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ENERGY EFFICIENCY EVALUATION OF THE HOUSING COMMUNITY PLAN DEVELOPED FOR SHAW AIR FORCE BASE

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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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We were able to efficiently perform the field inspections because of the assistance of the above individuals. Their patience with us during the field visit and throughout the project is greatly appreciated.

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ABSTRACT

The purpose of this project was to determine if energy efficiency is adequately addressed in Housing Community Plans being developed for Air Force Tactical Air Command bases. Although renovation work specified in the plans generally complies with current Air Force regulations and is generally consistent with public energy standards, an expected level of energy efficiency that should be readily attained following renovation will not necessarily be achieved. Design and construction flaws can exist in the housing that adversely affect energy consumption. These housing deficiencies are not completely addressed in the current Air Force regulations or guidelines and, thus, are not addressed in the Housing Community Plans. A four-fold plan is recommended to ensure that future plans address improvements in energy efficiency to the fullest extent possible. The recommendations include revising guidance documents, improving field inspections, and implementing monitoring programs.

EXECUTIVE SUMMARY

The purpose of this project was to determine if energy efficiency is adequately addressed in Housing Community Plans being developed for Air Force Tactical Air Command bases and, if not, to provide recommendations for ensuring that energy efficiency is addressed. This purpose was accomplished by reviewing the Housing Community Plan developed for Shaw Air Force Base (AFB) and conducting energy audits of selected housing units at the base.

Renovation work specified in Housing Community Plans being developed for the Tactical Air Command generally complies with current Air Force regulations and is generally consistent with public energy standards. Energy efficiency improvements will result from the renovation work that will help decrease energy consumption. Nevertheless, an expected level of energy efficiency that should be readily attained following renovation will not necessarily be achieved. Design and construction flaws can exist in the housing that adversely affect energy consumption. These housing deficiencies are not completely addressed in the current Air Force regulations or guidelines and, thus, are not addressed in the Housing Community Plans. Additionally, some renovation work specified in the Housing Community Plans is not energy efficient and contributes to increased energy consumption.

Major items in the Housing Community Plan developed for Shaw AFB that will improve the energy efficiency of the units include installation of high-efficiency space-heating and space-cooling equipment, new ductwork (if properly insulated and sealed), proper amounts of insulation in walls and ceilings modified during renovation, thermally efficient windows and exterior doors, and energy-efficient lighting.

Major design and construction flaws in the housing at Shaw AFB that can be corrected during renovation but were not addressed in the Housing Community Plan include (1) design problems with the distribution systems that allow outside or attic air to enter the return air stream, (2) leaks in the distribution supply ducts, (3) leakage sites in the envelope of the units (primarily the attic) that increase the infiltration of the units, and (4) envelope insulation missing in non-routine locations. Some envelope insulation present in the housing at Shaw AFB did not meet current standards but was not addressed in the plan. Recommendations in the plan for

relocating space-heating, space-cooling, and hot-water heating systems outside will likely decrease energy efficiency. Occupant education is needed to achieve an expected level of energy efficiency; however, this was not addressed in the plan. These are the same type of problems being found in private and public sector housing across the U.S.

Specific recommendations for Shaw AFB are detailed in the report. A four-fold plan is recommended to ensure that future Housing Community Plans developed for Tactical Air Command address improvements in energy efficiency to the fullest extent possible.

- The Air Force Whole House/Whole Neighborhood Planning Guide should be revised to include guidance concerning energy efficiency improvements that need to be considered in developing a Housing Community Plan.
- A field inspection procedure should be developed that allows planners to perform a thorough energy evaluation of representative housing units.
- Inspection procedures should be developed and implemented to ensure that contractor work complies with the design intent and to accurately diagnose future problems.
- A monitoring program should be implemented to verify the energy-efficiency improvements following renovation.

Weatherization programs operated by the Department of Energy, states, and utilities are addressing these deficiencies. Although many local contractors will not be able to perform all the tasks necessary to improve these housing units because of the special skills needed, organizations are available to perform the work or provide the necessary training to base and contractor personnel.

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ENERGY EFFICIENCY EVALUATION OF THE HOUSING COMMUNITY PLAN DEVELOPED FOR SHAW AIR FORCE BASE

1. INTRODUCTION

Housing Community Plans are being developed for selected Air Force Bases (AFBs) to provide a comprehensive plan for family housing that will help create an efficient, attractive family housing community. These plans are prepared following the Whole House/Whole Neighborhood Concept, which addresses individual units as well as the entire family housing community. These plans address the appropriate extent of repair and modernization needed to upgrade these housing units to new Air Force construction standards for energy efficiency, life safety, habitability, durability, and functional requirements, while concurrently improving neighborhood amenities and support facilities. Although energy efficiency is addressed in the plans, additional energy improvements not considered by the plans may be cost effective and further help to improve the housing quality.

The primary purpose of this project was to determine if energy efficiency is adequately addressed in Housing Community Plans being developed for Tactical Air Command bases and, if not, to provide recommendations for ensuring that energy efficiency is addressed. This purpose was to be accomplished by reviewing the Housing Community Plan for a single base and conducting energy audits of selected housing units at the base. The base chosen for this project was Shaw AFB located near Columbia, South Carolina. The heating degree-days, base 65°F, for Shaw AFB are 2481, and the cooling degree hours, base 74°F, are 19,860 (ASHRAE 1990).

A secondary purpose of this project was to develop specific recommendations for energy improvements to be made during housing unit renovation and community improvements at the selected base. The resulting recommendations, together with the existing Housing Community Plan, would provide guidance for preparation of detailed project designs and specifications.

Because housing renovations are currently being performed at Shaw AFB under a separate program, a third purpose of the project was to determine the extent energy efficiency is being addressed under this ongoing program. Insight gained from inspection of the current renovation program would enhance the review of the Housing Community Plan.

2. FIELD INSPECTION

Housing at Shaw AFB is divided into three principle areas: on- and off-base Wherry, 4000 area, and 5000 area. Seven representative units were inspected over a one week period in October 1991. The inspection of each unit generally included visually examining the building shell and attic, determining insulation levels, measuring the air tightness of the unit, and inspecting the space-heating and space-cooling systems. Results of these inspections will be presented by housing area for the following reasons:

- Each housing area is distinctive regarding the time period the units were constructed, the design of the units, and the construction practices employed.
- Differing degrees of renovation work have been performed in the three housing areas over the last 10 years.

Air tightness was measured using a blower door. A blower door consists of a large fan, mounted temporarily in an exterior door, that can induce a large and roughly uniform pressure difference across the building shell. The air flow required to maintain this pressure difference is then measured using instruments supplied with the door. A series of pressure differences (ranging from about 10 to 60 Pa) and corresponding air-flow rates were measured. ASHRAE (1989a) and Nelson (1990) provide overviews of blower door testing. CGSB (1986) and ASTM (1987) should be consulted for detailed procedures on how to conduct air-tightness tests. Results of the air-leakage tests are presented in Table 2.1 (see Appendix A for calculation details) and are reported as the air-flow rate required to maintain a pressure difference of 50 Pa across the building shell (cfm50) and normalized leakage. Normalized leakage is a dimensionless value calculated from the leakage area, building height, and floor area that describes the relative air tightness of the envelope. As a general rule-of-thumb, the seasonal average air-change-rate per hour (ACH) is equal to the normalized leakage.

ASHRAE Standard 119-1988 (ASHRAE 1988) establishes performance requirements for the air tightness of residential buildings based on normalized leakage to reduce the air-infiltration load. Based on the climate at Shaw AFB, the acceptable range of the normalized leakage is 0.00

Table 2.1. Air-leakage measurements.

Unit	Air Leakage (cfm50)	Normalized leakage*	Leakage area (in^2)	Unit floor area (ft^2)	Number of stories
24A	1796	0.67	105	1090	1
478B	1210	0.50	65	899	1
4055A	3441	1.25	220	1500	1
4073B**	3088	1.16	214	1584	2
5174B	3047	1.09	198	1556	2
5425A	2629	0.88	160	1556	2
5429B	2747	0.87	172	1686	2

*As a general rule-of-thumb, the seasonal average air-change-rate per hour (ACH) is equal to the normalized leakage.

**This is a multifamily unit. Air flow from adjacent units likely leads to an overestimate of the actual air leakage of this unit.

to 0.80.[1] In air-tightening a building, it is important not to over tighten the building unless mechanical ventilation will be provided to avoid indoor air quality and moisture problems. ASHRAE Standard 62-1989 (ASHRAE 1989b) requires 15 cfm per person or 0.35 ACH, whichever is greater. Assuming 4-5 persons per housing unit and multiplying cfm by 20 to convert to cfm50, units should not be tightened below about 1200-1500 cfm50 to meet the per person requirement. Current Air Force regulations (Air Force 1988) recommend that houses be tightened to no lower than 0.5 ACH unless mechanical ventilation is provided.

