Engineers, Inc.

2. Reardon, J., C. Shaw, 1997. Evaluation of five simple ventilation strategies suitable for houses without forced-air heating. *ASHRAE Transactions*, Vol. 103, Part 1, pp. 731-744. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

3. Lubliner, M., D. Stevens, B. Davis, 1997. Mechanical ventilation in HUD-Code manufactured housing in the Pacific Northwest. *ASHRAE Transactions*, Vol. 103, Part 1, pp. 731-744. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

4. Sherman, M., N. Matson, 1997. Residential ventilation and energy characteristics. *ASHRAE Transactions*, Vol. 103, Part 1, pp. 731-744. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

5. Holton, J., M. Kokayko, T. Beggs, 1997. Comparative ventilation system evaluations. *ASHRAE Transactions*, Vol. 103, Part 1, pp. 731-744. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

6. Miller, J., C. Conner, 1997. Estimated costs of ventilation systems complying with the HUD Ventilation standard for manufactured homes. Battelle Pacific Northwest Laboratory, PNL-8947/UC-350, November.

7. *Energy Design Update*, 1997. "Controller Improves the Efficiency of Furnace-Based Ventilation Systems." Cutter Information Corp., Arlington, MA. September.

8. *Builder*, 1998. "Space Shot Building Products," *Builder Magazine*, January. Hanley-Wood, Inc., Washington, D.C.

9. HUD 1994. Part 3280 Manufactured home construction and safety standards, interpretive bulletins to the standard, excerpted from the Code of Federal Regulations Housing and Urban Development.

10. WSBCC 1997. *Washington State Ventilation And Indoor Air Quality Code (1997 Edition)*, Chapter 51-13 WAC. Department of Community Development, Washington State Building Code Council, Olympia, Washington.

11. ASHRAE, 1993. *ANSI/ASHRAE Standard 90.2-1993, Energy-Efficient Design of New Low-Rise Residential Buildings*. Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

ACKNOWLEDGMENT

This project was sponsored by the U. S. Department of Energy, Office of Building Technology, State and Community Programs, George James-Program Manager.

PRESSURE RELATIONSHIPS IN HOSPITAL CRITICAL-CARE FACILITIES

A. J. Streifel[1], B.B. Bridges[1], D.T. Grimsrud[1], B.C. Krafthefer[2]

[1]University of Minnesota, USA
[2]Honeywell, Inc. USA

ABSTRACT

This field study was organized to track differential pressure relationships in critical care units of a metropolitan hospital. Maintaining design pressure balances is essential to control risk of airborne disease transmission within these units. The pressure differentials that exist between two patient isolation facilities (positive and negative) and their surrounding spaces were monitored continuously for one week. In addition, individual room challenges were recorded that tracked pressure changes associated with opening and closing doors in the patient room, the hallway, the anteroom of the patient room, and the adjacent patient room. Containment was excellent in the positively pressurized, occupied room. It was unacceptable in the negatively pressurized, unoccupied room. Room design features contributing to these observations are discussed.

INTRODUCTION

Control of airborne transmission of disease in a health-care facility occurs in many ways [1-3]. An important strategy is isolating the air containing airborne agents of concern from individuals who are susceptible to infection. One building-related strategy is to maintain positive or negative pressure differences between adjacent spaces that prevent airflow from the contaminated space to a non-contaminated space.

In the context of a health-care facility an immune compromised patient is placed in a room having higher pressures than adjacent spaces, thus limiting flow into the room containing the susceptible patient. On the other hand, when a patient carries a contagious disease that may be transmitted through the air, the opposite strategy is adopted.

This field study was organized to track differential pressure relationships in critical care units of a metropolitan hospital. The study was organized to challenge the containment pressures in each room using activities that were typical of its expected use. As these activities occurred, pressure differentials that exist between two patient isolation facilities (positive and negative) and their surrounding spaces were monitored and logged. This paper reports the results of the door operation challenges and performance of the rooms over a one-week interval.

METHODS

The two rooms monitored in this study are located in nearly the same position on the floor plan, but are separated by two floors. Room A+, having a volume of 50 m^3, is held at a positive pressure with respect to adjacent spaces and is used for bone marrow transplant, i.e., immune compromised, patients. Room B-, with a volume of 28 m^3, has negative pressure for infectious patients. Both rooms are actually a suite of three sub-rooms: the anteroom, the patient care room and the toilet room. A door (1.2m x 2.2m) separates each room. Automatic door closers are installed on the door between the anteroom and the hall, and between the patient room and anteroom. Each door swings as expected for egress:

from the toilet room into the patient room, from the patient room into the anteroom, and from the anteroom into the hall.

