THREE CASE STUDIES: MOISTURE CONTROL IN A HOT, HUMID CLIMATE

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ABSTRACT

This paper will present case studies of the investigations of three different buildings exhibiting moisture control problems along the Gulf Coast. We will briefly discuss the original, or existing, conditions that led to our involvement, as well as analysis of the problems, and recommendations for correction. Each of these projects would be classified an air-conditioned building in a hot, humid climate, and subject to the problems and design issues concomitant with these types of projects.

The first case study was a historic residence in Houston that had experienced concealed condensation within the wood-framed floor system located over a crawl space. The floor framing had been insulated with an extruded polystyrene rigid board insulation, but with no vapor retarder.

The second case study was a new pre-manufactured residence located in the pine woods of Southeast Texas. The residence had been occupied for two summers when the occupants began to complain of adverse health effects. Indoor air quality testing revealed the presence of mold spores, which prompted the residents to vacate the premises to allow appropriate remediation. Our investigation occurred simultaneously with the remediation and allowed us to determine the sources of moist air infiltration that had resulted in the wall condensation and mold growth.

The final case study was a modern, four-story office building recently constructed in New Orleans, Louisiana. The cladding system consists of a clay brick veneer installed over a #30 felt weather-barrier, ½" exterior gypsum sheathing, metal studs with a glass fiber batt insulation, and interior gypsum board. The interior finishes consisted of heavy duty vinyl wall coverings that had been specified by the architect-of-record. After only two Summer seasons of occupancy, the building began to experience fairly widespread mold growth at specific floor levels. Based upon an extensive evaluation of the exterior building envelope, it was found that there were very limited anomalies pertaining to direct water leakage. Primarily, the mold growth was associated with inward water vapor diffusion and moist air infiltration during the summer months. In addition, it was found that the interior spaces of a large portion of this building were experiencing negative pressure with respect to the exterior conditions. Remediation of this building for indoor air quality purposes allowed confirmation of our initial assessment and appropriate remedial recommendations have been implemented.

HISTORIC RESIDENCE IN HOUSTON, TEXAS

Background

The subject of the first case study was a large residence in Houston, Texas that was constructed around 1910. During some minor remodeling, it was noted by the general contractor that plywood and floor joists occurring within the retrofit floor assembly of a previous addition to the original structure was wet and deteriorated in several locations. In addition, these construction assemblies exhibited water accumulation that could be wiped from the surfaces of wood framing members when the cavities were first opened.

Construction

This was a wood framed structure supported by a pier and beam foundation with a crawl space under the entire house, except at concrete slab-on-grade patios occurring on the North and East elevations of the residence. These patios had been cast-in-place against the original residence on two sides, effectively blocking crawl space ventilation along those elevations. The original floor was uninsulated and consisted of nominal 2" tongue and groove wood plank over wood joists. During various remodeling and renovation projects, the old house was retrofitted with a central air-conditioning system, significantly altering the vapor drive characteristics of the building envelope. In addition, one of the major remodeling efforts included a large addition to the house, which basically enclosed two sides of the crawl space. Finally, portions of the more recent floor assembly within the building addition included a plywood floor deck, with a layer of extruded expanded polystyrene (XEPS) insulation installed between the floor joists without a vapor retarder.

Investigation

Our firm had been called in to consult on this project by the general contractor responsible for the new renovation work. Observation by the contractor of moisture conditions at the plywood and floor framing members raised concerns regarding these anomalous conditions and appropriate steps were taken to determine the cause for this moisture accumulation. Our investigation at this project included visual observations of the various construction assemblies that were readily visible, as well as several locations that had been exposed by the interim construction work. The exposure of these areas eliminated the need for selective demolition to be performed as part of our investigation. Sketches were made of the actual construction at both the original construction of the house, as well as the previous addition. In addition, we performed an inspection of the conditions occurring in the crawl space under the residence. It was noted that ventilation potential of the crawl space had been significantly restricted by the additions located along the North and East perimeters. We also observed a general dampness occurring within the soil under the house, as well as a few locations of standing water.

