CORRECTING THERMAL DISTRIBUTION PROBLEMS FOR A LARGE UNIVERSITY CAMPUS

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ABSTRACT

Texas A&M University main campus in College Station consists of 114 buildings served by two central plants. The two main campus loops are more than 50 years old with a total piping length for each loop in excess of 13 miles. The main campus has long had a problem with thermal distribution to the 114 buildings served by the central plants. Pressure problems were encountered in the chilled water and hot water distribution system during peak demand periods. The differential pressure between supply and return headers at buildings far from the central plants was negative, in the middle area was neutral, and close to the plant was positive. Various modifications were performed over the years without completely solving this problem. Discovering the real cause could help improve the thermal distribution and help determine how to best operate the system. This paper presents the causes and recommendations for the correction of the thermal distribution problems, which include not only malfunctioning automatic building hydraulic controls, but also some building hydraulic configurations themselves. Based on the findings, the thermal distribution problems will be solved by repairing the controls and retrofitting building hydraulic configurations as needed.

INTRODUCTION

Engineers, staff, and facilities managers are constantly burdened with trying to improve central thermal distribution performance. On large campuses like Texas A&M University, it is extremely difficult to provide heating and cooling energy in an efficient manner. These thermal distribution problems not only cause occupant discomfort, but also increase building pump and central plant (chiller and boiler) energy use (Deng et al., 1998; Deng et al., 2000; Deng et al., 2001).

Many efforts have been made to reduce the amount of energy consumed by these large campuses. If the thermal distribution efficiency is improved, the overall energy consumption of the system is also improved (Deng et al., 2000). Several options that seem to improve the thermal transmission performance include: VFD systems for new construction (Kirsner, 1996; Mannion, 1998; Powell, 2002), piping and pump renovation for existing buildings (Karalus, 1997; Vople, 2001), as well as primary and secondary loop reconfigurations. Troubleshooting is one way to relieve some of the thermal distribution problems (Kirsner, 1995; Kirsner, 1996; Hattemer, 1996), but to ensure that the system is working properly commissioning of the entire campus should be performed (English, 2001; Rishel, 1998). Several detailed commissioning steps have been described (Deng et al., 1998; Deng et al., 2000; Deng et al., 2001; Utesch, 1995).

The Texas A&M University campus encountered several problems related to thermal distribution (Deng et al., 2001). Most of them were caused by control systems in individual buildings that were improperly maintained so coils or other components were operating wild. For buildings near the plant, malfunctioning building control valves sometimes permit excessive flow, even when the building pump is off. Under high negative loop differential pressures (DP), some buildings had no flow or even backflow if there is no check valve installed or the check valve has failed. This often leads to pump failure within the building and comfort complaints from the occupants during peak heating and cooling load times.

Table 1: Hot Water Loop Measurements for Butler Building

1:00 pm	Building Loop		Primary Loop		Field Note
	P (psi)	T (F)	P (psi)	T (F)	Hot water pump was
Supply	44	131	44	131	
Return	56	160	56	160	
DP or DT	- 12	-29	- 12	-29	