The blower door is a useful tool in locating the major leakage sites in a house. Often, leaks around windows, doors, and other similar areas are not the major sites for air movement into and out of the house. Openings connecting the house to the attic (often referred to as attic bypasses) are usually bigger leakage sites. These openings can be fairly visible, such as openings

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[1]Air-tightness standards being developed for new houses often have tighter specifications. For example, North Carolina's proposed standard requires houses to be less than 5 ACH50 (approximately 0.25 ACH) or 0.67 cfm50 per square foot of floor area.

around flue pipes, water lines, and attic hatches. Often, though, these openings are visible only from the attic. The space behind interior walls may not be sealed at the attic, connecting the inside of the house to the attic. Passageways built for ductwork, flues, plumbing pipes, and ventilation pipes to run from the first floor to the second floor or attic may not be sealed, allowing air to flow throughout all parts of the house. Drain lines running through interior portions of the house may end up connecting different parts of a house to each other and the attic.

In inspecting the units, care was taken to closely examine the air-distribution systems of the units. Recent research (Tooley and Moyer 1989, Jenkins 1991, Proctor 1991, and Coyne 1992) is clearly demonstrating the detrimental effect distribution systems can have on the efficiency of a house. These problems can become more prominent in slab-built houses because ductwork is often located in unconditioned spaces and building components are used as ductwork rather than installing separate, rigid duct. Typically encountered problems that reduce system capacity and efficiency include:

- Ductwork that has become disconnected. With disconnected supply ducts, conditioned air is wasted to the outside. Because supply and return air flows are not balanced, the house operates in a depressurized mode, which causes an increased flow of outside air into the house when the system operates. With disconnected return ducts, non-conditioned air (outside air, attic air, etc.) is drawn into the system.

- Interior closet areas are used as return plenums that inadvertently have holes leading to the attic or outside. If the areas in question were tight, there would be no problem with this design. Because construction crews do not understand how these areas will be used, these areas are typically not tight. Holes connecting the closet areas with the outside or, worse, the attic can be very important because of their unique location. With the distribution system operating, attic or outside air is drawn into the system because the areas are slightly depressurized. In the summer, hot and moist attic or outside air reduces the efficiency and capacity of the air conditioner. Cold air drawn into the system during the winter has a similar affect on the space-heating system.

- Closed bedroom doors affect air distribution in the house. If only a central return grill is used in the distribution system, closed bedroom doors can cause the bedrooms to operate in a slightly pressurized state and the remaining areas of the house to operate slightly depressurized. In addition to decreasing the flow of air through the distribution system, this increases the flow of outside air into the house. Because of the size and layout of the housing units at Shaw AFB, closed bedroom doors seemed to be a likely occurrence.

Leaks in the distribution system are included in air-leakage measurements. Because the distribution system operates under greater pressure differences than that which occurs naturally across the envelope of the units, these leaks are more significant than blower-door tests may indicate.

2.1 WHERRY HOUSING AREA

The Wherry housing area is composed of an on-base section and an off-base section. The on-base units were built in the 1940's, with operation of the units taken over by the military in the 1950's. Our best information indicates that the on-base units were built by a single contractor. The off-base Wherry units were built by the government in the 1950's.

The units in the Wherry housing area are generally single-story duplexes, with some being single-story detached. These units were previously renovated over 10 years ago. This renovation included the installation of wall insulation; vinyl siding; double-pane, aluminum windows; high-efficiency heat pumps (high-efficiency at the time of installation); and devices to utilize the heat pump's superheated refrigerant to help heat domestic hot water. Further renovation of these units is addressed in the Housing Community Plan developed for Shaw AFB.

Two Wherry housing units (both duplexes) were inspected (24A and 478B). Efforts to improve the efficiency of the building envelope and space-heating and space-cooling equipment were evident. Fiberglass batt insulation, 3.5 inches thick, was found in all the walls of the two units. Insulated sheathing boards were used when the vinyl siding was installed. Double-pane, aluminum windows and sliding glass doors without additional storm windows or window treatments (awnings, films, solar screens, etc.) were installed in both units. Both solid and hollow core external wood doors were present, with storm doors installed in all cases. Concrete slabs, uninsulated around the exposed perimeter, served as the foundations for the units. The attics were completely insulated, with 12 inches of blown fiberglass in unit 24A and a combination of blown fiberglass and fiberglass batts that totaled 6.5 inches in unit 478B. In each unit, attic ventilation was provided by a gable vent that had little open area, soffit vents (either individual registers or continuous vent), and a thermostatically controlled attic fan. In the unit with soffit registers (24A), the registers appeared to be covered (plugged) by the attic insulation. Electric heat pumps were installed in both units and controlled by standard thermostats (rather than setback type models). The air-distribution systems' supply ducts were generally located in dropped ceilings running the length of the units. The ductwork was visible in unit 478B and was found to be insulated. To furnish conditioned air to family rooms that appeared to have been added to the units since their original construction, flexible ducts running in the attic were installed. Electric water heaters were installed in indoor closets or storage rooms in both units. Unit 478B was equipped with a heat recovery device on the heat pump to assist in heating domestic water. Insulation blankets were not installed on either hot-water tank.

Air-leakage measurements showed that the units were fairly tight: their normalized leakage was in the acceptable range and their cfm50 values were close to or within minimum levels. Major sources of leakage were from dryer vents (because dampers were not operating), recessed lights, the sliding glass door, and the "return distribution system" in one of the units (discussed below).

Return systems constructed from ducts were not present in these units. As typical of slab-constructed units, the indoor unit of the heat pump was located in a hallway closet. In unit 24A, a panel was removed from the indoor unit such that the entire closet was depressurized by the distribution fan, effectively making the closet part of the return system. A grill was placed in the closet door to allow house air to return to the indoor unit. The storage room next to the equipment closet also served as a return system: the door to the storage room was louvered and a grill was used to connect the storage room with the equipment closet. Small but identifiable openings into the attic were found in the equipment closet. In the storage room, water lines from the water heater ran through the ceiling, and the attic access hatch was located in this room. Because the storage room is not typically thought of as a return duct, the importance of any openings in this room may not be appreciated. Although blower testing indicated that the unit was relatively tight, openings (leaks) found in both rooms are significant because of their unique location. Other Wherry housing units with this design could have more significant problems than those found in this unit.

In unit 478B, the indoor unit of the heat pump was located in a hallway closet on a raised floor. The raised floor was installed so that the plenum space created below could be used as a return plenum. Return air entered the return plenum from the hallway through a grill and flowed up, through a hole in the floor, directly into the indoor unit. This return plenum was found to be well constructed and air tight. Because plenums such as these are often not tight (see Sects. 2.2 and 2.3), other Wherry housing units with a similar design could have problems.

In both units, the supply ducts were located in dropped ceilings running the length of the units. In unit 478B, a portion of the attic floor above the dropped ceiling was missing. This opened the space above the dropped ceiling to the attic. Because the dropped ceiling was not insulated, the attic insulation was essentially being bypassed in this area. If this area were not open, conditioned air lost through any supply leaks would eventually enter the interior of the unit; in the present condition, lost conditioned air would likely just enter the attic.

After closing all bedroom doors in the two visited units, pressures in the closed bedrooms were 3-5 Pa greater than the remainder of the units. Although these results are not severe, the pressure increases should be less than 3 Pa.

Two problems were found with the domestic water-heating system:

- The temperature settings on the thermostats controlling the water-heater elements were found to be 140°F and 150°F. Such high settings increase energy consumption and pose a safety hazard due to the presence of scalding water.

- A simple test of the heat recovery device installed in unit 478B indicated that it may not be working. The water pump designed to circulate water from the hot water tank through the heat recovery device's heat exchanger never operated after draining the tank of hot water, turning off power to the heating elements located in the hot-water tank, turning on power to the heat pump and heat recovery device, and setting the heat pump thermostat to different operating settings (heat, cool, etc.). Fuses in the device were checked and found to be unbroken. Hot-water temperatures are likely being maintained by the heating elements installed directly in the hot-water tank, which remain operational even with the heat recovery device installed. Consequently, occupant needs are being met at an energy penalty, and there is no feedback to help determine when the devices become inoperable.

The attic of unit 24A could not be inspected because the severely low-sloped roof did not provide sufficient room and because of the deep insulation levels. Such conditions could impede the completion of energy efficiency work called for in the Housing Community Plan or lead to poor workmanship.

2.2 4000 HOUSING AREA

The housing units in the 4000 area were built during the 1960's. The housing units in this area are predominately two-story quadplexes, mixed-story quadplexes (two inner units are two-story and the two end units are single-story), and single-story duplexes. No major improvements have been made to these units since their construction. Renovation of these units is addressed in the Housing Community Plan developed for Shaw AFB.

Two 4000 area housing units were inspected: a unit in a two-story quadplex (4073B) and a unit in a single-story duplex (4055A). Fiberglass batts, 3.5 inches thick, were found in the walls of both units; there was no insulated sheathing under the wood siding. Single-pane, wood windows were installed; these were without storm windows or other exterior window treatments. Solid core wood doors were installed with storm doors. Concrete slabs, uninsulated around their perimeter, served as the foundations for the units. Attics were insulated with six to eight inches of blown fiberglass. Attic ventilation was provided by continuous soffit vents and ridge vents. Gable vents were also present. A natural gas, forced-air furnace provided heating for each unit. In unit 4073B, the furnace was located in an outdoor equipment room built next to the unit. In unit 4055A, the furnace was located in an indoor closet. Air conditioning was provided in each unit using an A-coil installed with the forced-air system. The systems were controlled by a standard thermostat, rather than a setback model. The air-distribution system's supply ducts were located in the attic of the single-story unit, and in both the attic and the space between floors in the two-story unit. In both units, the ducts were insulated, as they were constructed from rigid duct board. In the single-story unit, a return grill was located in the living room and connected to the forced-air system by a one foot length of duct. In the two-story unit, the return grill was located halfway up the stairway, at the landing where the stairs turned 180°. The return duct ran in the space between the two floors; this duct was constructed from the existing floor joists and using sheet metal to enclose the bottom. Gas water heaters were installed in both units, one in an indoor closet and the other in the outdoor equipment room next to the unit. The hot-water tank in the latter unit was equipped with an external insulation blanket.

