received 5 March 2014
Received in revised form
5 May 2014
Accepted 20 May 2014
Available online 12 June 2014

Keywords:
Infective-aseptic room contamination
Differential pressurization
Door operation effect
Dirty air transfer

ABSTRACT

Today it is common practice to try and obtain airborne contamination control through pressurization-depressurization areas. Moreover, there is some qualitative evidence that turbulence induced by the operation of a door between different pressure areas, could overcome the differential pressurization effect, and cause a pouring effect between zones, and consequently a contamination. The paper investigates the described matter through an experimental setup, with a scale physical model. Obtained results confirm that door operation is able to produce a dirty air transfer in the clean room, and that transfer entity is almost independent from differential pressure and flow rate imbalance, at least for the experimentally tested values, while it appears strongly related to air volume displaced in the door opening operation, and has the same order of magnitude of it.

Practical implications

Several standards and guidelines recommend differential pressure to control contamination between adjacent rooms. This study shows that operation of a conventional (rotating) communication door may overcome the effect of the differential pressure and get a mutual air contamination. The air pouring is of the order of the air volume displaced by the door during its motion. Then, the type of door, its management and operation frequency, appear as further problems to be taken into careful consideration.

1. Introduction

Physical isolation of airborne contaminant sources is considered a very efficient strategy to control the diffusion of infections although, in some cases, it is not sufficient to prevent the contamination. Airborne sources of infection, as virus, bacteria and fungal spore, have diameters variable in a range between 0.02 μm and 100 μm and are susceptible to remain suspended in the air for long periods. So a proper attention to isolation rooms air-conditioning and ventilation systems design must be employed to prevent these fine particles to be transported over long distances through airflow patterns, increasing the risk of transmitting the contagion to people far away from infection sources [1–3].

A common practice is to try and obtain airborne contamination control trough pressurization-depressurization areas. Solutions adopted to obtain pressurization-depressurization areas are usually based on the mechanical ventilation system inlet and outlet air flows disequilibrium. Furthermore, standards and Regulations give rules about pressure differences, not about air flows disequilibrium, with significant differences between different Standards. Table 1 shows a direct comparison between different standards limitations, with reference to isolation ward rooms.

Several studies have been conducted aiming to evaluate the performance of such rooms with regard to the maintenance of differential pressure across doors when closed; among others, Rice et al. [4] did a measurements campaign two seasons long, measuring differential pressure values in 18 rooms: standard rooms, isolation rooms (infectious patients) and protective rooms (patients with low immune defense system), and they found strong variations especially in protective rooms.

Rydock et al. [5,6] describe a technique for tracer containment testing in presence of differential pressure and supply-extract air imbalance. Saravia et al. [7] conducted a measurements campaign of pressure differentials values and ultrafine particles in 678 airborne infection isolation rooms and their surrounding areas.

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http://dx.doi.org/10.1016/j.buildenv.2014.05.031
0360-1323/

Table 1
Comparison between different standards limitations.

Guidelines	Indoor adjacent ambient relative pressure	Minimum external air change required
ASHRAE	Positive/negative/neutral	6–15 ac/h
U.S. Dep. of Healt.	±8 Pa	>12 ac/h
Victorian Advisory Committee	±30 Pa	Up to 15 ac/h
Ministero della Salute Italiano (AIDS patients)	±80 Pa	>4 ac/h

Hayden et al. [8] developed a model to predict the relationship between pressure differential and supply-extract air imbalance with closed doors. Tung, Y.C. et al. [3] conducted experimental studies on differential pressure efficiency, and found that the best ventilation efficiency to extract contaminants was obtained with a differential pressure equal to -15 Pa.

By contrast, relatively few studies have been conducted, assessing the effect of the doors operation and healthcare worker behavior on pressure and airflows regime.

Indeed, a pressure difference between adjacent rooms can be obtained only if the separation door is kept closed and is airtight, so that the disequilibrium air flow can produce a large pressure drop while passing through the door.

When the door is opened, the pressure loss through the door is weakened, and the previously induced pressure differences are strongly reduced and become negligible; vice versa, in most of the cases with mechanical ventilation some tenths of Pascal variation of the room pressure, slightly modifies air flows and their disequilibrium, so that an air flow in the wanted direction can be ensured, but at very low velocities (order of some cm/s).