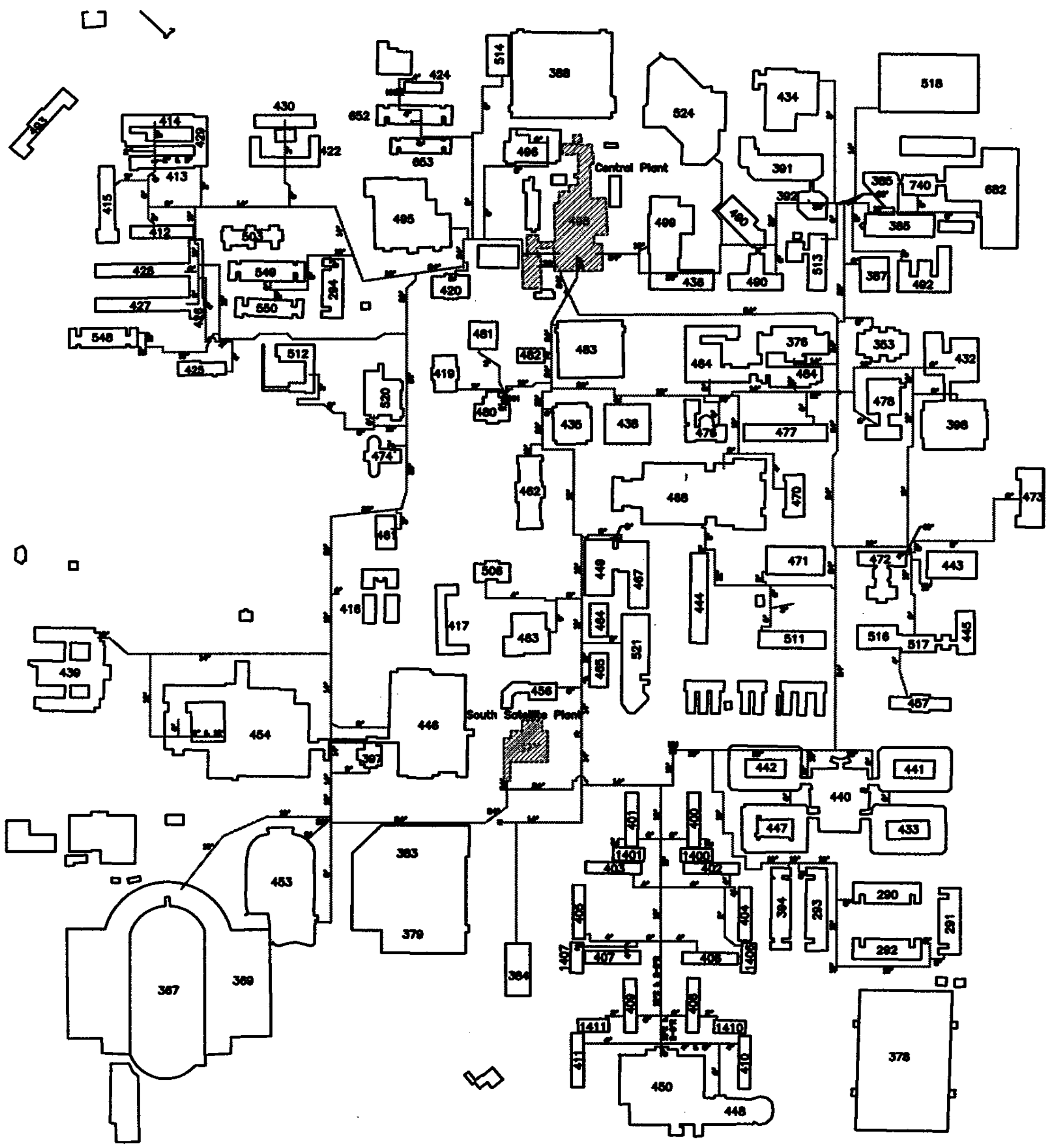

Figure 1: Main Campus Central Chilled Water Loop at Texas A&M University

Table 1 illustrates the high negative DP for the Butler building, one of the troubled buildings. Every year many buildings display the same characteristics as the Butler building.

In order to correct comfort complaints and flow problems, several emergency balances were performed over the years. This was only a temporary solution for the problems. After cold weather ended, the need for hot water decreased and other priorities emerged.

This paper presents the findings of an extensive field survey of the thermal distribution systems based on the campus. It also includes recommendations for completely resolving the typical thermal distribution problems found on large campuses.

FACILITY INFORMATION

Two separate central plants, the main plant and the south satellite plant, serve the chilled water loops while only the main plant provides hot water for the Texas A&M main campus. These two plants have a combined cooling capacity of 24,700 tons. The main plant has a total heating capacity of 170 million Btu per hour. All of the loops pass through common supply and return headers in the main plant. Figure 1 shows the main campus chilled water loop. The main campus hot water loop typically runs parallel to the chilled water loop.

The basic chilled water and hot water loop configurations in the main campus can be separated into four different types. A survey of campus buildings showed these different configurations are used within the buildings as summarized in Table 2.

1. ***Two-way flow scheme without bypass***
   Figures 2 and 3 represent the two-way piping schemes. Figure 2 shows constant speed pumping within a two-way flow loop, without a blending station or building bypass. Figure 3 shows a two-way variable speed flow loop with control valve, but without any bypass.
2. ***Two-way constant speed loop with bypass***
   Figure 4 shows a two-way constant speed flow loop with blending station.
3. ***Three-way constant speed pumping with a blending station***
   Figures 5 and 6 illustrate the three-way constant speed-pumping configurations with a three-way control valve and a blending station.
4. ***Three-way flow scheme without a pump***
   Figure 7 shows a three-way control valve configuration without a pump. The scheme has a manual building bypass, a two-way temperature control valve, and a three-way control valve.

Table 2: Summary of Loop Configurations

Type	2-way without bypass	2-way control with bypass	3-way with a blending station	3-way control valve (no pump)	Total
Chilled Water	51	2	58	1	112
Hot Water	7	20	86	0	113

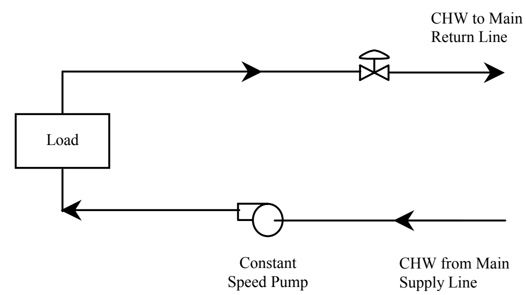

Figure 2: Two-way constant speed flow loop without bypass

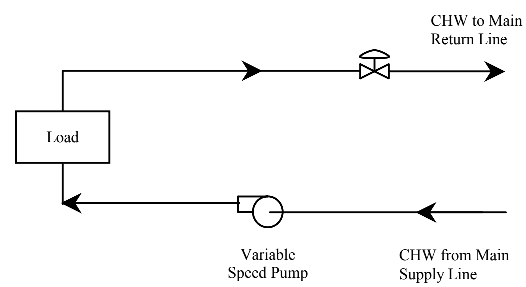

Figure 3: Two-way variable speed flow loop without bypass

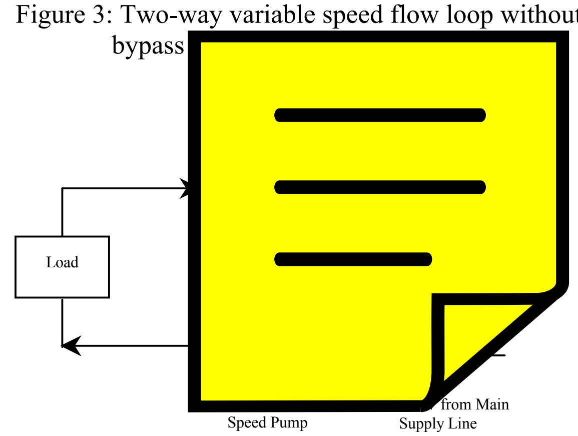

Figure 4: Two-way constant speed flow loop with bypass

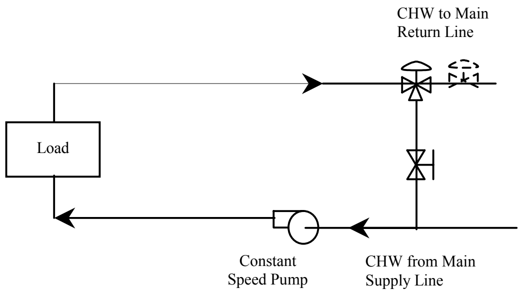

Figure 5: Three-way flow loop with constant speed pumping (a)