Inspection of the air-distribution systems revealed significant problems in each unit. In unit 4055A (the single-story unit), the distribution system located in the attic was disconnected in several places (see Figs. 2.1a-c). It appeared that duct tape used to attach sections of the rigid duct board lost adhesion. Ducts leading to outlet registers were offset several inches from the main supply duct, leaving physical separations big enough to put one's hand through. Sections of the main supply duct had also shifted from each other, leaving similar size openings. Walking boards placed along the main supply ducts indicated a significant level of work had been performed in the attic; perhaps this work hastened the separation of the ductwork (a ridge vent was added to the roof, although this by itself should not have impacted the distribution system).

In unit 4073B (the two-story unit), leaks in the supply and return ducts located in the outdoor equipment room were readily apparent using a smoke pencil and with the distribution fan running (see Fig. 2.2). The return leaks caused unconditioned air from the equipment room to be drawn into the distribution system. Because the gas furnace and gas water heater were located in this room, the return leaks could cause flue gases to backdraft and enter the unit. The supply leaks were located in the housing unit, causing air to be blown out the crack around the supply duct where it penetrated the building shell. As shown in Fig. 2.3, duct tape sealing a joint in the supply duct located in the attic was beginning to peel away, creating a supply leak.

Air-leakage measurements showed that the air tightness of the single-story unit (4055A) was considerably outside the acceptable range (even with two bedroom doors shut during the test to accommodate sleeping occupants). This was primarily due to the disconnected supply ducts in the attic, as discussed above. The following attic bypasses were also found in this unit: an interior wall open at the top to the attic (Fig. 2.4), openings around flue pipes, and ducts providing combustion air to the gas furnace and water heater. The need to provide combustion air to the gas appliances with dedicated ducts is believed to be required by local building codes.[2]

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[2]A path for combustion air must be provided to gas appliances. In many applications, appliances draw combustion air from the indoor space through louvered doors. It is not known if local building codes allow such an installation to be used.

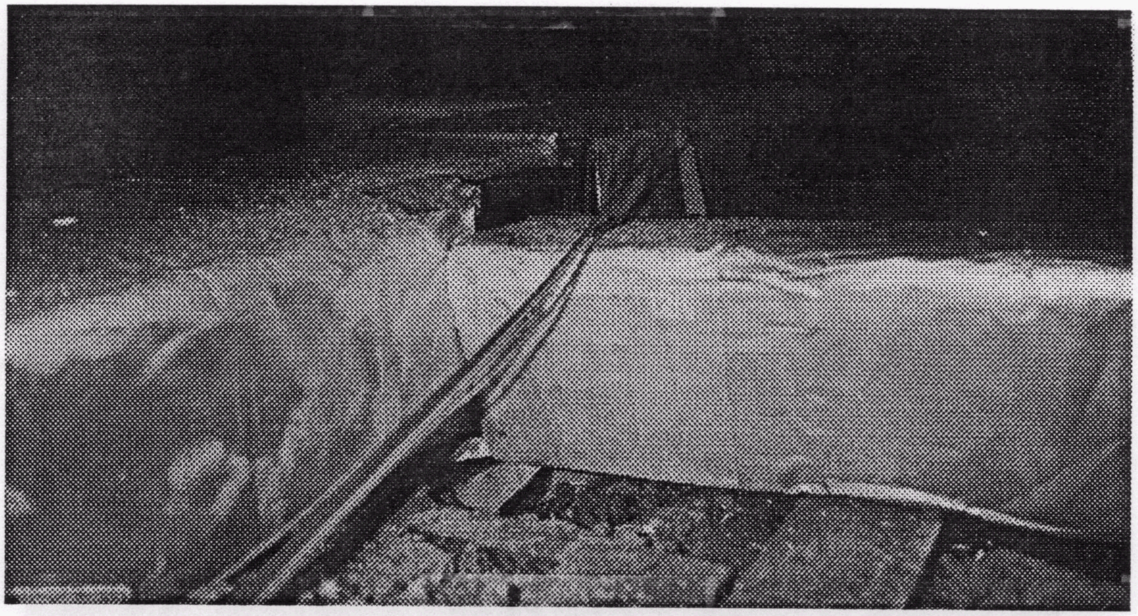

Fig. 2.1a.

Fig. 2.1b.

Fig. 2.1c.

Fig. 2.1. Disconnected supply ducts as found in the attic of unit 4055A.

Fig. 2.2. Supply and return ducts as found in the outdoor equipment room of unit 4073B. The return duct was located on the left and leaked where the duct butted up to the ceiling of the room. The supply duct entered the housing unit through the wall on the right. With the distribution fan on, air was forced out the cracks around the duct where it penetrated the wall.

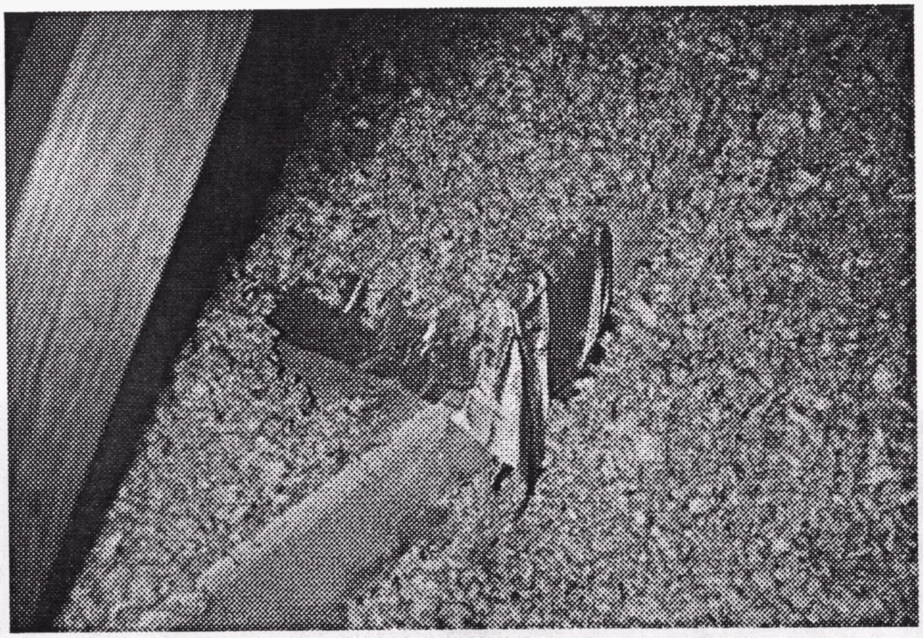

Fig. 2.3. Duct tape sealing a joint in the supply duct located in the attic of unit 4073B was beginning to peel away, creating a supply leak.

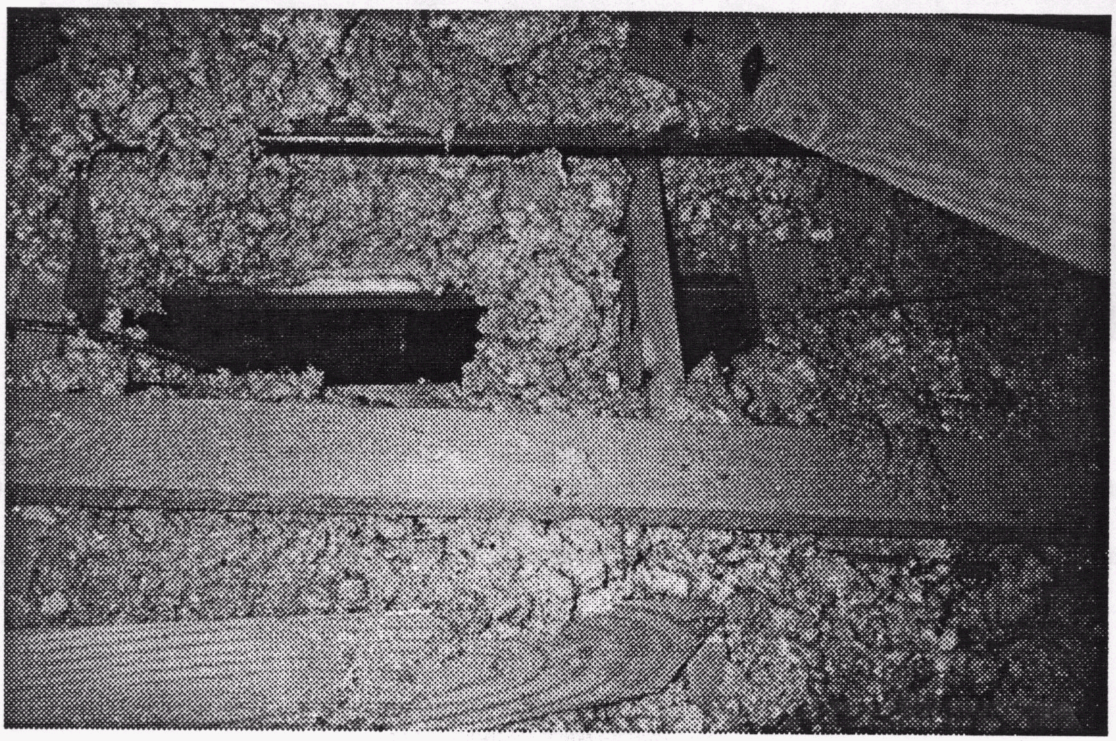

Fig. 2.4. The top of an interior wall in unit 4055A was open to the attic.