Since the house was unoccupied at the time of our site visit, we had no information regarding the temperature and humidity conditions maintained within the home on a regular basis, nor was any information available pertaining to the pressurization characteristics of the building envelope. Utilizing several simplifying assumptions, we performed a thermal and vapor flow analysis of the typical floor assembly using the ASHRAE method. It was found that the existing floor assembly would exhibit condensation and moisture accumulation in the Average Summer design condition, a condition that exists for a considerable portion of the year at this project. Similar calculations with the floor assembly modified by installing a vapor retarder on the bottom side of joists did not exhibit similar problems for the extended period of time represented by the Average Summer. Although there was a slight problem with the modified floor in the Extreme Winter condition, it was decided that this should not be detrimental since the floor materials were hygroscopic and the Extreme Winter conditions occur for such a short period of time.

Conclusions & Recommendations

Our analysis indicated that the crawl space was a very moist environment with minimal (restricted) ventilation. In addition, no effective vapor retarder had been incorporated into the re-designed floor assembly, and these components were hygroscopically sensitive. The recommendations developed for this project centered on three interrelated components or systems of the structure. We considered it to be of foremost importance to re-establish the integrity of this building envelope by constructing a floor assembly that incorporated adequate insulation and utilized a vapor retarder located away from the living space (i.e., toward the ground). We recommended installation of an extruded or batt insulation between the floor joists with a vapor retarder across the bottom of the floor joists. We determined that the best method of installing the vapor retarder would be to use a foil-faced isocyanurate foam sheathing, or a proprietary laminated kraft paperboard sheathing with polyethylene facers, mechanically-fastened to the bottom of the floor joists, with the seams, joints, and perimeters taped and sealed.

We further recommended that drainage be improved under the house to fill low places and provide for positive drainage. Also, we recommended that an appropriate sheet membrane ground cover be loose-laid on the soil below the house to define the crawl space. Finally, we recommended that ventilation of the crawl space be re-established by either providing the required quantity of ventilation openings with proper distribution around the perimeter of the residence crawl space, or else by powered ventilation.

Results & Building Performance

This case study points out the need to fully consider all aspects of the building envelope moisture balance when planning or implementing retrofit systems or modifications. The previous additions and modifications to the original residence were functional and aesthetically pleasing, but did not take into consideration the special problems of an air conditioned building in a hot, humid climate. In addition, addition of the slab-on-grade foundations along the North and East perimeters had disrupted the original crawl space ventilation scheme without making alternative provisions for code stipulated ventilation rates. The vapor retarder installed on the bottom side of the floor joists provided appropriate resistance to the predominately inward vapor drive and eliminated the concealed condensation previously experienced at this project. These corrective measures were implemented during the summer of 1999 and, based on reports received to date, have been successful in remedying the problems previously exhibited.

PRE-MANUFACTURED HOME IN SOUTHEAST TEXAS

Background
This project was a small pre-manufactured home located in the pine woods of East Texas. See Figure 1.

Figure 1

It had been occupied for approximately two years in 1999, when during the second Summer, the owner observed mold growth on the surface of certain walls and ceilings. Several of these areas were adjacent to bathroom facilities, and initial steps of action included correction of any plumbing leaks or suspected problems with respect to direct water leakage in these “wet” areas of the residence. However, these initial measures were not successful in addressing the problems, which continued to manifest themselves during the cooling season of 2000. Younger members of the family reportedly began to experience respiratory and allergy problems, when indoor air quality testing was conducted to assist in determining the extent and severity of these problems. Ultimately, the family had to abandon the residence due to adverse health effects to their small children. A full remediation of the mold and mildew problems was implemented by the owner and their insurance company. Our assignment was to analyze the types of moisture problems exhibited and determine the cause for these anomalies.

