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## Demonstration of Air Leakage Reduction Program in Navy Family Housing

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**REFERENCE:** Verschoor, J. D. and Collins, J. O., "Demonstration of Air Leakage Reduction Program in Navy Family Housing," *Measured Air Leakage of Buildings, ASTM STP 904*, H. R. Trechsel and P. L. Lagus, Eds., American Society for Testing and Materials, Philadelphia, 1986, pp. 294-303.

**ABSTRACT:** The Department of Defense has an ongoing program to conserve energy at its installations. One method of energy conservation in residential units is the reduction of excessive air leakage by appropriate retrofits.

Under the sponsorship of the Office of Navy Family Housing, a demonstration of air leakage reduction was undertaken at the Great Lakes Naval Training Center. Two procedural documents were prepared in draft form: a manual for use by supervision and a handbook for the on-base mechanics doing the air leakage retrofits. The retrofits were designed to be incorporated at the time of change of occupancy, when routine interior maintenance and refurbishing are normally scheduled.

The demonstration consisted of measuring the "before" air leakage rate of each unit by the fan depressurization method. Major air leakage sites were noted. Retrofits were made in about half of the units, and the resulting reduction in air leakage was measured. Air leakage data are presented on a representative sample of 65 units of the housing inventory at Great Lakes.

**KEY WORDS:** energy conservation, air leakage, fan depressurization, infiltration, retrofit, residential housing

The Department of Defense has an ongoing program to conserve energy at its installations. As part of this program, the Office of Navy Family Housing undertook a demonstration of the potential for air leakage reduction in housing units at a major base. The purpose of the demonstration was to apply air leakage reduction methods from research type projects to the real world of family housing maintenance. A secondary purpose was to obtain actual air leakage data on a significant sample of family housing units at a base. If the

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demonstration program was successful on a pilot basis, air leakage reduction could be included as a standard maintenance procedure and expanded to other locations.

Normally, interior routine maintenance and refurbishing are scheduled at the time of change of occupancy of housing units. It was proposed to incorporate air leakage reduction as part of these procedures, before interior painting was completed.

A detailed manual and handbook for air leakage reduction were developed in draft form for implementation by base maintenance personnel. The air leakage manual was intended for use by base management and covers general objectives to be achieved and requirements. The handbook was designed for maintenance personnel and was written in language they would understand. It comprises background air leakage information and specific recommendations for materials, equipment, and procedures. It was felt that both documents were required because of the divergent information requirements of supervision and the mechanics actually doing the retrofits. Both manuals were designed to be self-explanatory, with no formal training sessions intended to instruct the users in how to follow the procedures described.

### **Supervisors' Manual**

The air leakage management manual was prepared primarily for use by public works officials and facilities maintenance managers and planners. It details the technical aspects of air leakage, retrofit crew size and qualifications, and summarizes the steps in the retrofit procedure and the materials and equipment required.

The discussion points out that minimum air leakage is desirable from the standpoint of energy conservation. However, with too little ventilation there could be an undesirable buildup of pollutants. It was decided, with the current limited state of knowledge in this field, that an average of 0.5 air changes per hour (ACH) under naturally occurring conditions represented good present practice.

Where to set the desired air change rate under the induced test depressurization pressure of 50 Pa [0.20 in. water ( $H_2O$ )] was given considerable thought. There is wide local variation in the natural conditions causing infiltration (primarily terrain, shielding, wind speed and direction, and temperature difference factors). However, a mechanic requires a precise guide. As a preliminary specification, it was decided that the desired induced air change rate or retrofit goal (at -50 Pa) should be not more than 8 ACH, nor less than 5 ACH. As general knowledge is gained and specific locale requirements are found necessary, this general specification might well be changed.

The supervisors' manual is still in draft form; experience with its use at other Navy bases could dictate improvements.

### Mechanics' Handbook

The handbook, designed for use by the maintenance superintendent, foremen, crew leaders, and mechanics, is in two parts. Like the supervisors' manual, it is also in draft form to facilitate future modifications.

Part I contains a discussion on why air leakage should be reduced, typical air leakage locations, and how to detect and correct excessive air leakage. Specific materials and methods are described. Equipment required and suggested crew are discussed.

Part II contains a detailed step-by-step procedure to be followed for air leakage retrofits. Numerous cautions are enumerated to insure minimum hazard to personnel and structure.