When these ducts were installed, the equipment closets were not closed off and sealed from the rest of the housing unit. Therefore, when the appliances were not actually running, these ducts served as direct leakage paths to the attic.

The air-leakage measurements made in the two-story unit (4073B) must be analyzed with care and are difficult to interpret. This unit is part of a multifamily structure, and air-leakage testing of such structures is less well developed than that for detached or duplex units. With multifamily structures, individual units may not be well sealed from each other. Much of the air flowing into the unit while conducting a blower-door test may be coming from adjacent units rather than the outside. Because only the movement of unconditioned outside air into the unit is the quantity of interest, the air-leakage measurements may overestimate the leakage of the unit. A blower door installed in each of the adjacent units and operating at the same pressures as the tested unit would allow a more accurate test to be performed. This could not be performed during this inspection because only one blower door was available.

In conducting the air-leakage test in the two-story unit, the following observations were made:

- This unit was not sealed from the adjacent units. Cooking odors from the adjacent unit were readily smelled at the beginning of the test.
- The return duct was not sealed well. With the unit depressurized 40 Pa, the flow of air through the return grill was substantial. Considering the amount of flow, it appeared that at least some of this air was coming from the adjacent unit. With the system operating normally (the return system is 15 Pa below house pressure), a portion of the return air likely comes from this adjacent unit. This causes the adjacent unit to be depressurized, which increases the infiltration rate of the adjacent unit. A similar coupling could allow operation of the adjacent distribution systems to increase the infiltration rate of the tested unit.
- Sealing the return register caused the air leakage of the unit to drop about 200 cfm50, from 3088 cfm50 to about 2900 cfm50. In doing so, supply registers began to leak noticeably. Leaks found in the supply and return ducts likely contribute to this interconnection.
- A passageway (Fig. 2.5), built to allow the supply duct and kitchen exhaust to run from the space between floors to the attic, was not sealed at the attic. This effectively coupled the inside of the unit to the attic, increasing the natural

Fig. 2.5. A passageway built into unit 4073B to allow the supply duct and kitchen exhaust to run from the space between floors to the attic was not sealed.

infiltration rate of the unit. Additionally, plumbing vent lines were not sealed where they penetrated the attic.

- The kitchen exhaust and dryer vent were found to be quite leaky.

Several problems with the insulation installed in unit 4073B were found. As shown in Fig. 2.6, loose fill attic insulation had been blown into the middle of the attic, leaving the attic floor six feet from the front of the unit uninsulated. This may have occurred due to high winds generated from hurricane Hugo. Both the front and rear second-story overhangs had no floor insulation; these floors were directly exposed to ambient conditions and were likely leaky. The attic floor under and around the attic supply ducts was not always insulated. The insulating blanket installed on the water heater was falling off, rendering it ineffective (Fig. 2.7).

A final problem found during the inspection of unit 4073B was with the ventilation fans. Upstairs bathroom fans were vented into the attic rather than the outside. This increases attic moisture levels, which can cause structural problems.

2.3 5000 HOUSING AREA

The housing units in the 5000 area are predominately single-story duplexes and two-story detached units (although carports of adjacent units are connected, making the units appear to be attached, duplex structures). These units were built during the 1970's. Renovation work is being performed on the units in this area under a program separate from the Housing Community Plan developed for Shaw AFB. This work concentrates on the housing units and does not address the neighborhoods. New, combined gas furnaces and water-heating systems were recently installed in most units. The following renovation work has been completed in about half the units: installing exterior vinyl siding directly over the present siding, adding ceiling insulation, installing double-pane vinyl windows, and refinishing the interior. Renovation of the remaining units will be completed in the next several years. This work is performed by local contractors, who are awarded approximately 24 units at a time.

Because renovation work will be completed on all 5000 area housing units in the next several years, the Housing Community Plan does not address the renovation of these units.

Fig. 2.6. Loose fill insulation in the attic of unit 4073B had been blown away from the edge, leaving a portion of the attic floor uninsulated.

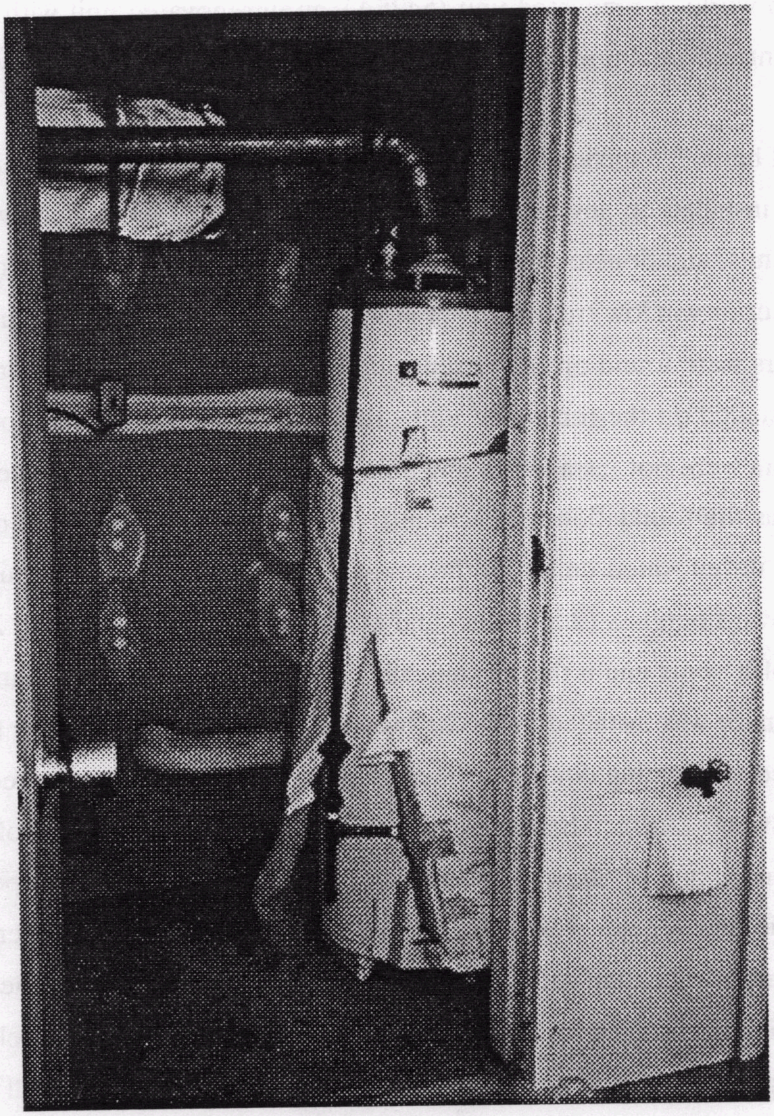

Fig. 2.7. The insulating blanket installed on the water heater of unit 4073B was falling off.

Nevertheless, the following three two-story units were inspected during the site visit to characterize the units and determine the degree that energy efficiency was addressed under the current renovation work: a renovated unit (5425A), an unrenovated unit with the same floor plan (5174B), and an unrenovated unit with a different floor plan than the other two units (5429B).

Rock wool batts, 3.5 inches thick, were found in the walls of all three units. Insulated sheathing was not installed on any of the units. Single-pane aluminum windows were installed in the unrenovated units, and double-pane vinyl windows were installed in the renovated unit. There were no exterior window treatments or storm windows installed in any unit. Solid core exterior wood doors were found on the unrenovated units, and metal doors (presumed to be insulated) were installed on the renovated unit. Because the exterior doors opened to the carport, storm doors were not installed in any unit. A concrete slab, uninsulated around the perimeter, served as the foundation for each unit. Rock wool was blown to a depth of six inches in the attics of the unrenovated units. In the renovated unit, the attic was insulated by a combination of blown fiberglass (2.5 inches) and blown cellulose (3.5 inches). Attic ventilation was achieved by soffit vents and a thermostatically controlled attic fan in all three units. A condensing gas furnace was installed in the hallway closet of each unit. These furnaces were also the sole heat source for heating domestic water (a closed glycol loop transferred heat from the furnace to the hot-water tank). These systems were approximately two years old, having been recently installed under one of Shaw AFB's energy efficiency programs. It appeared that the previous air-conditioning systems were not replaced when the new furnaces were installed. Standard thermostats, rather than setback models, were installed to operate the systems. The furnace in each unit was installed on a raised floor in the closet. The space below the raised floor served as a return plenum, with air entering the plenum through a hallway grill (in unit 5429B, a return grill also allowed air to enter the return plenum from the laundry room). The supply ducts were located in the space between floors and in the attic.