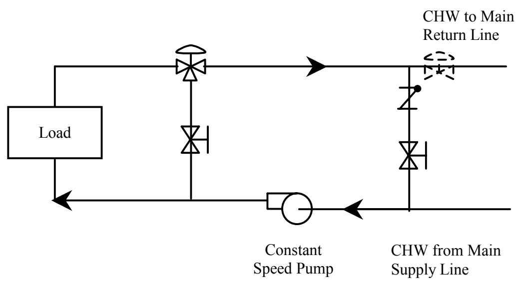

Figure 6: Three-way flow loop with constant speed pumping (b)

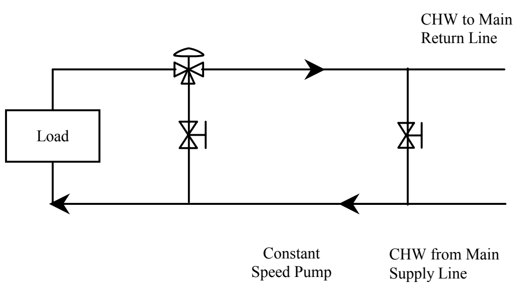

Figure 7: Three-way control valve without pump

Variable frequency drives (VFD) are installed in 39 buildings for chilled water systems and 20 buildings for hot water systems on the main campus.

Nearly half of the 114 buildings with VFDs have functional Energy Management Control Systems (EMCS). 15% of these buildings have no functional EMCS at all. The other 35% of these buildings use local pneumatic controllers.

FINDINGS AND RECOMMENDATIONS FOR BUILDING HYDRONIC LOOPS

Two Way Constant Speed System without Bypass or Blending Station (Figure 2)

Initial field surveys show that at least 30 building chilled water and hot water loops are two-way flow loops with constant speed pumps with no building bypass or blending station. These buildings have 3-way control valves for the coils in the air-handling units (AHUs). Ninety five percent of the main return control valves in these buildings were always fully open allowing for maximum water flow. Either the pneumatic air line was disconnected or the set point was set such that it kept the main return control valve open. Previous emergency balancing utilized the building isolation valve, which was acceptable for only a short time.

The inoperative controls caused much of the thermal distribution problems on the main campus. These 2-way constant speed flow systems (Figure 2), without a bypass or blending station, are located in many buildings. The constant speed pump without feedback control disrupts loop distribution. The existing building controls must be replaced to correct these thermal distribution problems. Three approaches are as follows:

- Install a VFD for the pumping system.
- Install a building blending station for constant speed pumping control. This modification returns the system to its original design intent.
- Install a heat exchanger and a bypass for the building water systems.

The preferred approach is the VFD because a VFD saves not only pumping energy, but also reduces chilled water and hot water consumption. Based on the locations of buildings or varying differential pressures of the primary loop, the following recommendations are made for installing a VFD in a two-way constant speed system without blending station or bypass:

1. Typically, engineers specify a building pump expecting to have positive differential pressure from the campus loop. The existing differential pressure from this primary loop varies from positive to negative. When the loop pressure differential is negative, the building pump needs to be sized properly. The pumping capacity is supposed to overcome the negative differential pressure from primary loop and the pressure loss in the secondary circuit. It must also provide water flow to the coils. In this case a VFD gives the engineer flexibility and allows for loop fluctuations with a larger pump's capacity.

2. When the loop pressure differential is positive by 5 psi, and the horsepower of the existing constant speed pump is over 5 hp, a VFD with direct digital controls (DDC) should be installed to improve operation. If the existing constant speed pump is less than 5 hp, a DDC controlled bypass should be installed.
3. If the pressure differential from the primary loop is higher than 10 psi, the building pump can be turned off. No VFD needs to be installed.

Two Way Variable Speed Systems without Bypass or Blending Station (Figure 3)

Figure 3 shows the two-way variable pumping system. This is the preferred system, but it must operate as designed. The VFD should operate according to an optimized building differential pressure reset schedule. The optimized building differential pressure reset schedule can be based on the temperature of the outside air unless other more direct feedback from the actual system allows for the development of a more sophisticated schedule. With the outside air temperature, the reset schedule is simple. The problems and solutions for the Figure 3 systems are as follows:

1. Some main control valves were always fully open due to control or component malfunctions. The key is to design automatic reactive building control valves to maintain building differential pressure or temperature set points.
2. Pressure and temperature sensor failures, or improper sensor location need to be determined. Move, repair or recalibrate as needed to insure proper control
3. Programming of EMCS may need to be modified if sequence of control and schedule are not optimal.