Construction
Construction of this pre-manufactured residence consisted of typical materials with a steel framed base, typical platform wood framing, and exterior ribbed vinyl siding installed over 7/16" thick oriented strand board (OSB) with unknown weather barrier or underlayment. The walls were common 2 x 4 studs with R-11 fiberglass batt insulation, which had been provided with a kraft facer and friction fit between the studs (kraft facer toward the interior space). Interior finishes consisted of 3/8" thick gypsum board that had been prefinished using a heavy vinyl wall covering. The entire floor assembly had been provided with a reinforced plastic vapor retarder installed between the metal framing and wood framing of the floor system. Although this component of the home construction was predominately in tact, we observed several anomalies that would have violated it’s integrity and effectiveness. See figure 4. The roof system was comprised of three tab composite shingles installed over 7/16" thick OSB roof deck that was supported by pre-fabricated gang-nailed wooden trusses. The scissor-type trusses were insulated using blown-in cellulose insulation with no discernable vapor retarder. The ceiling consisted of 3/8" thick gypsum board with a textured paper facer. The truss space was also provided with roof vents to the exterior, which appeared to be two-way, open-throat, vents. This type of vent, however, would allow significant amounts of outside warm, moist air into the truss cavity, which also contained small, small air conditioning ducts for distribution of the HVAC supply air.

This residence had approximate dimensions of 28 feet by 70 feet (1,960 S.F.) and had been constructed in two halves that were transported to the site and fitted togther along a spline that ran the entire length of the home. No special provisions had been taken to exclude moist air infiltration along this joint spline. We also observed an un-shuttered, open vent through the exterior wall of the residence at the utility room that allowed significant, unhindered, air infiltration to the interior spaces. It is suspected that this vent was intended to provide fresh air make-up, which having entered the interior space, is drawn into the HVAC return air and distributed throughout the living space.

Investigation

Our investigation at this project consisted of thorough visual examination of the existing construction, as well as observation of typical construction assemblies at several locations where selective demolition was performed. We observed that there appeared to be a strong correlation between the occurrence of significant mold growth in certain wall, floor, and ceiling cavities and the presence of unsealed openings that allowed significant and unhindered moist air infiltration. See Figure 2.

Figure 2

These unsealed cavities consisted of deliberate openings at plumbing penetrations, as well as inadvertent openings occurring within the cladding between siding installations and trim pieces. See Figure 3.

Figure 3

It was noted that many of these inadvertent openings were caused by inadequate design and careless or poor workmanship. These anomalies appeared to be widespread and prevalent throughout the cladding of this pre-manufactured residence. The correlation between un-sealed openings and the presence of mold growth was so strong that wall stud spaces immediately adjacent to those with the unsealed openings often exhibited no bio-organic contamination at all.

We observed that the interior vinyl wall covering, most likely utilized in an attempt to reduce maintenance, represents a low permeance wall covering on the "wrong" side of the wall. In addition, the heavy sheet vinyl floor covering also represents a low permeance floor material. Based on information provided, each of these conditions were most likely exacerbated by excessively low interior temperatures within the living space during the summer cooling season. In the Kitchen and Breakfast Room, we observed that the manifestation of moisture accumulation and mold within the floor system occurred primarily along the joint lines of the OSB floor deck, where vapor drive would find the least resistance.

Figure 4

Other locations observed to be exhibiting suspected moisture accumulation and mold growth were along the ceiling in several different areas. One location in the ceiling corner of the Master Bathroom was believed to be associated with openings in the vinyl siding and related trim occurring within the exterior cladding due to poor workmanship. Selective demolition in another location in the ceiling of Bedroom No. 2 was found to be immediately below the location of an air conditioning flexible duct. This same situation was also observed in the Living Room ceiling, where selective demolition revealed that the minimally insulated flexible duct was wedged into a joint of the wood roof truss immediately adjacent to, and in contact with, a perforated metal gang-nail plate. Since the roof truss space has vents that allow direct infiltration of outside warm, moist air, it is suspected that the immediate contact of the duct with the metal gang-nail plate has "super-cooled" the gang-nail plate to a temperature below the exterior dewpoint, causing continual condensation, moisture accumulation, and potential mold growth. See Figure 5.