Air-leakage measurements made in the three units indicated that the air tightness of each unit was above the acceptable range. Leaks in the distribution system (discussed in detail below) were a major contributor to the air leakages. The other major contributor to the air leakages was attic bypasses. Three leakage sites connected the interior of the first floor to the attic in units 5174B and 5425A (the renovated and unrenovated units with the same design):

- A passageway (Fig. 2.8) allowed the gas furnace flue, combustion-air pipes, and supply duct to extend through the second story of the unit to the attic. This passageway was not sealed at the attic. A similar bypass was also found in unit 5429B.

- With the installation of the condensing furnace, a plastic flue pipe (with about a 2.5-inch diameter) was installed. The new flue was run inside the previous flue pipe (with about a 6-inch diameter) to the attic and out the roof, but the space between pipes was not sealed at either end (see Figs. 2.8 and 2.9).

- A pipe (with about a 6-inch diameter) was installed between the attic and interior equipment room to provide combustion air to the gas furnace (see Fig. 2.9). As discussed in Sect. 2.2, this pipe served as an attic bypass when the furnace was not operating.

In units 5174B and 5425A, the space between a second-floor interior wall was open to the attic, and a plumbing vent rose through this space (Fig. 2.10). This bypass connected the interior of the second floor to the attic; combined with the passageway and plumbing run, the entire unit was likely connected to the space between floors and, hence, the outside. It is important to note that the current renovation work did not fix these bypasses because they existed in the renovated unit as well as the unrenovated unit.

Major design problems were identified with the distribution systems in all three units. These problems resulted primarily from using the building as supply and return ducts rather than installing rigid ductwork. The most significant problems were observed in units 5174B and 5425A, the units with a similar design.

- The distribution systems of these two units were extremely leaky. In unit 5174B, the air leakage was reduced from 3047 cfm50 to 1903 cfm50 (a 38% reduction) by sealing all supply registers, the return register, and the louvered doors of the interior equipment room. This reduction was due to sealing off distribution leaks as well as the attic bypasses found in the equipment room. Other measurements were made to try to measure the leakage of the supply and return ducts individually, although the design of the equipment room, the location of leaks, and the interaction between the leakage sites made this difficult. Our measurements indicated that most of the leakage was due to return leaks and attic bypasses, with these being about equivalent.

- The return plenum of each unit was connected to the attic and/or outside by the interior walls used to form the plenum, gaps around plumbing running through the plenum, and a pipe used to run refrigerant and condensate lines outside to the condensing unit (see Figs. 2.11a-b). Operation of the distribution fan (which

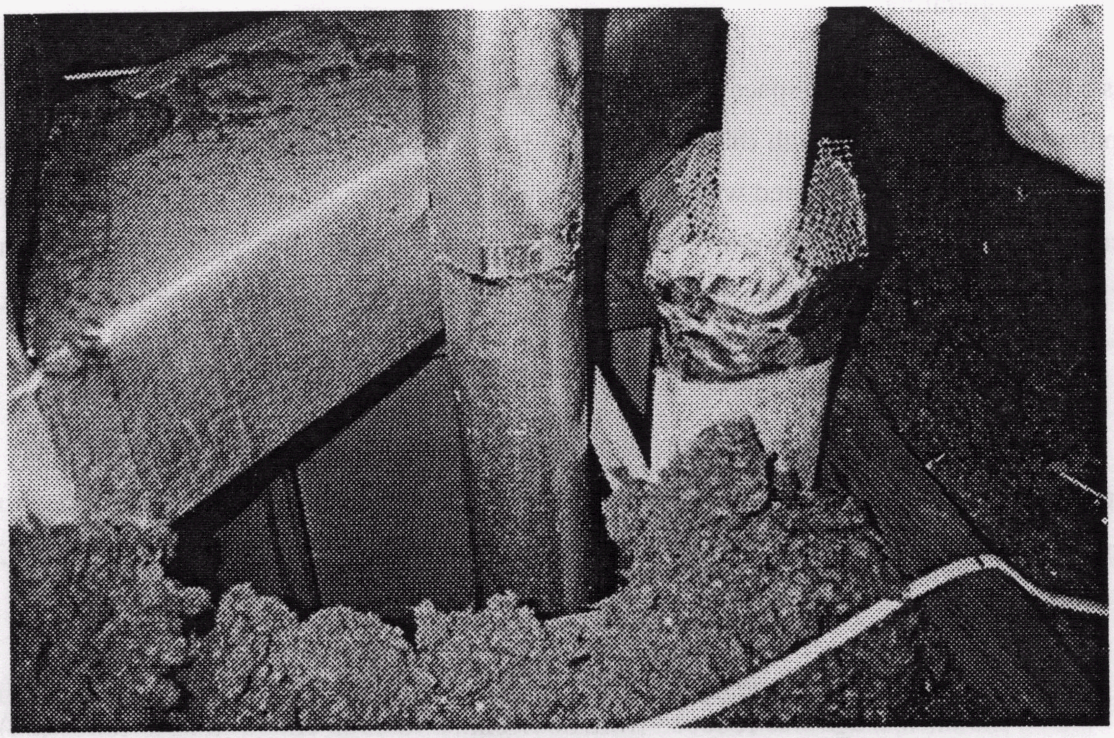

Fig. 2.8. A passageway built into units 5174B and 5425A allowed the gas furnace flue, combustion-air pipe, and supply duct to extend from the first floor to the attic. This passageway was not sealed at the attic. A new plastic flue pipe was run inside the old flue pipe to the attic. A screen was placed over the annulus area to prevent insects from entering the house, but the opening was not sealed.

Fig. 2.9. In units 5174B and 5425A, a plastic flue pipe was run inside the old flue pipe (seen in the upper portion of the figure). A combustion-air pipe was also present (next to the plastic flue pipe).

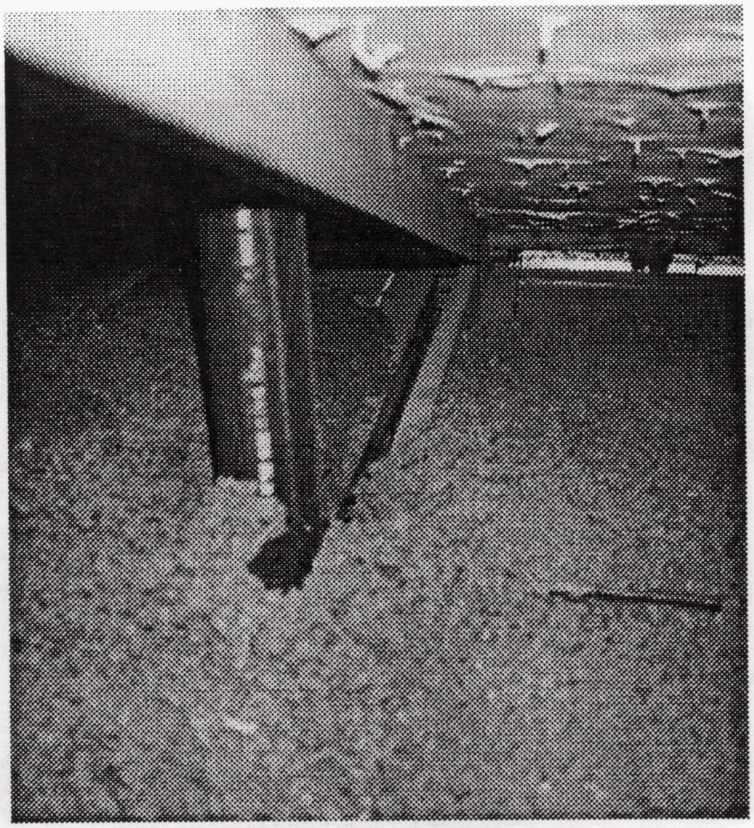

Fig. 2.10. In units 5174B and 5425A, a second floor interior wall was open to the attic and a plumbing vent rose through this space.

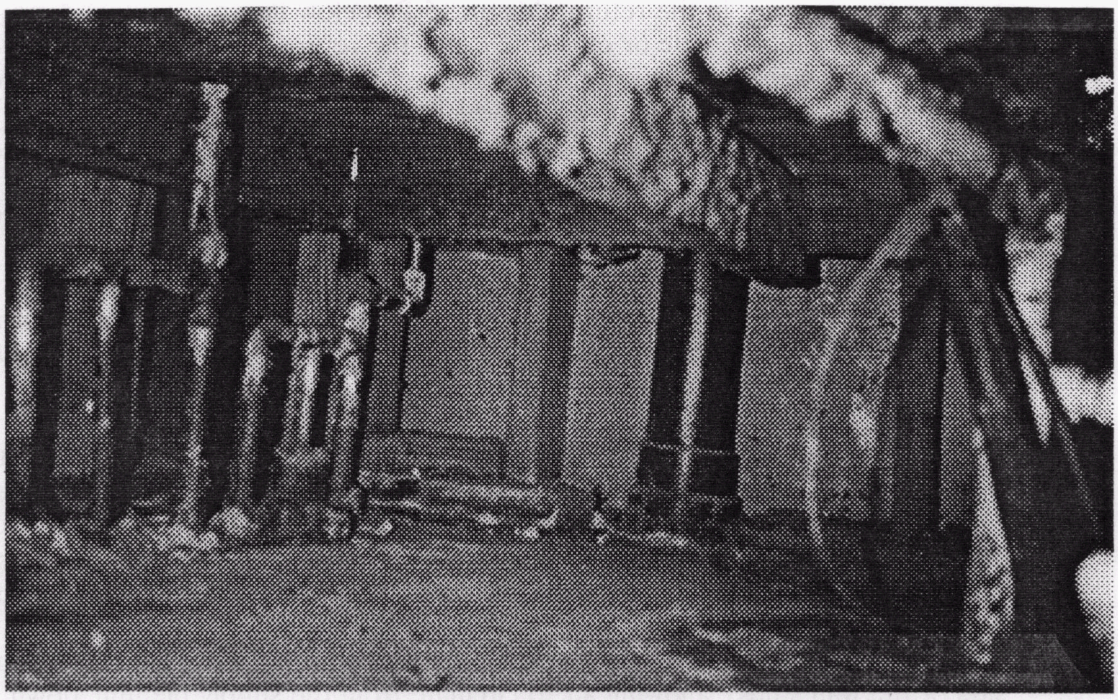

Fig. 2.11a.