For variable hot water or chilled water pumping with EMCS capability, the control sequence is suggested as follows:

- When primary loop differential pressure is positive and actual load is low, try to shut off the pump and use the building control valve to maintain building differential pressure set points.
- When building control valve is modulated to meet the differential pressure set points, the minimum position of the valve should be at least 20% open.
- If more water flow is needed or the actual building differential pressure becomes lower than the set points, then the control valve should open fully and one of the two parallel pumps should be activated. If after the first pump is turned on, the actual building differential pressure is still lower than the set point, the second pump needs to be turned on and run at the same speed as the first pump.
- Whenever the pump is on, the building control valve (either hot water or chilled water) should be fully open.

Two Way Constant Speed Systems with Bypass or Blending Station (Figures 4)

Figure 4 shows the two-way constant speed system with a blending station. This is an original design based on differential temperature set point. The main two-way return control valve and the blending station can be modulated to maintain a stable water loop. Removing these blending stations and installing a VFD for pump motors larger than 5 hp.

Three Way Constant Speed Systems with Blending Station (Figures 5 and 6)

Figures 5 and 6 show three-way valve constant speed system with a blending station. This type of system is more widely used than the two-way system in the hot water as well as the chilled water systems on this campus. In Figure 5, the constant speed pump is used to pump water directly to AHUs equipped with two-way or three-way control valves. These terminal control valves have three connections, which allow them to direct all the constant water flow through the coil in the terminal coils or completely bypass the terminal coils and go back to the primary return water loop. This configuration results in low water differential temperature across the primary loop, high operating costs and poor comfort when the building load is not near the design condition. The following options are recommended for improving three way constant speed configurations:

- Install a VFD for pump motors (larger than 5 hp) as shown in the two-way constant speed system with a blending station. The three-way valve on the terminal coil should be changed to a two-way terminal coil valve if the existing coil has a three-way valve, and the three-way main valve and blending station should be removed. At the terminal coil, the two-way valve modulates open or closed as needed to maintain the desired supply air temperature, varying the flow through the terminal coil and building loop. This option will improve the existing system hydraulics and makes it more efficient than the three-way constant speed scheme.
- A new control valve needs to be installed in the return main water pipe before the blending station as shown in Figures 5 and 6. In fact, the existing blending station was rarely used in the original building loop control. The modification

converts this configuration to two-way constant speed pumping.

COMMON BUILDING LOOP PROBLEMS

Automatic control valves

Field observation showed that almost 100% of the control valves in two-way constant speed configurations without a bypass or blending station (see Figure 2) were fully open. This is generally caused by controls or valves that are inoperative or malfunctioning.

Constantly opened control valves allow for no differential pressure control and no flow control to the entire building loop. This generally leads to excessive flow in the building loop (with accompanying low DT) and inadequate water available for buildings farther down the loop.

Sixty percent of the control valves of the two-way variable speed systems (Figure 3) and 70% of all the control valves of three way piping systems with bypasses or blending stations (Figures 5 - 7) were fully open. These automatic control valves were supposed to modulate the building load to control differential temperature or differential pressure. These valves were generally open due to one of the following problems: the pneumatic control line was disconnected or in override; the control programming was incorrect; or valves and sensors were malfunctioning; or sensors were in the wrong locations.

Manual Isolation Valves

Manual isolation valves were adjusted to a partially open position (normally at 50% open or less) during previous emergency balancing and have remained in that position. The partially opened manual valves reduced pump power for variable and constant speed pumps, and caused a huge pressure drop in the water pipe and reduced the chilled water and hot water flow to the buildings. In addition, these valves were not able to adapt to fluctuations of the water loop system after the emergency balancing was performed.

Using Manual Control Valves for Balancing

Globe valves and gate valves were improperly used as balancing valves. Neither should be used for long-term water balancing. During emergency situations, however, any valve that works may need to be utilized temporarily, as was done in this case.

Internal Water Balancing for AHUs

Field surveys indicate that improper pumping controls generally caused observed imbalances in the AHU loops. The building's AHUs and fan coil units (FCU) must be properly balanced, or building problems may exist and may be falsely blamed on the campus loop.

Other Recommendations

The following recommendations or options are also presented:

1. DDC energy management control systems can monitor all the hydraulic loop parameters including major plant and building hydronic differential pressures and differential temperatures, flow rates, VFD speeds, control valve positions, equipment on /off settings, etc. DDC controls can dynamically vary the thermal distribution to satisfy occupants' requirements.
2. Campus thermal distribution maps (differential pressure and differential temperature) need to be established. The thermal distribution map is based solely on monitored data and enables us to trend capacity for chilled water and hot water. A map particularly needs to be labeled with monitored water parameters at critical locations in loops and critical buildings.

Energy Savings

Energy savings will be achieved in the following ways:

1. Savings can be achieved from a reduction in building pumping energy when unnecessary pumps are turned off;
2. Savings also can be obtained from increased chiller efficiency associated with increased loop differential temperature;
3. Hot water consumption will be reduced; and
4. Chilled water consumption will be reduced.

CONCLUSIONS

This paper presents diagnostic and analysis techniques for application to existing thermal distribution problems. Two-way constant pumping schemes without a bypass should be retrofitted to either reinstall a building bypass, which returns the building to original design conditions, or a VFD should be installed for greater flexibility and savings. VFD control is the preferred option in order to save pumping power and thermal consumption. Automatic control for all the three-way systems needs to be reactivated and if possible, VFDs installed. Only automatic building controls can adapt the building loop to the dynamic changes from the primary loop.