The objectives of the program caused certain simplifications to be made in writing the standard procedures: tests are conducted under negative pressure only (to facilitate leakage site detection), tests are made at only one differential pressure (50 Pa), and the living space volume (in cubic feet) is assumed to be eight times the gross floor area (in square feet). The use of infrared (IR) equipment would have been helpful for detection of air leakage locations. However, the cost of the equipment and the time and skill level required for proper IR scans ruled this out.

Tables of air flow rates at  $-50$  Pa for the Navy blower doors are included in the mechanics' handbook. In addition, for those cases of very leaky units where the blower door does not have enough fan capacity to depressurize to  $-50$  Pa, tables at lower pressures are included. The air flow rates in the reduced pressure tables were corrected to a pressure of  $-50$  Pa using a value of the exponent  $n$  of 0.65.

To assist the mechanics in the field to remember the details of the procedures, a pocket-sized checklist was included (Fig. 1). A final feature of the procedures was the preparation of an air leakage retrofit report form for each unit (Fig. 2). This report will assist program managers in evaluating the current air leakage condition of the housing units and the effectiveness of the air leakage reduction energy conservation program. It was recognized that certain conditions may require more time for completion than would be available during a normal "change of occupancy" refurbishing. Space was provided on the report form for noting these conditions for further follow-up.

### Demonstration

The Great Lakes Naval Training Center (GLNTC) has 2089 family housing units. Sixty units for senior officers were constructed before World War II. All of the other units were built following World War II in various military construction financing programs. Because of the limited number of senior officer quarters, they were not included in this demonstration program.

**NAVY FAMILY HOUSING - AIR LEAKAGE RETROFIT  
Checklist**

**Step 1 - Blower Door Installation**

- a. Snug in door frame.
- b. Air leaks sealed with masking tape.
- c. Level control panel.
- d. Zero pressure gauge.
- e. Connect electrical wire and pressure tubing.
- f. Direction switch on "Off".
- g. Fan speed control at "0".
- h. SAFETY - Keep foreign objects out of fan.

**Step 2 - Retrofit Report - Exterior Inspection**

- a. Enter unit location, type and features on report.
- b. Calculate living space area and volume.
- c. Inspect exterior caulking on windows and doors.
- d. Inspect storm window and door condition.
- e. Enter problem areas remaining on report for later repair.

**Step 3 - Air Leakage Test Preparation**

- a. Disconnect furnace and hot water heater flue.
- b. Close and latch windows and doors (except for blower door).
- c. Close storm windows and doors.
- d. Open interior doors except closet, cupboard and cellar.
- e. Close fireplace damper (seal temporarily if defective).
- f. Check water seal in plumbing traps.

**Step 4 - "Before" Leakage Test**

- a. Adjust fan speed for 0.20 in. water pressure differential.
- b. Readjust to 0.15 or 0.10 if lack of fan capacity.
- c. Average 5 readings if gusty wind.
- d. Calculate leakage volume and air change rate.
- e. Record data on report.

**Step 5 - Decision - Retrofit Required?**

- a. Object - as much less than 10 ach as possible, but not less than 5 ach.
- b. Less than 5 ach - no retrofitting required.
- c. 5 to 8 ach - minimum retrofits.
- d. 8 to 12 ach - retrofit steps 6 through 9.
- e. Greater than 12 ach - complete retrofit program.
- f. Greater than 20 ach - look for major air leaks.

**Step 6 - Vent Retrofits**

- a. Replace dryer vent.
- b. Inspect/repair/replace other vents.
- c. Note those with remaining problems on report.

**Step 7 - Exterior Door Retrofits**

- a. True door if required.
- b. Repair/replace weatherstripping.
- c. Repair/replace threshold.
- d. Weatherstrip sliding glass patio doors.

**Step 8 - Electrical Retrofits**

- a. Seal main electric service box (power OFF).
- b. Seal around ceiling light fixtures (do not seal recessed type).
- c. Seal and gasket wall switches.
- d. Seal and gasket receptacles, install safety caps.

**Step 9 - Attic Inspection and Retrofits**

- a. Report type and thickness of attic insulation.
- b. Repair and seal attic hatch.
- c. Seal utility chase from attic side.