In these conditions, the kinetic energy induced by the door opening can overcome the one of the air flux due to the air flow rates disequilibrium, and can cause the two rooms air mixing, thus neutralizing the contamination control action.

Tang et al. [9], used a scale model of an isolation room without differential pressure, with water to simulate air and food dye to simulate infectious aerosols, and captured the door and dye motions by a video camera. Experimental tests showed, on a quality level, that there was a clear fluid exchange between the isolation room and the clean room: authors supposed that this effect could persist also in presence of a differential pressurization if the door opening motion was fast enough.

Tung et al. [10] investigated through numerical studies air exchanges between the isolation room and the anteroom, in presence of mechanical ventilation with differential pressurization, when the communication door was open; they found that to obtain an air flow direction completely from the anteroom to the room, at least 24 air changes per hour air flow rates were necessary requested from the anteroom to the room.

Eames et al. [11] estimated motion and diffusion of a contaminant in an isolation room, in absence of differential pressure, through a physical scale model with water instead of air, and food dye as contaminant, doing visualizations through optical methods. They showed that there was a fluid exchange between the rooms caused by a door operation (opening and closing), and estimated the exchanged air volume through a grey-scale analysis of images captured using a machine vision camera. The operation model consisted of opening the door in a time $\Delta\tau_0 = 2$ s, keeping the door open for 30 s and then closing the door in a undeclared time.

Adams et al. [12] investigated the matter, releasing fluorescent microspheres as contaminant into the isolation room, and measuring airborne concentration inside the room, in the anteroom and corridor, with differential pressures ranging from 2.5 to 20 Pa, and conditions of null or high care provider traffic. They found that operating the doors and provider traffic adversely affect containment.

Finally Tang et al. [13] realized a scale model, with water to simulate air, and a colorant as contaminant, where also the door opening operation, a human figure passing through the door, and the subsequent door closing were simulated, but without differential pressure across the doorway.

The scale model has been used to obtain, on a quality level, the contaminant diffusion visualization for different door types (hinged or sliding doors) and different combinations of door operation and human figure movement.

For hinged doors, experimental tests were conducted with constant angular velocity of the door operation, with $\omega = 163 \div 184$ deg/s ("fast movement") or $\omega = 86 \div 98$ deg/s ("slow movement"). Results confirmed that the hinging door operation can produce a contaminant pouring, more significant as the operation velocity grows; results also showed that sliding doors induce much less airflow across the doorway than hinged doors, and that the movement of a healthcare worker through the doorway induces an additional airflow movement.

The mentioned studies on door operation effects have substantially a qualitative nature, take into account situations without differential pressure only, and are referred to reasonable but arbitrary door movement laws.

In this context, this paper experimentally and in a quantitative way investigates, on a two rooms scale model, the door operation effect on air transfer, and consequent airborne contamination, also in presence of unbalanced supply-extraction flows and consequent differential pressurization, and applying a door movement law deducted from full scale experiments.

These steps have been followed in the study:

1) First approximation theoretical study of the transient flow during the first moments of the door opening in a differentially pressurized two rooms environment.
2) Experimental study of door movement during the real opening/closing operation.
3) Analysis of the physical similarity between design solutions and scale model features.
4) Model and instruments description.
5) Quantitative experimental study through opacity measure method.
6) Experimental results.
7) Comments and conclusions.

2. Theoretical analysis

A first approximation analysis on pressure trend in the pressurized room, during door opening operation, has been conducted.

The analysis is referred to a system made of two adjacent rooms, connected by a door; $Q_{NET} = Q_{IN} - Q_{OUT}$ is the air flow rate flowing, with the door closed, from a room to the other.

It is assumed that the small pressure variation induced in the room by the door opening does not influence air flow rates Q_{IN} and Q_{OUT}, deriving from the air-conditioning system, and consequently Q_{NET}.

Moreover common experience show that in pressurized rooms with differential pressures of some tens of Pa order of magnitude with the door closed, during the door opening air velocity increases substantially only close to the door opening gap; so it seemed appropriate to assume that in the room body velocities maintain always very low values, and then pressure can be considered uniform in the room, although variable during the time.