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Homes produced with airtight duct systems (around 15% savings in Htg and Cooling Energy)

Palm Harbor Homes	22,000
Southern Energy Homes	8,000
Cavalier Homes	1,000
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Subtotal	31,000

Technical measures incorporated in BAIHP homes include some or many of the following features - better insulated envelopes (including Structural Insulated Panels and Insulated Concrete Forms), unvented attics, “cool” roofs, advanced air distribution systems, interior duct systems, fan integrated positive pressure dehumidified air ventilation in hot humid climates, quiet exhaust fan ventilation in cool climates, solar water heaters, heat pump water heaters, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems.

HOMES BY THE FLORIDA HOME ENERGY AND RESOURCES ORGANIZATION (FL.H.E.R.O.)

Over 400 single and multifamily homes have been constructed in the Gainesville, FL area with technical assistance from FL H.E.R.O. These homes were constructed by over a dozen different builders. In this paper data from 310 of these homes is presented. These homes have featured better envelopes and windows, interior and/or duct systems with adequate returns, fan integrated positive pressure dehumidified air ventilation, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems. The innovative outside air (OA) system is described below.

The OA duct is located in the back porch (Figure 1) or in the soffit (Figure 2). The OA is filtered through a 12"x12" filter (which is readily available) located in a grill (Figure 3) which is attached to the OA duct box. The flex OA duct size varies depending on the system size - 4" for up to 2.5 tons, 5" for 3 to 4 ton and 6" for a 5 ton system. The OA duct terminates in the return air plenum after a manually adjustable butterfly damper (Figure 4).

Figure 1 OA Intake Duct in Back Porch

Figure 2 OA Intake Duct in Soffit

Figure 3 Filter Backed Grill Covering the OA Intake

Figure 4 Butterfly Damper for OA control

The damper can be set during commissioning and closed by the homeowner in case the OA quality is poor (e.g. forest fire). This system introduces filtered and conditioned ventilation air only when the cooling or heating system is operational. The ventilation air also positively pressurizes the house. Data on the amount of ventilation air or positive pressurization is not available from a large sample of homes. A few measurements indicate that about 25 to 45 cfm of ventilation air is provided which pressurizes the house in the range of +0.2 to +0.4 pascals.

Measured Home Energy Ratings (HERS) and airtightness on these FL. H.E.R.O. homes is presented next in figures 5 through 8. Data is presented for both single family detached (SF) and multifamily homes (MF). See Table 2 below.

Table 2. Summary statistics on FL.H.E.R.O. Homes
n = sample size

	SF	MF
Median cond area	1,909	970
% constructed with 2x4 frame or frame and block	94%	100%
Avg. Conditioned Area, ft^2	1,993 (n=164)	1,184 (n=146)
Avg. HERS score	87.0 (n=164)	88.0 (n=146)
Avg. ACH50	4.5 (n=164)	5.2 (n=146)
Avg. Qtot (CFM25 as %of floor area)	6.9% (n=25)	5.0% (n=72)
Avg. Qout (CFM25 as %of floor area)	3.0% (n=15)	1.4% (n=4)