**Step 10 - Interior Sealing Retrofits**

- a. Remeasure air leakage rate.
- b. Do not continue retrofits that reduce rate below 5 ach.
- c. Interior sealing areas:
  - walls
  - windows and frames
  - door frames
  - heating system
  - vents
  - utility services
  - other potential leakage areas

**Step 11 - "After" Leakage Test**

- a. Test conditions same as "Before".
- b. Adjust fan speed for 0.20 in. water pressure.
- c. Calculate leakage volume and air change rate.
- d. Look for additional leaks if greater than 10 ach.
- e. Calculate percent improvement.
- f. Record data on report.

**Step 12 - Blower Door Removal**

- a. Remove blower door.
- b. Retrofit that door (Step 7).

**Step 13 - Furnace and Hot Water Heater**

- a. Check/reconnect/replace flue.
- b. Relight pilots.
- c. Check operation.

**Step 14 - Retrofit Report**

- a. Check that completed fully.

FIG. 1—Pocket-sized checklist.

## AIR INFILTRATION RETROFIT REPORT

Address \_\_\_\_\_ Apt no. \_\_\_\_\_ Housing project \_\_\_\_\_

Type: \_\_\_\_\_ Stories: \_\_\_\_\_ Style: \_\_\_\_\_ Mech. System: \_\_\_\_\_ Fuel: \_\_\_\_\_  
 prior '50 \_\_\_\_\_ 1 \_\_\_\_\_ single \_\_\_\_\_ furnace \_\_\_\_\_ gas \_\_\_\_\_  
 Wherry \_\_\_\_\_ 2 \_\_\_\_\_ duplex \_\_\_\_\_ boiler \_\_\_\_\_ oil \_\_\_\_\_  
 Capehart \_\_\_\_\_ 3 \_\_\_\_\_ townhse \_\_\_\_\_ air cond. \_\_\_\_\_ wood \_\_\_\_\_  
 Mil Con \_\_\_\_\_ basmt \_\_\_\_\_ flat \_\_\_\_\_ heat pump \_\_\_\_\_ elect. \_\_\_\_\_  
 '59 - '69 \_\_\_\_\_ split \_\_\_\_\_ other \_\_\_\_\_ base bd. \_\_\_\_\_ central \_\_\_\_\_  
 1970 + \_\_\_\_\_ other \_\_\_\_\_ other \_\_\_\_\_  
 Living space: area \_\_\_\_\_ sq ft; volume \_\_\_\_\_ cu ft

Exterior inspection: wind: speed \_\_\_\_\_ MPH, direction \_\_\_\_\_  
 window caulk \_\_\_\_\_ door caulk \_\_\_\_\_ other \_\_\_\_\_  
 storm window \_\_\_\_\_ storm door \_\_\_\_\_ other \_\_\_\_\_

Attic inspection: insulation \_\_\_\_\_ avg. thick \_\_\_\_\_ inches

## Air Leakage retrofits:

Vents: \_\_\_\_\_ Exterior doors: \_\_\_\_\_ Electrical service: \_\_\_\_\_ Attic: \_\_\_\_\_  
 dryer \_\_\_\_\_ front \_\_\_\_\_ main box \_\_\_\_\_ flue \_\_\_\_\_  
 kitchen \_\_\_\_\_ kitchen \_\_\_\_\_ clg. lights \_\_\_\_\_ hatch \_\_\_\_\_  
 1/2 bath \_\_\_\_\_ side \_\_\_\_\_ switches \_\_\_\_\_ hatch seal \_\_\_\_\_  
 bath #1 \_\_\_\_\_ patio \_\_\_\_\_ receptacles \_\_\_\_\_  
 bath #2 \_\_\_\_\_ rear \_\_\_\_\_ t'stat \_\_\_\_\_

## Interior sealing:

## Use code:

OK=alright

NG=no good

RPR=repair(ed)

RPL=replace(d)

S=sealed

G=gasketed

	kitchen	din rm	liv rm	fam rm	1/2 bath	mastr BR	MBR bath	BR #2	BR #3	bath #2	utility rm	basement	other
walls													
baseboards													
windows													
int. doors													
heating													
vents													
TV/phone													
utilities													
other													