Figure 5

We also conducted a thermal and vapor flow analysis of the typical floor and wall assemblies using the ASHRAE method. Our analysis indicated that the wall assembly would be subject to concealed condensation and moisture accumulation during the Average Summer condition for the construction provided with the vinyl wall covering on the interior. In our opinion, the reason the "normal" exterior wall did not typically exhibit this problem on a more widespread basis is that the conditions were not quite right for a full-blown out break of condensation and mold growth. On the other hand, at those locations where the plumbing penetrations have allowed excessive moist air leakage, the conditions were "enhanced" to the extent that profuse condensation and mold growth would occur. In addition, the vinyl floor would exhibit condensation and moisture accumulation during the Average Summer condition whenever the floor vapor retarder had been violated or circumvented. As previously described above, the manifestation of moisture problems along the ceiling in several locations is related to super-cooled metal gang-nail plates that have an inexhaustible supply of outside warm moist air that may condense and accumulate moisture within the ceiling gypsum board.

Conclusions & Recommendations

Our analysis indicated that integrity of the building envelope had apparently not been carefully maintained during design and construction of the pre-manufactured home, and that, after problems had been reported, attempts by the manufacturer's service representatives to investigate and correct the problems may have actually exacerbated these problems. Accordingly, excessive infiltration of exterior moist air into wall cavities occurring between air conditioned spaces was common. In addition, interior finishes included gypsum wall board that incorporated a vinyl wall covering that would exhibit a relatively high vapor resistance.

Figure 6

Results & Building Performance

At the time of this writing, renovation of the building envelope has not been completed to the extent that it's performance during a cooling season could be appropriately monitored. Our firm may be retained during renovation to assist in developing proper remedial measures and, hopefully, at that time we will be able to evaluate the building performance subsequent to these efforts.

MODERN OFFICE BUILDING IN LOUISIANA

Background

The third project was a four-story office building recently completed on the lake front shore near New Orleans, Louisiana. See Figure 6. We were retained by the general contractor to assist in determining the cause for mold and mildew growth, as well as to diagnose the cause for several specific chronic leak locations. See Figure 7. Our investigation included a review of the original construction documents, visual inspections, selective demolition, field leak testing, and a thermal and vapor flow analysis of the typical wall assembly. See Figure 7.

Figure 7

Construction

Construction at this project consisted of typical steel framing with an exterior cladding composed of cold-formed metal framing, exterior gypsum sheathing, air space, and nominal 4" brick veneer. The exterior cladding had been designed and constructed with no supplemental weather barrier over the gypsum, the exterior sheathing joints were not taped or sealed, and significant openings existed around the punched windows and associated framing. In addition, the architect-of-record was from a Northern climate and specified a heavy-duty vinyl wall covering as the interior finish. Actual construction complied with the original design fairly well, except the general contractor had provided a #15 coated building paper over the exterior gypsum sheathing as a supplementary weather barrier. The contractor also provided some flexible membrane flashings at the window jambs that were not called for on the construction documents.