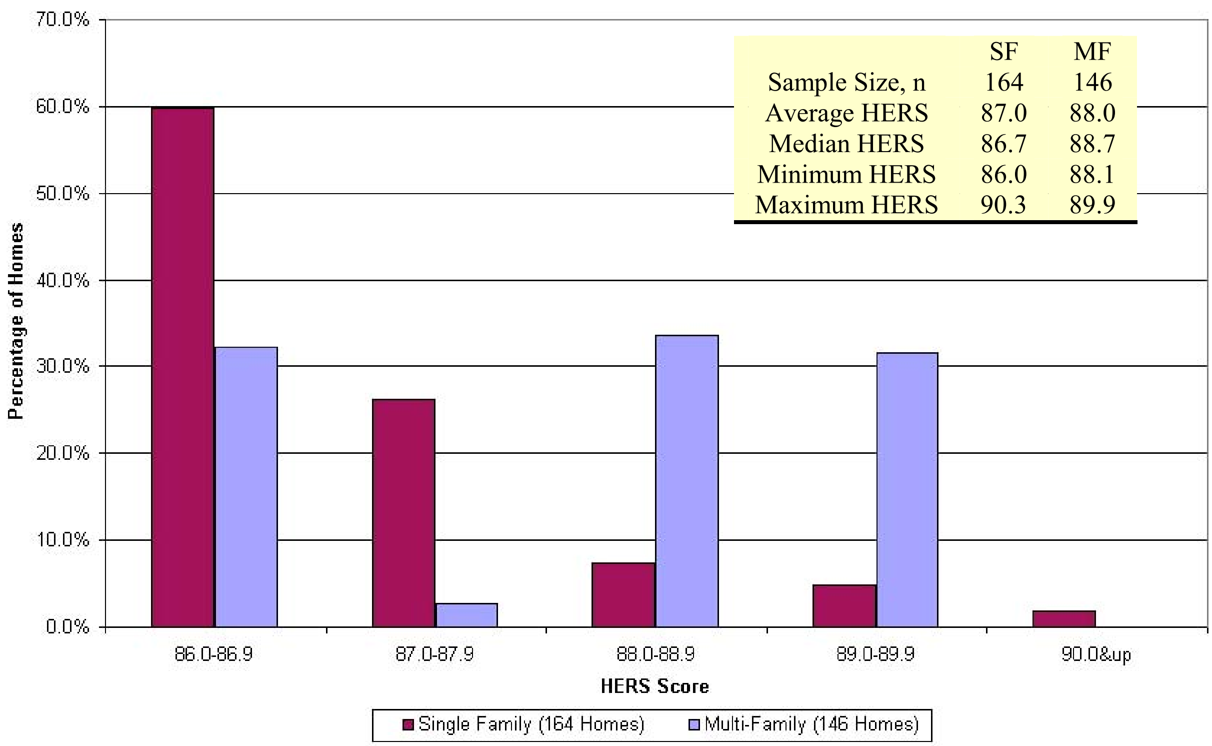

Figure 5 HERS Scores for FL H.E.R.O. Homes

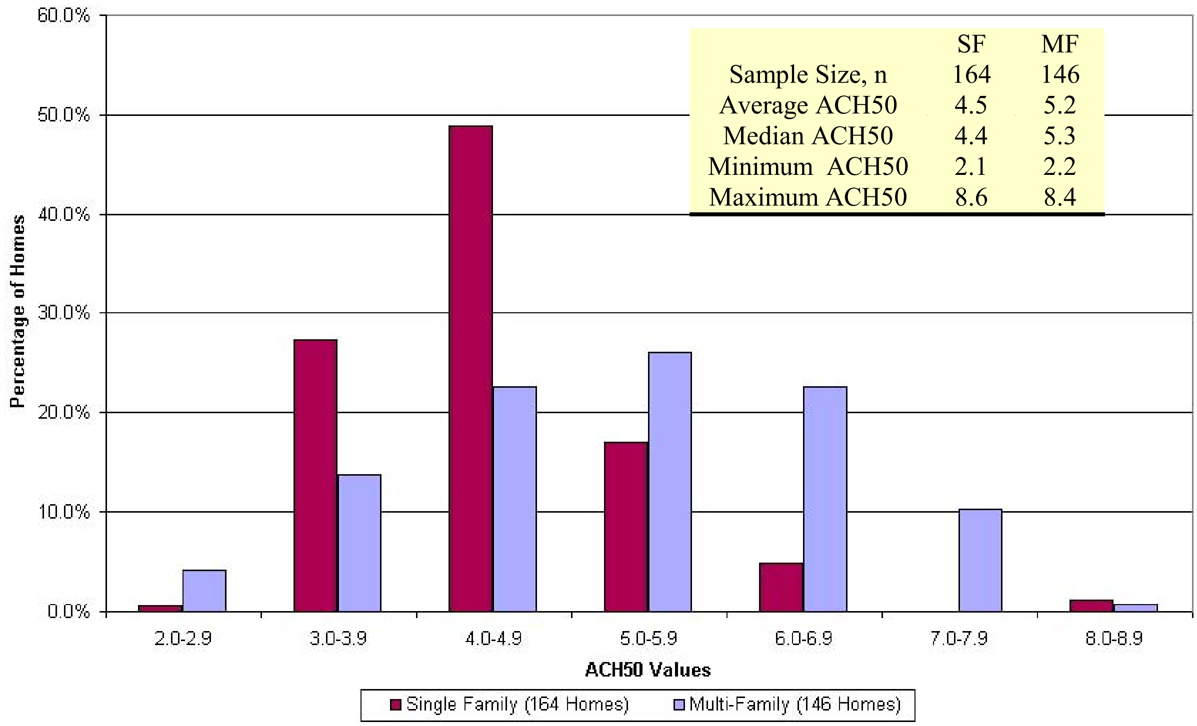

Figure 6 ACH50 Values for FL H.E.R.O. Homes

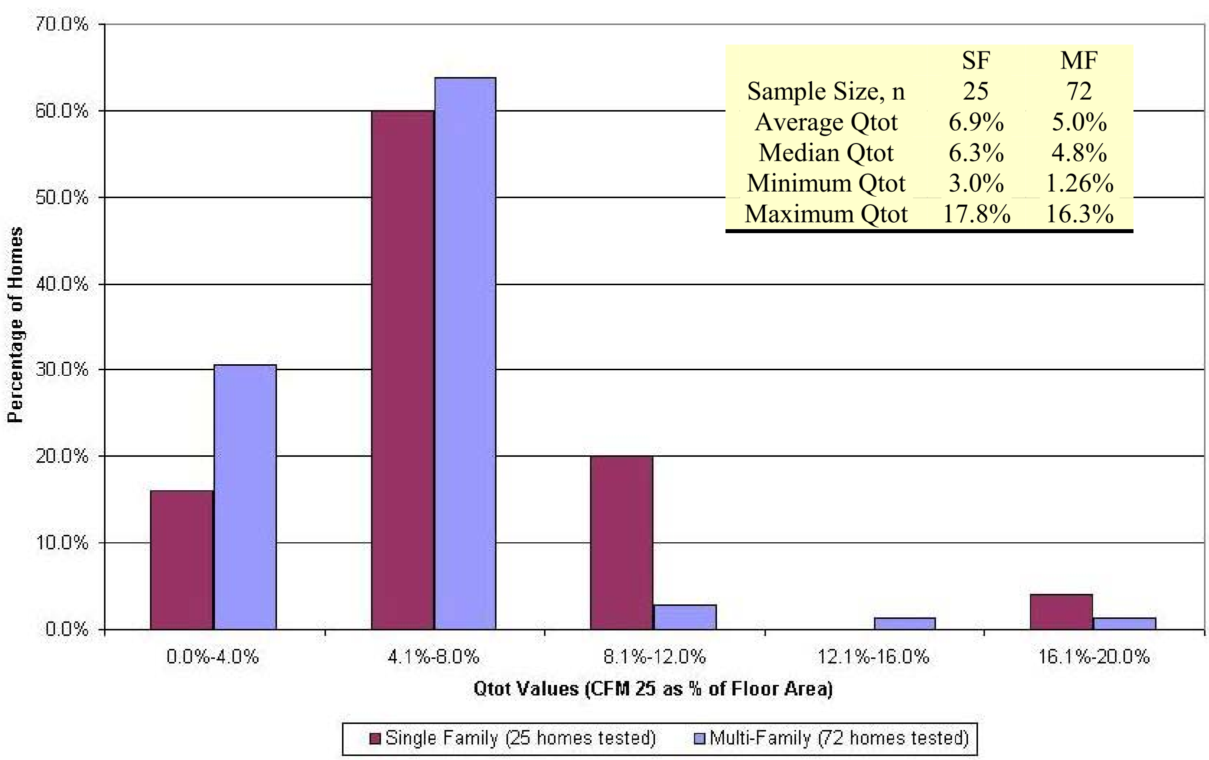

Figure 7 Qtot Values for FL H.E.R.O. Homes

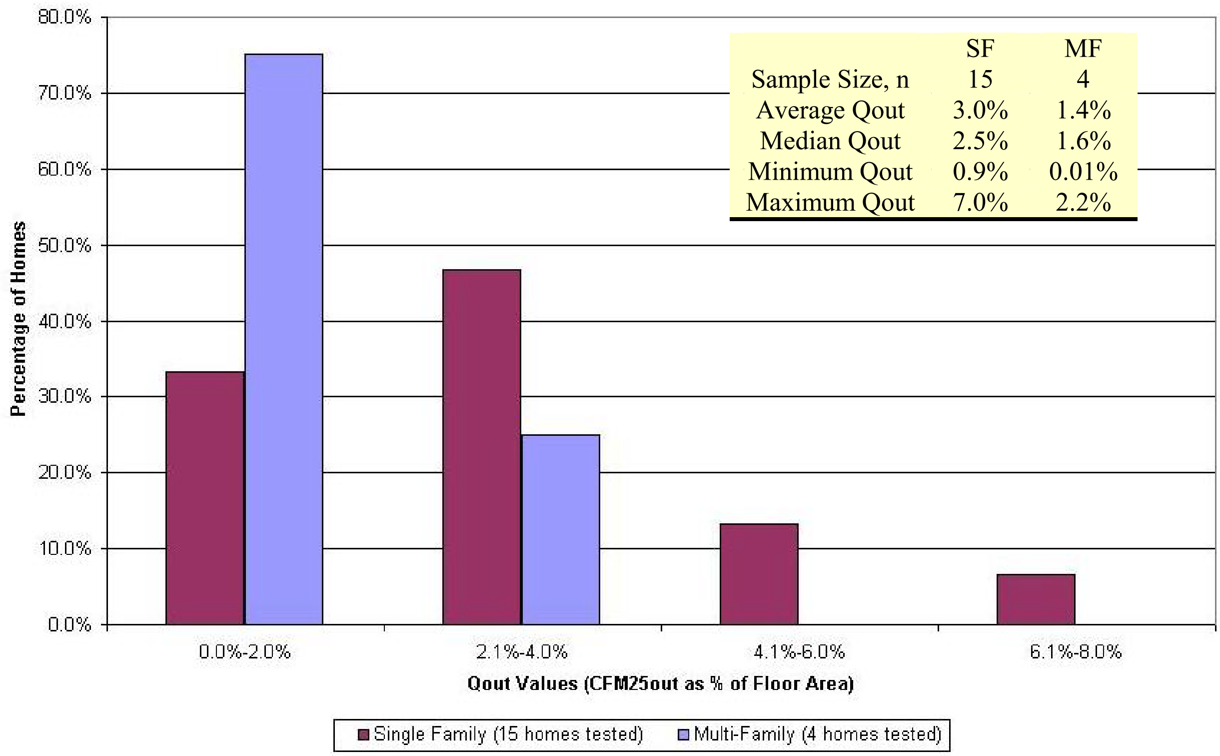

Figure 8 Qout Values for FL H.E.R.O. Homes

Data is available for other typical non BAIHP, new Florida homes (FPL , 1995 and Cummings et al, 2001). The FPL study had a sample size of over 300 single family homes and the median Qout was 7.5% , three times that of the FL. H.E.R.O. homes. In the Cummings study of 11 homes the measured average values were : ACH50= 5.7, Qtot=9.4% and Qout=4.7%. Although the sample sizes are small the FL. H.E.R.O. homes appear to have significantly more airtight duct systems than typical homes.

The remainder of the paper presents status of other tasks of the BAIHP project.

OTHER BAIHP TASKS

Moisture Problems in HUD code homes

The BAIHP team expends considerable effort working to solve moisture problems in existing manufactured homes in the hot, humid Southeast.

Some manufactured homes in Florida and the Gulfcoast have experienced soft walls, buckled floors, mold, water in light fixtures and related problems. According to the Manufactured Housing Research Alliance (MHRA), who we collaborate with, moisture problems are the highest priority research project for the industry.