Fig. 2.11b.

Fig. 2.11. The return plenum of units 5174B and 5425A was connected to the attic and/or outside by the interior walls used to form the plenum (no dry wall was installed on the plenum side of the studs as shown in Fig. 2.11a), gaps around plumbing running through the plenum, and a pipe used to run refrigerant and condensate lines outside (Fig. 2.11b).

reduces the pressure in the return plenum 15 Pa below house pressure) drew significant amounts of attic or outside air into the return air stream. Interior partition walls were used to form the plenum. These walls had drywall or paneling on the side that faced living spaces; however, no drywall was installed on the plenum side of the studs. A major drain line from the second floor ran down one of the cavities formed between the studs. During the blower-door testing, air flow was readily evident coming down the wall cavities and from around the drain pipe, indicating that the cavities were open at the top and connected to the space between floors, which was subsequently connected to the attic or outside. A plastic pipe (with about a 4-inch diameter) was run under the slab of the unit and contained the refrigerant and condensate lines. Because this pipe was not sealed at either end, it directly connected the return plenum to the outside.

- Conditioned air recirculated directly back to the return plenum in the two units because of the open wall cavities described above. The condensing furnace was an upflow model with an A-coil installed on top. Conditioned air exiting the A-coil directly entered a small supply plenum above it. Ducts then directed conditioned air from the supply plenum to outlet registers. The supply plenum was formed using two of the same interior walls as the return plenum. One cavity in each of these walls was open in the supply plenum (there was no drywall on the plenum side of the wall studs), allowing air to circulate from the supply plenum, down the wall cavity, and into the return plenum. Photographs taken with an infrared camera demonstrate this in Fig. 2.12.

- Air filters in both units were very dirty.

In unit 5429B, a somewhat different set of problems was found.

- A similar return plenum was built below the raised floor of the interior equipment room. The wall cavities were open on the return plenum side, but no significant air flow from them was detected (indicating that they were sealed at the top in this type of housing unit). In this unit, one wall of the return plenum was an exterior wall. Although no significant plenum leakage was found in this unit, problems could easily exist with other similar units. A plastic pipe was again present to run refrigerant and condensate lines in. This pipe allowed outside air to be drawn into the return stream.

- Indoor air entered the return plenum through a grill in the hallway and a grill in the laundry closet. With the door to the laundry room closed (a likely position for this door to be maintained in), there is potential for the return air flow to be greater than the supply air flow in this room. If this occurs, the room becomes depressurized and outside air is drawn into the unit and return system; outside air can easily enter this room from the dryer vent, leaks around the water lines, leaks around the exterior door, and through a vent installed in the equipment room for combustion air.

Fig. 2.12a.

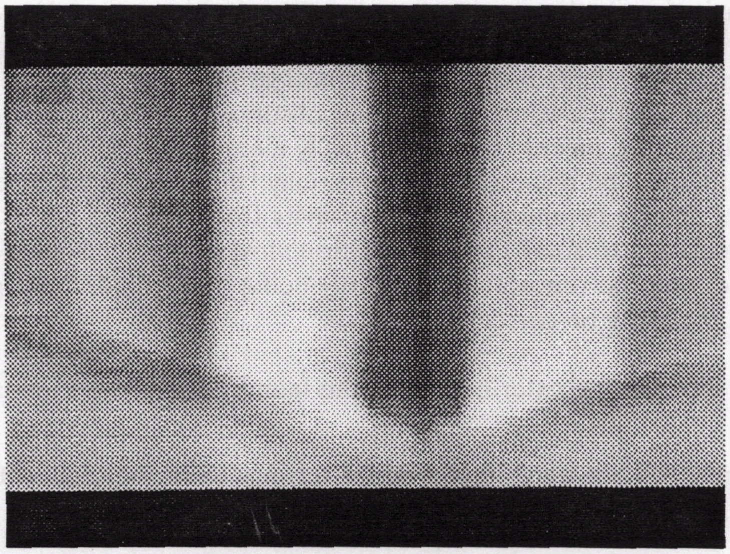

Fig. 2.12b.

Fig. 2.12. The interior equipment room is behind the two walls shown in Fig. 2.12a. A supply plenum was at the top of the room and a return plenum below. With the system operating in the heating mode, the infrared picture (Fig. 2.12b) shows hot air flowing down a stud cavity in each wall (white indicates a hot surface).

- A few leaks were identified in the supply ducts located in the equipment room. Duct tape installed where the ducts joined the furnace and each other was not installed well and/or was loosing adhesion. These leaks were allowing some conditioned air to recirculate back to the return plenum through unsealed holes in the raised floor. These leaks could also allow conditioned air to flow out the hole designed to supply combustion air.

- The air filter was plugged with dirt.

After closing all bedroom doors in two of the three visited units, pressures in the closed bedrooms were 1-4 Pa greater than the remainder of the unit. Although these results were not severe, the pressure increases should be less than 3 Pa.

The following problems were found with insulation installed in the units:

- The floors beneath second-story overhangs were uninsulated. This was true even in the renovated unit.

- An inspection using an infrared camera revealed that wall insulation was missing or defective in a few of the wall cavities in unit 5429B: two cavities in the stairwell, one cavity in a bedroom closet, and several cavities under the window in the master bedroom. The cavities beneath a window are a common place to skip insulation or to have insulation that has lost its effectiveness because of moisture leaking in from the window. Peculiar observations were noted on the front wall behind the face pieces running vertically along the outside of the unit. The insulation may be missing in this area, may be defective because of moisture, or outside air may be entering the wall cavity from the face pieces, circumventing the wall insulation to some extent. Because vinyl siding is installed over the existing siding during the renovations currently being performed, these problem areas would not likely be corrected.

- Water pipes in the exterior wall of the laundry room were uninsulated.

In all three units, the hot-water temperature settings were too high, often being set at 150°F.

3. REVIEW OF THE HOUSING COMMUNITY PLAN

In reviewing the Housing Community Plan developed for Shaw AFB, emphasis was placed on identifying items that would affect energy consumption and developing recommendations addressing these items. Renovation work specified in the Housing Community Plan that affects energy efficiency is summarized below, with each section concentrating on a specific topic. Following the summary in each section, recommendations for improving the specifications are presented. These recommendations also address items observed during the field inspections. As developed, the Housing Community Plan only addressed Wherry housing units and units in the 4000 area.

3.1 SPACE-HEATING AND SPACE-COOLING SYSTEM

The existing heating and air-conditioning system will be replaced in each housing unit. In many cases, the equipment is being moved to equipment rooms outside the housing unit. In the Wherry housing units, the existing heat pump will be replaced by a new heat pump. In the 4000 area housing units, a new gas furnace and split-system air conditioner will be installed to replace the existing equipment. In all housing units, the distribution system and controls will be replaced. The new ductwork will be insulated with 1.5 inches of insulation. The entire system will be tested and balanced by the installation contractor.

- Moving the equipment to outdoor equipment rooms is not recommended from an energy viewpoint because of the energy penalties it imposes. Reasons for moving the equipment to an outside location include improved access for maintenance personnel and better utilization of interior space. Moving the equipment requires the installation of a completely new distribution system, with a new layout and ductwork which runs outside the unit. Increased energy losses are likely to occur from increased length of ducts, and equipment and ductwork located outside the unit. As demonstrated during the site visit, leaks in distribution systems that adversely affect energy consumption (loss of conditioned air and introduction of attic or outside air into the return air) can frequently occur; ducts located outside the unit are more likely susceptible to these deficiencies. If equipment is to be moved outdoors, inclusion of detailed specifications to avoid the stated problems are imperative.

- Minimum efficiency standards stipulated by Congress (The National Appliance Energy Conservation Act of 1987) mandates that gas furnaces manufactured after January 1, 1992 will have an annual fuel utilization efficiency (AFUE) greater than or equal to 78%; current Air Force regulations (Air Force 1988) require a furnace to have an AFUE rating of 80% or better with no standing pilot flame. Higher efficiency equipment is not recommended unless justified by a detailed economic analysis.

- Minimum efficiency standards stipulated by Congress (The National Appliance Energy Conservation Act of 1987) mandates that central split-system air conditioners manufactured after January 1, 1992 will have a seasonal energy efficiency ratio (SEER) greater than or equal to 10.0. Higher efficiency equipment is not recommended unless justified by a detailed economic analysis.