Investigation

Our firm conducted a comprehensive investigation of this project over a protracted period of time, which included visual examinations, selective demolition of the exterior brick veneer at specific locations, selective demolition of the interior gypsum board, field leak testing of the aluminum and glass windows, as well as long term soaking tests of the brick masonry. In addition, we conducted a thermal and vapor flow analysis of the typical wall section using the ASHRAE method, assuming common thermal resistance values and typical permeance values for each wall cladding component. We also performed a thorough review of the original construction documents pertaining to typical details and assembly materials. Based on our investigation and analysis, we were able to ascertain that the windows were not allowing direct water leakage into the wall cavity. However, due to a lack of detailing and specific instructions in the original construction documents, there were no particular assemblies or air barriers stipulated within the documents or actually constructed in the field. In addition, we determined that the majority of the concealed condensation and associated mold growth was occurring due to excessive moist air infiltration through numerous unsealed openings within the exterior building envelope. Since no provisions for air barriers or vapor retarders located at the outside plane of the wall were stipulated or required within the documents, the general contractor and subcontractors provided typical masonry walls with appropriate protection from direct water leakage, but nothing to alleviate moist air migration. Accordingly, the combination of air diffusion and air leakage caused condensation where the vinyl wall covering had been utilized as an interior finish. It was noted that there was no mold growth observed above the suspended ceiling, since there was no vinyl wall covering used at those locations. There were unsealed openings that allowed excessive air infiltration around the window perimeters, at enlarged openings occurring at the roof parapet coping, as well as through cracks in the masonry and gaps within the cladding sealants. These problems were confirmed by the results of our thermal and vapor flow analysis.

Additional monitoring determined that the HVAC control systems and energy management system were not controlling the interior temperature or humidity as would be desired nor as had been designed by the mechanical engineer. This was particularly true during periods of off-design operation and set-back temperatures. In fact, recording thermo-hygrometers indicated that the interior temperature could regularly drop to between 56°F and 65°F during the night-time set-back, and the corresponding interior humidity would be between 40% and 45% relative humidity. Each of these conditions would significantly lower the interior vapor pressure, causing greater inward vapor drive.

Finally, we used appropriate pressure taps through the building envelope at window perimeters to determine that the building interior was being maintained at a negative pressure with respect to the outside conditions. Based on information provided, it was further determined that the building tenant had added a large exhaust fan that had not been accounted for within the original balance and adjustment of the HVAC system. This addition, as well as other tampering with the dampers controlling outside air, contributed to the negative pressure conditions within this building. These conditions would combine to significantly increase the pressure difference between the interior and exterior, with the exterior being relatively higher virtually all of the time. Other problems included direct water leakage at a flashing located above the garage that allowed water infiltration when weather systems originated from the North. In addition, a portion of the first floor of this building was composed of split-face concrete masonry units (CMU) that had been subject to chronic water infiltration during periods of inclement weather.

Figure 8

Conclusions & Recommendations

Our investigation revealed the obvious problems associated with use of a highly vapor resistant interior wall covering for an air-conditioned building located in a hot humid climate, as well as several flashing anomalies, and the fact that HVAC design, operations and controls may have adversely affected overall performance of the building envelope. We found that there were a number of paths allowing significant moist air infiltration during the cooling season, and that the interior spaces may have been negatively pressurized with respect to the exterior. In addition, the automatic temperature cont-rols and sensors may have been allowing interior temperatures to get down to 55°F for extended periods of time during periods of low occupancy.

Results & Building Performance

A number of different recommendations were implemented in order to correct each of these issues. We recommended removal of the vinyl wall covering and replacement using acrylic paint or high permeance (low vapor resistence) wall coverings. In addition, we recommended balancing and adjusting the supply air and exhaust air comprising the HVAC system, as well as establishment and implementation of an effective and proficient control system for the interior temperature and humidity. We further recommended that the HVAC supply air registers be moved further away from the exterior walls so that impingement of cold air is minimized at these surfaces. As a final adjustment, we recommended that the gaps and cracks within the brick masonry be sealed and that consideration be given in the future to applying a clear masonry sealer to the exposed brick surfaces. Other recommendations implemented at this project included comprehensive renovation of the garage flashing that had been previously leaking, as well as application of an elastomeric coating at the split-faced CMU.