The BAIHP team has conducted diagnostic tests (blower door, duct blaster, pressure mapping, moisture meter readings) on about 40 such problem homes from five manufacturers in the past two years and shared the results with MHRA. These homes were newly built (generally less than 3 years old) and in some cases just a few months old when the problems appeared. The most frequent causes were:

- Leaky supply ducts and/or inadequate return air pathways resulting in long term negative pressures.
- Inadequate moisture removal from oversized a/c systems and/or clogged condensate drain, and/or continuous running of the air handler fan.
- Presence of vinyl covered wallboard or flooring on which moist air condenses creating mold, buckling, soft walls etc.
- Low cooling thermostat set point (68-75F), below the ambient dew point.
- Tears in the belly board and/or poor site drainage and/or poor crawlspace ventilation creating high rates of moisture diffusion to the floor.

Note that these homes typically experience very high cooling bills as the homeowners try to compensate for the moisture problems by lowering the thermostat setpoints. These findings have been reported in a peer reviewed paper presented at the ASHRAE IAQ 2001. conference (Moyer et al)

The Good News:

As a result of our recommendations and hands-on training, BAIHP partner Palm Harbor Homes (PHH) has transformed duct design and construction practices in all of its 15 factories nationwide producing about 11,000 homes/yr. All Palm Harbor Home duct systems are now constructed with mastic to nearly eliminate air leakage and produced with return air pathways for a total cost of <$10/home!! The PHH factory in AL which had a high number of homes with moisture problems has not had a single problem home the past year!

Field Monitoring

Several houses and portable classrooms are being monitored and the data displayed on the web. (Visit http://www.infomonitors.com/). Of special interest is the side-by-side monitoring of two manufactured homes on the campus of the North Carolina A & T U. where the advanced home is saving about 70% in heating energy and nearly 40% in cooling energy, proving that the Building America goal can be met in manufactured housing. Other monitored sites include the Washington State U. Energy House in Olympia, WA; the Hoak residence in Orlando, FL; two portable classrooms in Marysville, WA; a classroom each in Boise, ID and Portland, OR. See other papers being presented at this symposium for details on two recently completed projects giving results from duct repairs in manufactured homes (Withers et al) and side by side monitoring of insulated concrete form and base case homes (Chasar et al).

"Cool" Roofs and Unvented Attics

Seven side-by-side Habitat homes in Ft. Myers, FL. were tested under unoccupied conditions to examine the effects of alternative roofing strategies. After normalizing the data to account for occupancy and minor differences in thermostat set points and equipment efficiencies, the sealed attic saved 9% and the white roofs saved about 20% cooling energy compared to the base case house with a dark shingle roof for the summer season in South Florida. Visit http://www.fsec.ucf.edu/%7Ebdac/pubs/coolroof/exsum.htm for more information.

Habitat for Humanity

Habitat for Humanity affiliates work in the local community to raise capital and recruit volunteers. The volunteers build affordable housing for and with buyers who can't qualify for conventional loans but do meet certain income guidelines. For some affiliates, reducing utility costs has become part of the affordability definition.

To help affiliates make decisions about what will be cost effective for their climate, BAIHP researchers have developed examples of Energy Star homes for more than a dozen different locations. These are available on the web at http://www.fsec.ucf.edu/bldg/baihp/casestud/hfh_estar/index.htm . The characteristics of the homes were developed in conjunction with Habitat for Humanity International (HFHI), as well as Executive Directors and Construction Managers from many affiliates. Work is continuing with HFHI to respond to affiliates requesting a home energy rating through an Energy and Environmental Practices Survey. 36 affiliates have been contacted and home energy ratings are being arranged using combinations of local raters, Building America staff, and HFHI staff.

HFHI has posted the examples of Energy Star Habitat homes on the internal web site PartnerNet which is available to affiliates nationwide.

"Green" Housing

A point based standard for constructing green homes in Florida has been developed and may be viewed at http://www.floridagreenbuildings.org/. The first community of 270 homes incorporating these principles is now under construction in Gainesville, FL. The first home constructed and certified according to these standards has won an NAHB energy award.

BAIHP researchers are participating as building science - sustainable products advisor to the HUD Hope VI project in Miami, redeveloping an inner city area with over 500 units of new affordable and energy efficient housing.

Healthy Housing

BAIHP researchers are participating in the development of national technical and program standards for healthy housing being developed by the American Lung Association.

A 50-year-old house in Orlando is being remodeled to include energy efficient and healthy features as a demonstration project.

EnergyGauge USA®

This FSEC developed software uses the hourly DOE 2.1E engine with FSEC enhancements and a user-friendly front end to accurately calculate home energy ratings and energy performance. This software is now available. Please visit http://energygauge.com/ for more information.

Industrial Engineering Applications

The UCF Industrial Engineering (UCFIE) team supported the development and ongoing research of the Quality Modular Building Task Force organized by the Hickory consortium, which includes thirteen of the nation's largest modular homebuilders. UCFIE led in research efforts involving factory design, quality systems and set & finish processes. UCFIE used research findings to assist in the analysis and design of two new modular housing factories – Excel homes, Liverpool, PA and Cardinal Homes - Wyliesburg, VA.

CONCLUSIONS

The entire BAIHP team of over 20 researchers and students are involved in a wide variety of activities to enhance the energy efficiency, indoor air quality and durability of new housing and portable classrooms.

In addition to energy efficiency, durability, health, comfort and safety BAIHP builders typically consider resource and water efficiency. For example, in Gainesville, FL BAIHP builders have incorporated the following features in developments:

- Better planned communities
- More attention given to preserving the natural environment
- Use of reclaimed sewage water for landscaping
- Use of native plants that require less water
- Storm water percolating basins to recharge the ground water
- Designated recreational areas
- Better designed and built infrastructure
- Energy efficient direct vented gas fireplaces (not smoke producing wood)

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