- Minimum efficiency standards stipulated by Congress (The National Appliance Energy Conservation Act of 1987) mandates that central split-system heat pumps manufactured after January 1, 1992 will have an SEER greater than or equal to 10.0 and a heating seasonal performance factor (HSPF) greater than or equal to 6.8. Such equipment is significantly more efficient than present units installed in the Wherry housing and will greatly reduce energy consumption in these units. We recommend that equipment with an SEER of about 11 and HSPF of about 7.5 be installed, as these are economically justified if the additional cost is less than $450.

- The project designer needs to carefully determine the correct size of the space-heating and space-cooling equipment for the housing unit in its weatherized status and loads of individual areas to determine proper air flows.

- The project designer needs to specify the location of the outdoor condenser unit. This location needs to be free of obstructions (such as bushes, decks, enclosure walls, and privacy fences) to avoid recycling exhaust air and be out of direct sunlight as much as possible.

- The project designer needs to specify the testing and balancing procedures to be performed following installation of the space-heating and space-cooling equipment. This is needed to ensure that all contractors perform their work properly.

- Installation of refrigerant line insulation needs to be included in the specifications.

- The installation of a programmable (set-back) thermostat needs to be included in the specifications. This is required by current Air Force regulations (Air Force 1988). Detailed specifications are included in the referenced regulation.

- The project designer needs to develop installation specifications for any new ductwork to be installed. This is needed to ensure quality installations that will remain functional over their intended lifetime. Installation of new ductwork without additional specifications will likely result in a repeat of some current deficiencies; namely, leaky ductwork due to lost adhesion of duct tape, construction of ducts using floor joists or other framing members instead of rigid duct material, and poor connections of ducts to the equipment. As a minimum, new ductwork must be sealed with an approved mastic at every joint. The specification of sheet metal ducts rather than fiberboard ducts should be considered because sheet metal ducts can be mechanically connected at joints and better sealed. It should be noted that installation of new ductwork in all units may not be needed if equipment is not moved to an outside equipment room. Additionally, limited attic space in the Wherry housing units and ductwork located in the space between floors in two-story units may prevent the installation of all new ducts.

- Duct insulation levels of R-6 are recommended for all units where ducts are located in the attics.

- The project designer needs to develop specifications addressing the air-distribution system deficiencies identified during the field inspection that would not be corrected by new ductwork. Installation of just new ductwork does not address fundamental design and construction problems found in the distribution system in the units; namely, return and supply plenums that were connected to attics, to the outside, and to each other. In most cases, these plenums would remain in their present condition if new ductwork was installed. To address this problem, the system in each unit needs to be inspected, problems diagnosed, solutions identified, and the work performed. This work cannot likely be performed by untrained personnel or typical contractors, because they do not have the required skills. Personnel need to understand the operation of the distribution system, air-infiltration principles, the construction of the unit, and the interaction of these areas. To perform the work, special diagnostic equipment (such as a blower door) and familiarization with special sealing techniques (materials and approaches) are needed. A comprehensive procedure needs to be developed to ensure a systematic approach to this problem. Personnel chosen to perform the work need to be adequately trained.

- Inspection of new and existing space-heating and space-cooling equipment and air-distribution systems by Shaw AFB personnel is critical. Current research shows that quality installations are not always obtained from contractors (Neal and Conlin 1988, Jenkins 1991, Proctor 1991, and Coyne 1992). The inspection needs to include checking

  - the installed efficiency, capacity, and air flow of the equipment, and

  - the air tightness of the air-distribution system and proper return flow with interior doors closed.

  An inspection procedure needs to be developed. Housing operations and maintenance personnel need to be thoroughly trained to perform the inspections.

3.2 WATER-HEATING SYSTEM

Shut-off valves will be installed on the cold water supply to all water-heating systems currently without them. Water-heating equipment will be moved to outdoor equipment rooms coincident with moving space-heating and space-cooling equipment to this location. Instant water heaters will be installed in all kitchens greater than 20 feet from the hot-water tank.

- Relocation of water heaters to an outside equipment room is not recommended from an energy viewpoint. Advantages of moving the system include improved access for maintenance personnel and more effective use of interior space. With the storage tank located in an outdoor environment, standby losses will increase considerably even if well insulated tanks and/or insulation blankets are installed. Increased piping runs will increase losses. Increased time to provide hot water at the usage point is being addressed by instant water heaters, which is an added expense and installation problem. If the systems are moved, sufficient specifications need to be developed to address the stated items.

- Installation of insulation on the first three to four feet of hot and cold water lines needs to be included in the specification. This task can be performed at the time the shut-off valve is installed.

- Installation of a water-heater insulation wrap on all tanks located in unconditioned spaces needs to be included in the specification. This task can be performed at the time the shut-off valve is installed.

- Setting the hot-water temperature setpoint to 135°F needs to be included in the specification. This task can be performed at the time the shut-off valve is installed. The setting should be checked whenever work is performed on the housing unit and when preparing the housing unit for new occupants.

- Installation of anti-convection valves on the water heater inlet and outlet needs to be included in the specification.

- The project designer needs to evaluate the need for an instant water heater in the kitchen and the cost-effectiveness of such an installation. The need for such a device is created by moving the hot-water tank to an outdoor location, which is not recommended. The cost of such a device may be greater than $130 as assumed in the Housing Community Plan (these devices may cost $400-$600). Installation of the device will likely require installation of a 220 volt power line or a gas line and flue. This can be difficult and expensive in renovation.

- The installation of low-flow faucet aerators needs to be added to the specifications.

- Inspection and repair of all heat recovery devices installed on the Wherry housing units needs to be added to the specifications to realize the energy savings potential of these devices. These devices should continue to be inspected at change of occupancy to ensure continued operation.

3.3 ROOFS AND CEILING

New roofs will be installed on housing units in the 4000 area that have not recently been replaced. All new roofs will be installed with ridge vents. All new ceiling areas created during the renovation will be insulated to R-30.

- Inspection of existing soffit vents needs to be added to the specifications to ensure that they are not covered by insulation or debris, that screening still exists, and that there is 1.0 ft^2 of free ventilation area for each 300 ft^2 of attic area. Any deficiencies need to be corrected.

- The use of soffit "dams" needs to be included in the specifications to ensure that soffit vents do not become covered by insulation or other debris in the future.

- Use of light-colored roof shingles needs to be included in the specifications to extend shingle life and reduce cooling loads.

- Inspection of existing attic insulation needs to be added to the specifications. The main problems to look for are lack of sufficient insulation (R-30) and insulation that does not evenly cover the entire attic, especially at the edges and under ducts. Any deficiencies need to be corrected.

3.4 EXTERIOR WALLS

New exterior walls installed in some housing units under the renovation will be insulated to R-11.

- Installation of R-13 insulation in new walls is recommended rather than R-11, in order that the total R-value of the wall system approaches R-15.

- Installation of a vapor retarder on the inside of new walls or when drywall repairs are made needs to be included in the specifications.

- Installation of an infiltration barrier and insulating board when siding is replaced needs to be included in the specifications.

- Installation of R-19 insulation on the exposed floors of second-story overhangs needs to be added to the specifications. A new weatherization approach that insulates and air seals should be considered for this application. Under this approach, cellulose insulation is blown into the overhang to a high density (Fitzgerald, Nelson, and Shen 1990).

3.5 WINDOWS AND DOORS

Existing single-pane, casement windows will be replaced in all housing units with double-pane, insulated, side-sliding or single-hung windows. Mini-blinds and new insect screens will be installed in all the units. Solid-core wood exterior doors will be installed on all the housing units. Sliding glass doors will be replaced with insulated designs in all housing units.

- Double-pane insulated windows need to be defined as aluminum designs with thermal breaks, wood, or vinyl in the specifications.

- The project designer needs to consider the use of solar screens instead of just an insect screen. Solar screens serve the dual purpose of reflecting solar radiation and keeping insects out. These screens may be appropriate for unshaded east, west, and south facing windows. The designer should also consider the use of other window treatments, such as solar films and awnings. Awnings can be high maintenance items and may not be economical based on energy savings alone; however, they could be used to reduce the institutional nature of the housing (use would be different on units depending on orientation and tree shading).

- Because sliding glass doors are notoriously leaky, the use of high quality doors needs to be included in the specifications, such as those currently being installed in the 5000 area housing units. French doors rather than sliding doors could also be recommended.

3.6 BATHROOM RENOVATIONS

Tubs, shower units, and toilets will be replaced in many housing units. Bathroom exhaust fans will be installed in bathrooms currently without them to prevent moisture problems.

- Before installing the new tub/shower unit, the exposed wall and floor area must be properly air-sealed, preferably with the guidance of a blower door (see Sect. 3.9), and insulated. This work needs to be included in the specifications.

- The use of low-flow showerheads needs to be included in the specifications. These must allow a flow of no more than 3.0 gpm.

- The use of low-water consumption toilets needs to be included in the specifications.

- Inspection of bathroom exhaust fans needs to be added to the specifications. Exhaust fans without dampers need to be replaced. Fans that vent into the attic rather than outside need to be modified to exhaust through the roof, as specified in current Air Force regulations (Air Force 1988).