Both rooms are served by variable volume ventilation systems. However, each room is operated with its control dampers fixed to provide constant air volume. Temperature control is provided with radiant ceiling panels. The positive pressure room (A+) has measured supply flows of 210 L/s and total exhaust from the patient room and toilet room of 100 L/s. The negative pressure room (B-), on the other hand, has supply airflow of 80 L/s and a total exhaust rate of 110 L/s. Slow drifts of the hall to patient room pressure were seen because the hall airflow is variable air volume.

Continuous data logging was undertaken in the two rooms using eight-channel differential pressure loggers. Each pressure sensor has a resolution of 0.1 Pa and auto-zeroes every two minutes during a measurement period. Each channel averages pressures over a predetermined period and sends its signal to a computer controller for storage during long-term monitoring.

Two measurement rates were used during our study of protective isolation. During a longitudinal study of pressure relations lasting several weeks, data were collected every 10 seconds. This interval is long enough to see small, slow changes in the pressure relations. The rate is frequent enough so pressure changes will be recorded each time a door is opened. The second rate was used during a short-term series of challenges. In this case the data collection rate was the order of three values a second. At this rate it is possible to see the relations of pressure change as a door swings through its arc (Figs. 1 and 2).

RESULTS

Negative Pressure Room (Room B-)

The first test session was located in a negative pressure room B-. Two data loggers were used for the longitudinal study to record eight pressure relations and two temperature values.

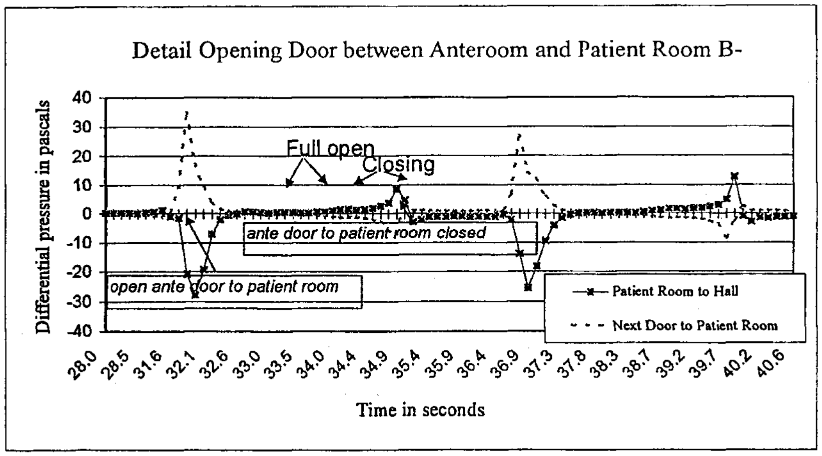

Figure 1 Pressure Relations as Anteroom Door is opened in Room B-

Door Opening Tests

Figure 1 shows results of door openings between the anteroom and the patient room. Noting that the door swings from the patient room into the anteroom opening the door [shown between 32 and 33 seconds and repeated between 37 and 39 seconds causes the pressure in the room relative to the hall to drop 30 Pa. When the door closes these pressure pulses reverse. During the closure period between 34 and 36 seconds and between 39 and 41 seconds the room becomes positive with respect to the hall, reaching a peak of about 10 Pa.

Room B- was unoccupied during the test period. Extended logging showed small variations in the relations between the patient room, the anteroom, the room next door, and the hallway. The pressure differences were small but a consistent gradient was observed. Over a week-long logging period with 9142 values recorded, one each minute, the statistical analysis shows (signal location compared to patient care room):

Table 1 Pressures (Pa) in Adjacent Spaces Relative to Room B-

Pressures	Average	Standard deviation	Minimum	Maximum
anteroom	0.36	0.07	-0.04	0.85
toilet in patient's room	-0.50	0.07	-0.62	0.11
Hall by patient room	0.03	0.02	-0.11	0.18

The measured pressure difference to provide containment is quite small. The average pressure difference between the patient room and anteroom is only -0.36 Pascal. The average difference between the patient room and the hall is even worse, only -0.03 Pa. Since leakage between the room and adjacent spaces was significant, this is inadequate. The pressure differences were fairly stable during our test period. There was little traffic on the floor and no activity in the room. However, occupancy and door swings that would result would cause loss of containment.