Special conditions \_\_\_\_\_

## Future conservation steps recommended:

Caulk exterior \_\_\_\_\_  
 RPR/RPL storm window(s) \_\_\_\_\_  
 RPR/RPL storm door(s) \_\_\_\_\_  
 Attic insulation \_\_\_\_\_  
 Other \_\_\_\_\_

Before work started: \_\_\_\_\_ After work finished: \_\_\_\_\_ Crew: \_\_\_\_\_  
 Time \_\_\_\_\_ Time \_\_\_\_\_  
 Fan \_\_\_\_\_ RPM Fan \_\_\_\_\_ RPM  
 Pressure \_\_\_\_\_ in. H2O Pressure \_\_\_\_\_ in. H2O (team leader)  
 Leakage \_\_\_\_\_ x1000 CFM Leakage \_\_\_\_\_ x1000 CFM Date \_\_\_\_\_  
 Change rate \_\_\_\_\_ / Hr Change rate \_\_\_\_\_ / Hr Improvement \_\_\_\_\_ %

FIG. 2—Typical air leakage retrofit report form.

## Results

The air leakage reduction demonstration was performed by regular GLNTC public works maintenance personnel during the period May-June 1983. As family housing units became available during normal occupancy change, air leakage tests and retrofits were scheduled. The air leakage rate was measured in the depressurization mode at  $-50$  Pa ( $-0.2$  in.  $H_2O$ ) with a commercially available blower door assembly. Major leakage sites were noted.

Retrofits were attempted on about half of the units, and the "after" air leakage rate was measured. Some of the retrofits were of a temporary nature due to time exigencies. For example, defective bathroom exhaust back draft dampers were not replaced. Instead, the grill was covered with plastic film for the "after" test. Had time permitted a permanent retrofit, the air leakage reduction achieved would be expected to be similar to that reported.

The air infiltration retrofit report forms, as completed by the GLNTC mechanics doing the work, were analyzed. The air leakage data are summarized in Table 1.

The average "before" air leakage rates for the 65 units in the demonstration was 7.5 ACH. Figure 3 shows a histogram of the "before" test results.

For the 34 units with both "before" and "after" air leakage data, the "after" average was 7.1 ACH compared with 9.2 ACH "before." This represents an average reduction of 23% for those units retrofitted. Figure 4 shows a histogram of the retrofitted units.

The most frequently occurring air leakage sites found are noted in Fig. 5.

## Analysis and Discussion

The retrofit report forms were not completely filled in for each family housing unit included in the demonstration. This made a detailed analysis of the

TABLE 1—Air Leakage Retrofit Demonstration Results  
(air change at  $-50$  Pa differential pressure).

Average	
All 65 units	7.5 ACH
34 retrofitted units:	
"Before"	9.2 ACH
"After"	7.1 ACH
Frequency analysis of "before" data	
10 units	<5.0 ACH
32 units	5.0 to 7.9 ACH
18 units	8.0 to 11.9 ACH
5 units	>12.0 ACH

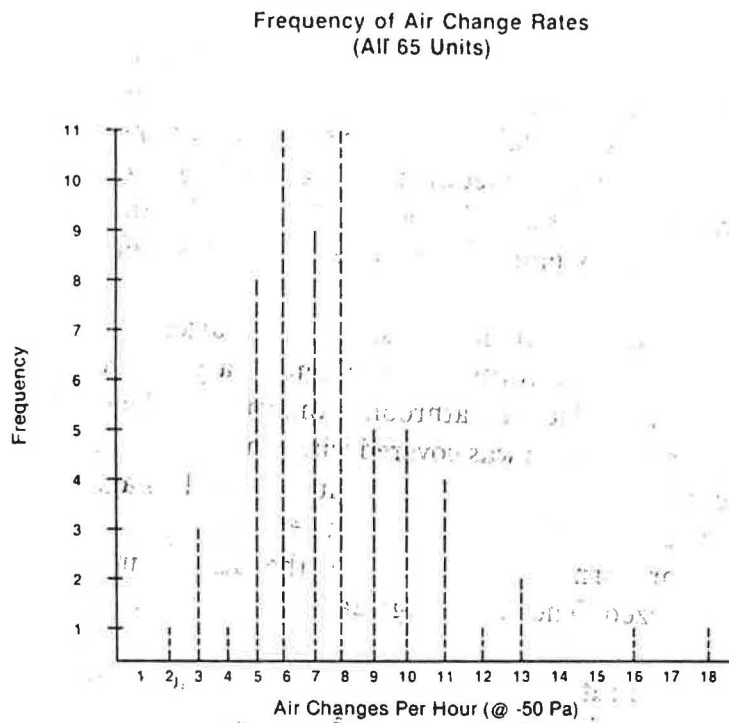


FIG. 3—Air change rate of all 65 units tested.