3.7 KITCHEN RENOVATIONS

Kitchen renovations will be performed in most of the housing units. These renovations include installation of a new dishwasher with energy saving features, electric stove, and exhaust hood.

- Installation of new dryer vents needs to be added to the specifications to reduce infiltration losses. Designs that avoid problems with standard sheet metal vent designs could be used.

- High-efficiency refrigerators, clothes dryers, and stoves should be used in case any of these appliances are replaced during renovation.

3.8 LIGHTING

Many new light fixtures will be installed in all the units, with most being fluorescent.

- The use of high-efficiency electric ballasts with the fluorescent fixtures needs to be included in the specifications.

- The use of fluorescent bulbs approved for outdoor use in the outdoor and carport fixtures needs to be included in the specifications. Cold outdoor temperatures can affect normal fluorescent bulb performance.

3.9 AIR INFILTRATION

No specific work is identified to reduce air infiltration, although items such as new windows and exterior doors do address this area.

- Blower-door-guided air sealing needs to be added to the specifications to reduce air infiltration of these units. New windows and exterior doors do not focus on the primary leakage sites of the units. Sealing of the distribution system (see Sect. 3.1) addresses one major leakage site found in the units. Air sealing under the guidance of a blower door is needed to address attic bypasses found in the units, as well as other leakage areas that may be peculiar to individual units.

- A general blower-door-guided procedure that includes feedback on cost effectiveness (Schlegel 1990) needs to be developed and followed to consistently seal the units. Because each unit type and even each individual unit is unique, general recommendations cannot address specific problems associated with each unit. Quality air sealing requires special skills and knowledge: using a blower door, identifying leakage sites, being familiar with durable sealing techniques that can be performed quickly and inexpensively, and knowing which leaks can be sealed cost-effectively. Appropriate personnel should be trained on the concepts of this approach in order to manage an effective air-sealing effort. Personnel chosen to air seal the units must be adequately trained. The local provider of the Department of Energy (DOE) Weatherization Assistance Program may have the necessary skills to air seal the units; DOE weatherization programs are administered through state offices.

- If outdoor air for combustion must be provided directly to gas appliances installed indoors to meet local building codes, the indoor equipment room should be sealed with tight doors and all penetrations should be carefully sealed. This is the best approach from an energy perspective. If the indoor equipment room cannot be sealed and building codes are in agreement, elimination of the combustion-air pipes should be considered.

3.10 YARD/EXTERIOR IMPROVEMENTS

Many housing units will have grading work performed around the units to improve drainage. Trees that are too close to the housing units will be removed. Carports will be added to some housing units.

- Slab edge insulation needs to be installed if extensive grading work is performed on any unit. R-5 insulation is recommended and it should extend to a depth of 2 feet.

- Although removing trees may be required for structural reasons, this action could increase the cooling load of the unit depending on the amount of shade provided. Proper landscape planning is necessary to locate replacement trees for optimum energy impact.

- Installation of carports could provide beneficial shading.

3.11 OCCUPANT EDUCATION

No occupant education program is currently planned.

- Current research (Quaid 1990) is demonstrating that energy savings can result from education programs. Because occupants control systems and interact with hardware, energy savings of measures depend on the actions of occupants. An occupant education program needs to be developed and performed. This program should be offered to all new tenants when they move into a unit to familiarize them with the unit and to encourage energy conserving practices. During this program, the following must be explained: operation of the setback thermostat, the need to regularly change distribution system filters, the importance of maintaining 135°F water temperatures, and the operation of gas appliances.

3.12 NEIGHBORHOOD IMPROVEMENTS

300/250 watt high-pressure sodium street lights will be added to the neighborhoods.

- Street lights need to be residential types.

4. CONCLUSIONS AND RECOMMENDATIONS

Renovation work specified in Housing Community Plans being developed for the Tactical Air Command generally complies with current Air Force regulations (Air Force 1988) and is generally consistent with public energy standards (The National Appliance Energy Conservation Act of 1987, ASHRAE 1990). Energy efficiency improvements will result from the renovation work that will help decrease energy consumption. Nevertheless, an expected level of energy efficiency that should be readily attained following renovation will not necessarily be achieved. Design and construction flaws can exist in the housing that adversely affect energy consumption. These housing deficiencies are not completely addressed in the current Air Force regulations or guidelines and, thus, are not addressed in the Housing Community Plans. Additionally, some renovation work specified in the Housing Community Plans is not energy efficient and contributes to increased energy consumption. These conclusions are based on a review of the Housing Community Plan developed for Shaw AFB and an inspection of several family housing units at the base.

Major items in the Housing Community Plan developed for Shaw AFB that will improve the energy efficiency of the units include installation of

- high-efficiency space-heating and space-cooling equipment,
- new ductwork, if properly insulated and sealed,
- proper amounts of insulation in walls and ceilings modified during renovation,
- thermally efficient windows and exterior doors, and
- energy-efficient lighting.

Major design and construction flaws in the housing at Shaw AFB that can be corrected during renovation but were not addressed in the Housing Community Plan include

- design problems with the distribution systems that allow outside or attic air to enter the return air stream,
- leaks in the distribution supply ducts,
- leakage sites in the envelope of the units (primarily the attic) that increase the infiltration of the units, and
- envelope insulation missing in non-routine locations.

Some envelope insulation present in the housing at Shaw AFB did not meet current standards but was not addressed in the plan. Recommendations in the plan for relocating space-heating, space-cooling, and hot-water heating systems outside will likely decrease energy efficiency. Occupant education is needed to achieve an expected level of energy efficiency; however, this was not addressed in the plan.

Specific recommendations for Shaw AFB are detailed in the body of the report. These recommendations, together with the existing Housing Community Plan, can be used to prepare detailed project design and specifications. The current renovation work being performed in the 5000 area at Shaw AFB, which is not included in the Housing Community Plan, does not address many of these inefficiencies. This work could also be improved by following the specific recommendations in the report.

It should be emphasized that the deficiencies identified in the Shaw AFB housing are not unique to that base or even the Air Force. These are the same type of problems being found in private and public sector housing across the U.S. Because housing styles change from base to base, another base would likely have its own, unique set of problems. Weatherization programs operated by DOE, states, and utilities are successfully addressing these deficiencies. Although many local contractors will not be able to perform all the tasks necessary to improve these housing units because of the special skills needed, organizations are available to perform the work (such as providers of the local DOE Weatherization Assistance Program administered through state offices) or provide the necessary training to appropriate base and contractor personnel.

A four-fold plan is recommended to ensure that future Housing Community Plans developed for the Tactical Air Command address improvements in energy efficiency to the fullest extent possible.

- First, the Air Force Whole House/Whole Neighborhood Planning Guide should be revised to include guidance concerning energy efficiency improvements that need to be considered in developing a Housing Community Plan.

- Second, a field inspection procedure should be developed that allows planners to perform a thorough energy evaluation of representative housing units. This procedure would include the diagnostic approaches used in this study. This field inspection would be performed at the same time other field information is gathered for developing the plan. Work needed to alleviate problems found during the field inspections should be addressed in the plans and carried through to the final designs.

- Third, inspection procedures should be developed and implemented to ensure that contractor work complies with the design intent and to accurately diagnose problems that occur in later years. Through extensive work performed in support of the DOE Weatherization Assistance Program and private sector programs (such as those administered by utilities and states), proven approaches for improving and maintaining energy efficiency of residential housing have been developed. Appropriate personnel involved with residential housing can be trained in these approaches through private contractors, publications such as Home Energy, conferences such as Affordable Comfort, and the DOE Weatherization Assistance Program.

- Fourth, a monitoring program should be implemented to verify the energy-efficiency improvements following renovation. Developing and maintaining energy efficiency programs at Tactical Air Command bases will be an iterative process requiring improved understanding of housing unit energy consumption. The insight and feedback obtainable only through monitoring is an essential element of this process.

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APPENDIX A. AIR-LEAKAGE CALCULATIONS

Under the air-tightness tests performed, a series of pressure differences (ΔP) and corresponding air-flow rates (Q) were measured. These data follow the power law form

$$Q = C (\Delta P)^N \qquad \text{(Eq. A.1)}$$

where C and N are constants. Because ln(Q) versus ln (ΔP) is a linear relation, these values were regressed by the method of weighted least squares to determine the best values of C and N.

The cfm50 value was calculated using Eq. A.1, the best values of C and N, and 50 Pa as the value of ΔP. The normalized leakage was calculated using the following equation (ASHRAE 1988):

$$L_n = 1000 \, (L/A) \, (H/H_o)^{0.3} \qquad \text{(Eq. A.2)}$$

where

L_n = the normalized leakage,
H_o = the height of a single story (8 ft),
H = the height of the building (ft),
L = the leakage area of the space (ft^2), and
A = the floor area of the space (ft^2).

The leakage area (L) required in Eq. A.2 was calculated using the following equation (ASHRAE 1989a):

$$L = 0.186 \, Q_r \, [p/2(\Delta P_r)]^{0.5} \qquad \text{(Eq. A.3)}$$

where

L = the leakage area of the space (in^2),
Q_r = the predicted air-flow rate using Eq. A.1 at ΔP_r (cfm),
p = air density (lbm/ft^3), and
ΔP_r = the reference pressure difference (4 Pa).

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