The small pressure differences between the room and the hall prompted a physical inspection of the room. The toilet, ceiling, and pipe chase, which had been assumed to be separate, were actually open to one another. The ceiling of the patient room had many small holes in the metal ceiling pans and more openings in the lighting frame. Insulation material used for sound control offered only token resistance to airflow and thus there was little difference seen in the pressure relations between adjacent spaces. The walls between the patient room and the hall and between the patient room and the room next door were solid from floor to ceiling pan. At the top of the wall between the room next door and the hall there was an open seam (about 6 mm wide) which was stuffed with fiber insulation. A solid ceiling over the anteroom joined the walls to provide separation from the patient room except through the door.

Positive Pressure Room A+

The tests in the positive pressure room (A+) differed in several important ways. This room was occupied during the tests. Results showed that substantial pressure isolation existed between the room and adjacent spaces. Door opening challenge results are presented below

Door Opening Tests

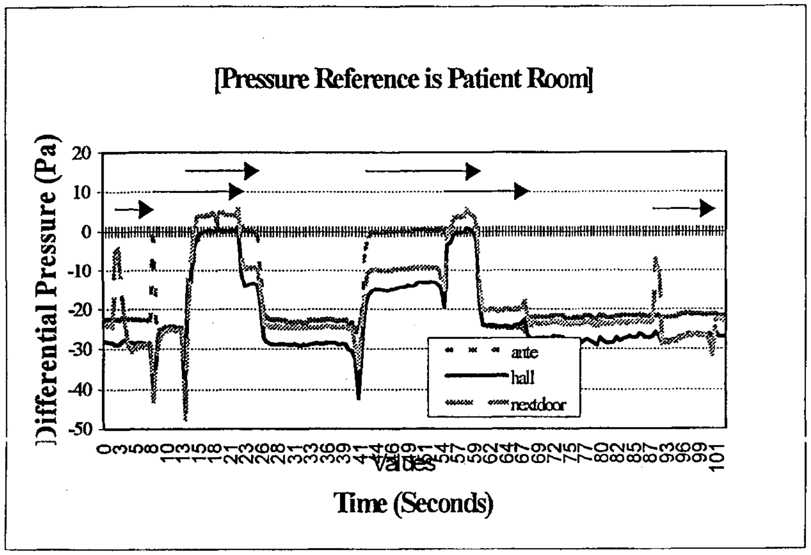

Figure 2. Pressure Responses to Door Openings in Room A+

Figure 2 shows results of door openings between the anteroom and the patient room. Horizontal arrows in the figure depict three separate door openings. (Note that the next door room does not have an anteroom and therefore represents an opening directly to the hall.) The arrows at +5 Pa represent the opening of the door from the next room to the hall. The arrows at +10 Pa represent the opening of the door from the anteroom to the hall. The arrows at +15 Pa represent the opening of the patient room to the anteroom. The results show that containment is lost in room A+ when both the patient door and anteroom door are open at the same time. This occurs even though this room operates at a high positive pressure with respect to surrounding spaces.

Week-long Operation

The analysis of logged data is more interesting for an occupied room. In addition to the variations of general building pressure caused by the HVAC system, each door opening has a significant impact on room pressure. The pressure signal generated identifies each time a door is opened and is a measure of the number of visits to a patient room. Over a weeklong logging period 63538 values were recorded, each an average over ten seconds. At this sampling rate the typical change in pressure caused by opening a door is fully captured because the typical door swing requires about 12 seconds to automatically close. The statistical analysis shows:

Table 2. Week-long Pressures Relative to Room A+ (Pa)

Signal Location	Average	Standard deviation	Minimum	Maximum
Hall	-31	3	-38	-0.04
Anteroom	-23	2	-28	0.2
Toilet Room	--1.1	0.8	-2.9	0.7

These are much larger pressure gradients than seen for room B-. The standard deviation of the hall/room pressure difference (3 Pa) is smaller than the normal, closed-room pressure difference (-31 Pa) and one that has at least one door open. (-15 Pa)

Table 3 gives the number of samples observed when the measured pressure difference between the patient room and hall was smaller than the average value of 31.4 Pa.

Table 3 Distribution of large changes in pressure in room A+

Pressure, P, in Patient Room A+ Relative to Hall (Pa)	Number of Samples in which Pressure Smaller than P	Percent of Total
28	3660	5.7
25	855	1.3
15	365	0.6
7	41	0.06
0	0	0.00

Figure 2 shows that the containment pressure drops to 25 Pa when the anteroom door is open to the hall. When this door is closed but the patient room door is open to the anteroom the containment pressure drops to 15 Pa. When both rooms are open simultaneously the containment is lost.

Table 3 shows that during the 7.3-day continuous monitoring period, containment is maintained. In 365 samples (0.6 percent of the total) the door to the patient room was open while the anteroom door was closed. The door to the anteroom was open to the hall in 855 samples or 1.3% of the time.