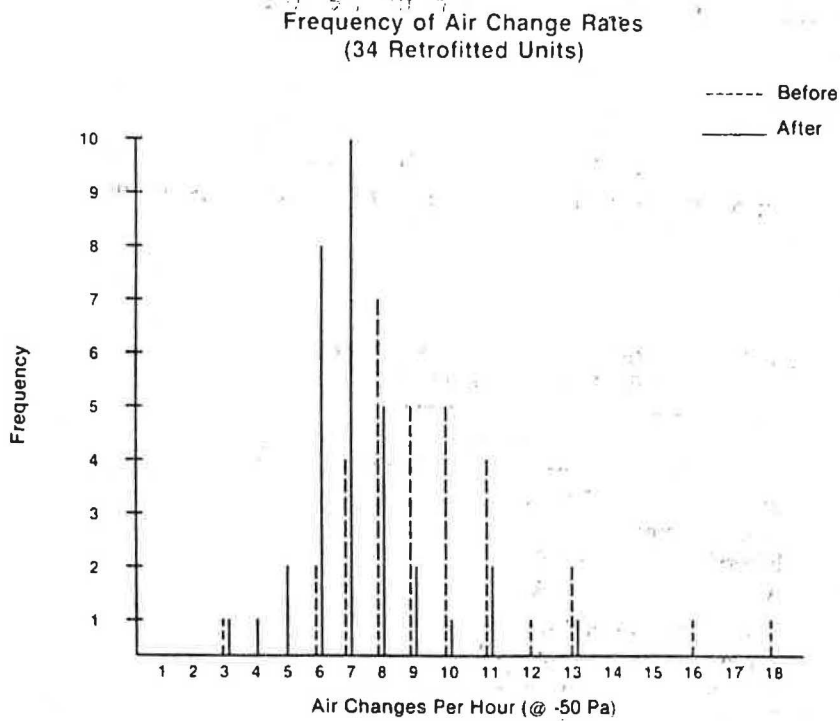


FIG. 4—Air change rate for 34 retrofitted units.

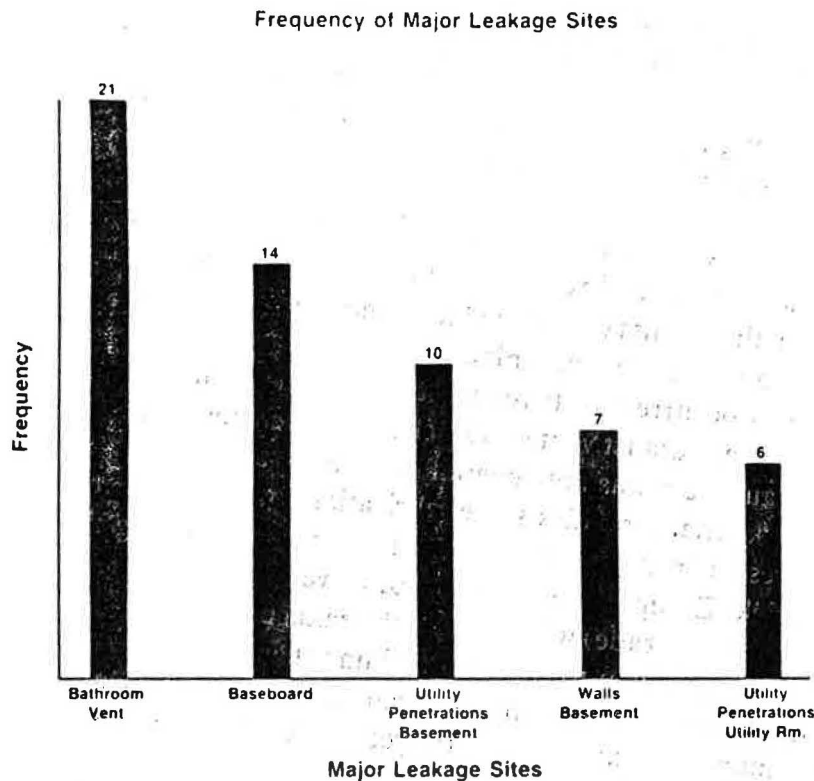


FIG. 5—Major air leakage sites.

data difficult. However, enough information was included to draw a number of interesting and valuable conclusions.