Key Words: condensation, mold growth, pre-manufactured home, vapor retarder, moisture migration, air infiltration, flashing, indoor air quality, brick veneer, vinyl wall covering, moist air, mold remediation, negative pressurization

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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
	= = =
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)

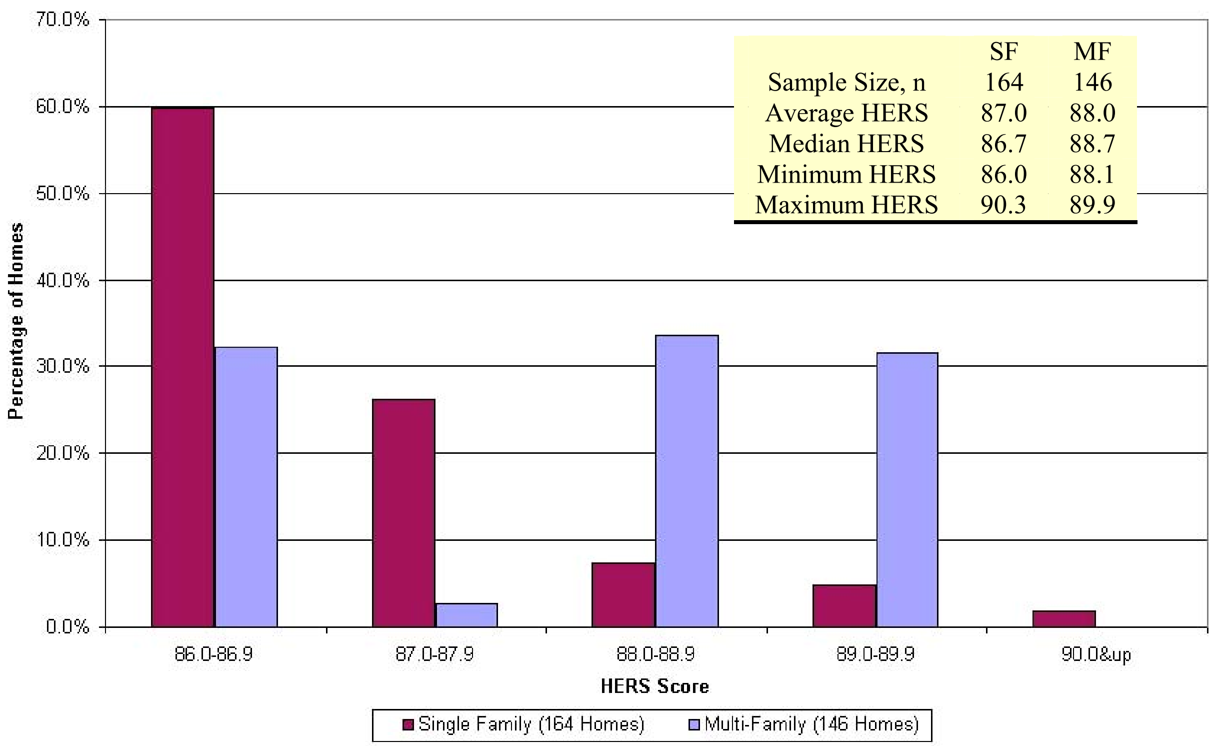

Figure 5 HERS Scores for FL H.E.R.O. Homes

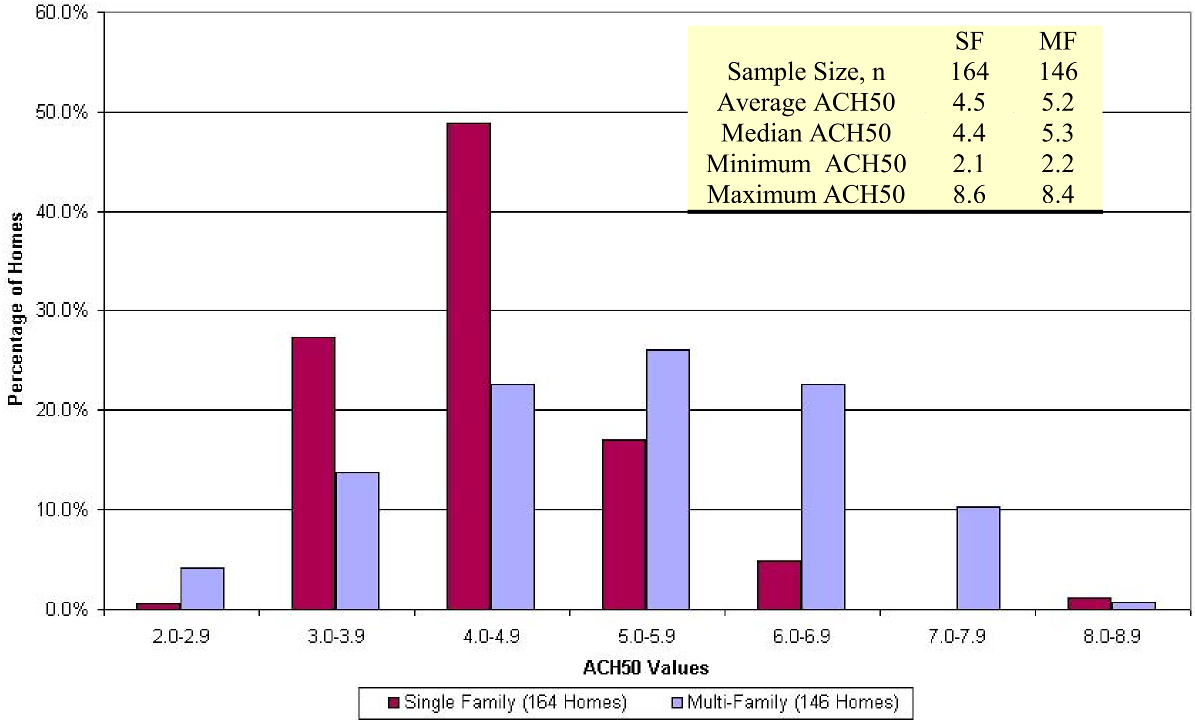

Figure 6 ACH50 Values for FL H.E.R.O. Homes