DISCUSSION OF RESULTS

Pressure management for control of airborne particles really refers to the providing consistent airflow direction during isolation. The airflow direction design criteria for airborne infection isolation rooms provided by AIA and ASHRAE indicate 'in' or 'out' for the airflow direction. The footnote states an offset from exhaust and supply to be 15% or 25 L/s [4,5]. The amount offset air differential to accomplish such a critical flow is often inadequate when excessive air leakage to adjacent spaces is present. This was shown in this study in room B-. Pressure differentials drive the airflow. The guidelines may continue to specify airflow differences between exhaust and supply to set up the room.

However, pressures should also be monitored to assure that the isolation is maintained. Design features such as inoperable windows and self-closing doors must be standard in order to assure consistent airflow.

The utilization of anterooms to assure isolation condition has been considered to reduce the impact of corridor airflow changes due to opening and closing of doors, elevator movement or other changes in air volume. This evaluation demonstrates the value of the anteroom in maintaining patient room pressure stability. Sufficient differential pressure for control is necessary but difficult to achieve unless the effort to minimize the movement of air other than through managed openings.

ACKNOWLEDGEMENTS
The authors acknowledge support from hospital staff and the Honeywell Corporation that allowed these measurements to be made.

REFERENCES

1. Nazaroff, W W, Nicas, M, and Miller, S L. 1998. Framework for evaluating measures to control nosocomial tuberculosis transmission. *Indoor Air.* Vol 8 (4), pp. 205-218.

2. Streifel, A J. 1995. Ventilation design for control of airborne infectious agents. *Infection Control and Sterilization Technology.* May, pp 18-22.

3. Streifel, A J. 1996. Controlling Aspergillosis and Legionella in hospitals. In *Indoor Air and Human Health,* R B Gammage and B A Berven, eds. Boca Raton: Lewis Publishers

4. AIA. 1997. *Guidelines for Design and Construction of Hospital and Health Care Facilities.* Washington, DC: American Institute of Architects Press. Chap. 5.

5. ASHRAE. 1995. *ASHRAE Applications Handbook.* Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. pp. 7.4-7.5.

HIGH EFFICIENCY DESICCANT SYSTEMS FOR AIR CONDITIONING APPLICATIONS

Luigi Schibuola

Dipartimento di Fisica Tecnica, Università di Padova, Italy

ABSTRACT

Suitable combinations of desiccant and evaporative cooling systems permit air processes alternative to the traditional ones for air conditioning applications. But owing to the high costs of desiccant wheels, we need very strong energy savings in order to demonstrate an economy validity. These savings can be possible today by the last generation of desiccant wheels where the most part of the regeneration heat can be supplied by heat recovery from chillers. In this paper the performances of metal-silicate wheels are investigated and presented in the case of their applications in European typical climatic conditions. The results seem very promising.

INTRODUCTION

The convenience and sometimes the necessity to use chemical adsorption, when low thermal or humidity levels are required, are just well-known. But the recent developments of new adsorbent materials have led to the introduction of desiccant rotors characterized by a strong increment of dehumidification efficiency. In this way it is possible today to achieve dehumidification capacities compatible with air conditioning treatment requirements also in presence of low regeneration thermal levels obtainable, for example, with heat recovery from chiller condenser.

In this paper a ventilation air treatment, based on a high efficiency desiccant system, is proposed and studied for a typical application in an office building.

THE PLANTS

The performances of a high efficiency metal-silicate wheel has been considered. Here a metal-silicate ($MgSiO_3$) is tightly fixed, by chemically synthesizing, on a ceramic fiber laminate which forms the honeycomb-shaped matrix of the rotor. Its performances, provided by the manufacturer, are reported in figures 1 and 2 , In detail figure 1 shows the output moisture for various input moistures and temperatures of process air in presence of regeneration air temperature of 40°C or 60°C. The figure 2 shows the corresponding output temperatures of the process air. The rotor wheel is 200 mm depth with a regeneration area equal to 40% and the rest reserved for process. Process and regeneration air flows are equal. The comparison with the normal performances of the traditional chemical wheels saturated of lithium chloride [1, 2, 3] points out the net increment of the possibility to achieve, also with low regeneration temperature, an acceptable dehumidification efficiency. Figure 3 shows the sketch of the desiccant plant for primary air treatment here studied (type A) while in figure 4 the corresponding air processes are reported in the psychrometric diagram. After dehumidification the process air is cooled in two cross flow type heat exhangers by outside or return air, first cooled by adiabatic humidification. If this is not enough, a final traditional cooling coil contributes to obtain supply air design temperature (20°C). In each exchanger, the two air