There were eight Wherry units included in the demonstration. These units were built in 1951 of concrete tilt slab construction. Originally they had single-glazed steel sash windows, which are very prone to excessive air leakage. In one of the recent Navy energy conservation programs, these units were replaced with very tight double-glazed horizontal slider and single-hung units. As a result, the Wherry units currently represent the "tightest" family housing units on base. Five of the eight had an air change rate of less than 5.0 ACH at  $-50$  Pa. Several of the units inspected had evidence of mold growth in closets, baths, and bedrooms. Housing management personnel stated that they received frequent complaints from occupants of these units of "mustiness." Corrective measures for these units were outside the scope of this program. The authors are not aware of what action, if any, the Navy intends to take on these units.

Many of the units in the demonstration were constructed in 1960 and 1962 under the Capehart program. These units are town houses with a front-to-back split level configuration. The rear portion consists of the bedroom and bath level above a basement that is partially below grade. The latter contains the furnace, the domestic hot-water heater, provision for washer and dryer,

and space that frequently had been made into a recreation area. The standard procedure called for all interior doors to be left open during the air leakage rate testing, except doors to closets and the basement. Even so, there were enough air passages connecting the basement to the living areas of these units that air leakage into the basement was an important factor in the leakage rate.

The Mil Con multifamily town house units were constructed in 1965 and 1969. These units have a central gas-fired boiler unit for each building. A common air leakage site in these units was related to the horizontal pipe chase connecting the boiler room to the housing units.

Several air leakage sites occurred with regularity. Frequently the back-draft damper in the bathroom exhaust vent was stuck in the open position. By contrast, the kitchen exhaust vent was not generally a problem area. Perhaps the grease present in the kitchen provides some lubrication for the damper, whereas the moisture present in the bathroom causes corrosion resulting in the damper tending to stick. Except for units with a brick veneer exterior, the lower level baseboards (slab-on-grade) were commonly leakage areas. Sliding patio doors were a frequent problem for units containing them.

Electrical receptacles and switches were not generally a significant air leakage site. With frequent interior repainting over the years, the plates were usually well sealed.

One unit was tested on two different occasions about three weeks apart. One member of the two-man crew was present both times. While the measured air leakage rate at  $-50$  Pa was identical on both occasions, the living space area determined was slightly different, resulting in an apparent change in the air change rate.

## Conclusions

In order to implement energy conservation in Navy family housing units, a draft retrofit procedure for reduction of air leakage was prepared. Two documents were written, a manual for use by supervision and a handbook for mechanics doing the retrofitting.

A demonstration of the air leakage reduction program was conducted at the GLNTC. The average "before" leakage rate for 65 units tested was 7.5 ACH at  $-50$  Pa. For the 34 units retrofitted, the average leakage rate was reduced from 9.2 to 7.1 ACH. This is an improvement of 23%.

Frequent air leakage sites noted were bathroom vents, baseboards, utility penetrations in the basements and utility rooms, and basement walls.

## Acknowledgment

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## DISCUSSION

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*M. W. Liddament*<sup>1</sup> (*written discussion*)—Several studies in Scandinavia have shown that dwellings constructed to a fabric airtightness of 3 ACH at 50 Pa are so tight that mechanical fresh air ventilation is essential. The 5 ACH at 50 Pa that you are aiming for is very close to this level. Therefore, what sort of provision is being made for fresh air ventilation?

*J. D. Verschoor and J. O. Collins* (*authors' closure*)—In this Navy program, 5 ACH at  $-50$  Pa is the minimum accepted air leakage; the desired level is a range of 5 to 8 ACH. Based on present information, this range should provide sufficient ventilation for most occupancies. This survey of Navy family housing units also found that units with 3 ACH at  $-50$  Pa were generally too "tight," as evidenced by moisture stress and mustiness complaints by the occupants. At this time, the authors have no information relative to any plans the Navy has to improve the ventilation in these tight units.

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