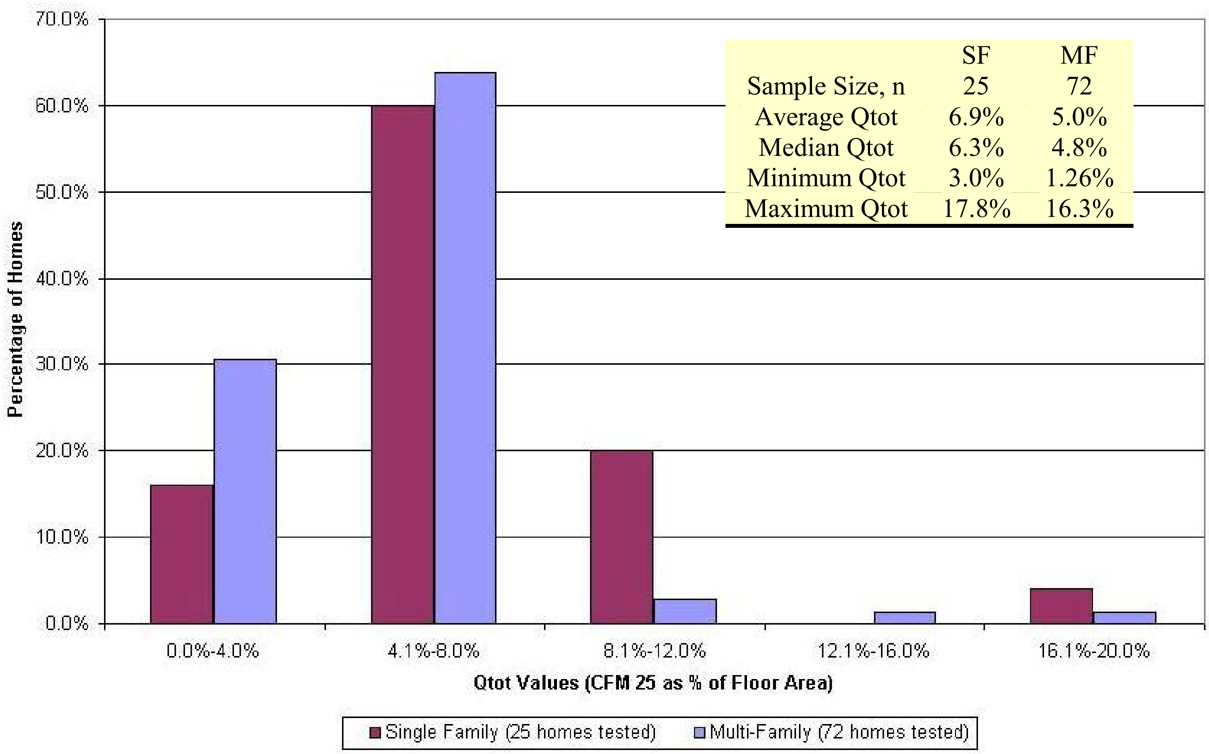

Figure 7 Qtot Values for FL H.E.R.O. Homes

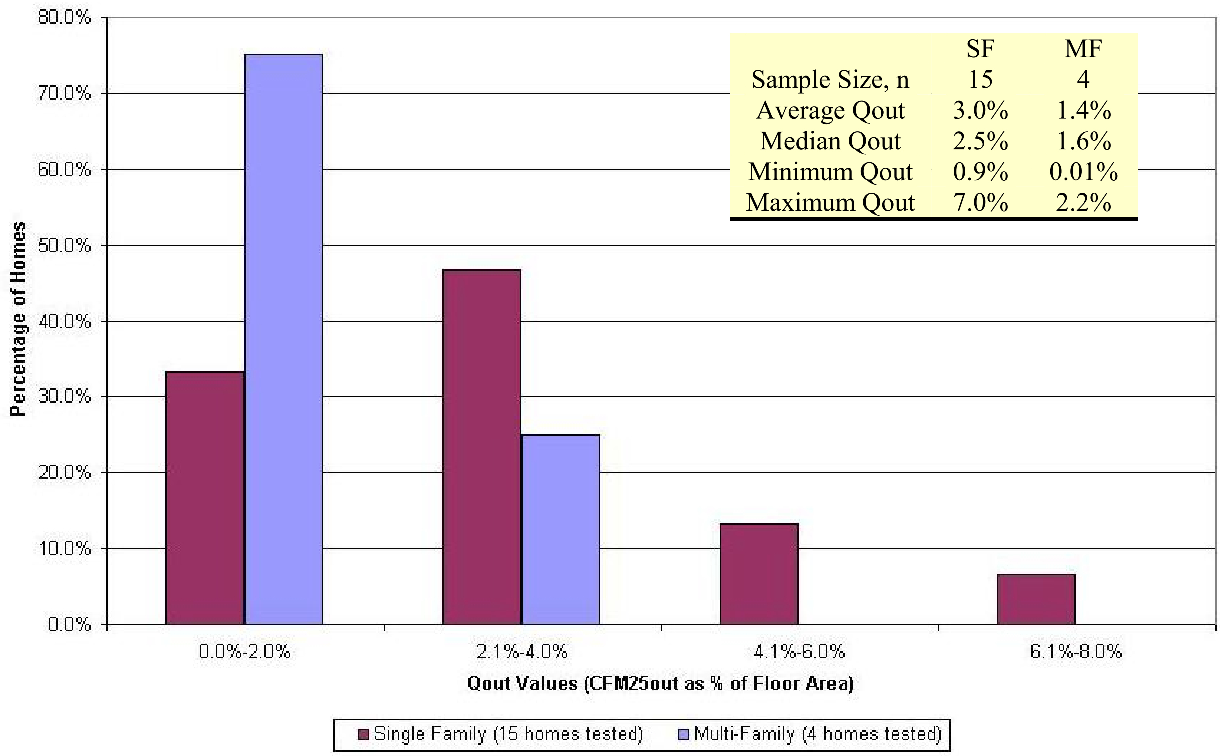

Figure 8 Qout Values for FL H.E.R.O. Homes

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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