Sensitivity of low sloped roofs designs to initial water and air leakage

Achilles Karagiozis, Ph.D
Senior Research Engineer,
Oak Ridge National Laboratory
1 Bethel Valley Rd,
Oak Ridge TN, 37831-6070

Mikael Salonvaara, M.Sc.
Research Scientist
VTT,
Espoo, Finland

Andre Desjarlais. B.Sc.E
Program Manager,
Oak Ridge National Laboratory
1 Bethel Valley Rd,
Oak Ridge TN, 37831-6070

ABSTRACT

Liquid water in low sloped roofs almost always causes problems. Roofs are designed only to control the migration of vapor, if at all. Small amounts of water leakage/penetration, may cause mold growth or catastrophic corrosion in current roofs systems. In a recent paper by the authors the effect of exterior surface emissive and absorptive properties was found to have a significant effect on the moisture performance of a roof that had a leak. Depending on the surface characteristics, roof systems can be designed to effectively manage water penetration, but at an energy cost. In the roofs system examined previously, air leakage was not included.

In the present study, the authors re-investigated the effect of water penetration and the influence of air leakage on the hygrothermal performance of a few selected roofs. The drying potential of a groove ventilated roof is examined. The performance concept is based on the fact that warming up of air in the groove increases it's ability to transport moisture to the outside. Solar radiation raises the temperature of air in the grooves and on average, during a sunny summer day 0.5 L of water can be ventilated out of the roof per 1m width of the roof.

In this paper, one climatic condition was investigated; a hot and humid Climate representative of Houston, TX. The specific questions that the paper addresses are: What are the vapor and liquid control dynamic involved in the moisture migration of a roof in Houston TX? and how does airflow influence the performance of a roof that is initially wet ?

A state-of-the-art numerical model was used to address these issues. Results showed that the drying potential depends on the ventilation rates. The roof system with ventilation grooves dried out faster from the initially wet stage than the roof without the ventilation grooves. The total increase in heat loss of the roof was found to be between 0 - 5 % depending on the thickness of the insulation. The ventilation can cool down the temperature of the roof in the middle of a hot and sunny day thus reducing the heat load to the inside.

1 INTRODUCTION

In the past some of the low-sloped roofs in cold climates employing a waterproof membrane directly attached to the insulation were ventilated with either mechanical or passive roof vents or turbines. The intention of these devices was to provide a negative pressure (suction) in the insulation, thereby allowing drying of a wet roof through these vents. In the passive set-up, the drying process was however quite slow due to uneven distribution of the limited air flow and took years to dry a wet roof system. The so called grooved ventilation flat roof system appeared in the market in the early 1980's, and got adopted by many Northern European countries. A range of grooved systems has appeared since that period, with different grooved shapes and insulation systems. The main purpose of these grooves has been to improve the ventilation by providing a direct passage for air flow through the grooves, thus improving moisture drying potential. This improved ventilation augmented the moisture mass transfer by forced convection and lead to drier roof systems. In a recent field survey, low-sloped roofs did not have a sufficient drying potential through breather vents. To improve the hygrothermal performance of low-sloped roofs, new methods for ventilating the roof structure were introduced in the 1980's. One such approach employed small ventilation grooves in the insulation layer as shown in Figure 1. The ventilation grooves were connected to breather vents by connecting channels.

A typical low-sloped roof has an insulation layer sandwiched between the vapor barrier and roofing membrane. A load-bearing roof structure is usually used in commercial applications and has either a concrete or corrugated steel deck. The insulation layer and roofing membrane is fastened with mechanical fasteners. These roofs are typically equipped with breather vents to even out the pressure difference between the insulation layer and effect due to the action of the wind. The hygrothermal roof design philosophy (double vapor retarder moisture control approach) has been challenged through the work carried out at ORNL by Desjarlais [1995], and Desjarlais and Byars[1998]. Work on several different roofing systems has demonstrated the importance of self-drying roofs as a valid alternative to existing face sealed systems. In these systems, vapor controlling elements employed closed to the inside of the roof systems are removed and the roofs are designed to handle the incidental moisture accumulation or moisture intrusion. This concept has been demonstrated to be a very efficient way to handle a roof that has become wet.

Salonvaara and Nieminen [2002], re-investigated the influence of placing ventilated grooved roof systems in cold climates. The authors found that drying performance of low sloped roofs can be significantly improved by using grooved ventilation openings. Grooves in the insulation layer ensured an even distribution of air flow over the whole roof area. Their laboratory tests and simulations showed that the effect of ventilation on the heat loss is insignificant and less than 5% depending on the insulation thickness and ventilation rate. They also recommended that the spacing between the grooves should be less than 0.5 m. A spacing of 0.2 m was found to perform well and to produce evenly distributed drying. Airflow rates of approximately 0.1 m^3/m^2h were found to adequate allow for drying of initial moisture contents in roofs during first summer.

Field survey studies before 1990 showed that there were moisture problems in about 30% of investigated low-sloped roofs. The high number of problem roofs comes partly from the fact that roofs chosen to be field test sites were considered to have a moisture risk, based on existing information on the roofs. The main causes for these roofing problems were improper structural details such as poor quality of jointing of lead-in installations or membrane up-lifts. Another cause of failure has been the initial built-in moisture by using wet materials or the incidental rain during installation of the insulation. In the 1980's rubberized bitumen roofing became general practice as roofing material. The physical condition of roofing system was improved compared to polymer bitumen roofing. The quality of roofing detail structures was improved at the same time, and these are detailed by NRCA [1996].

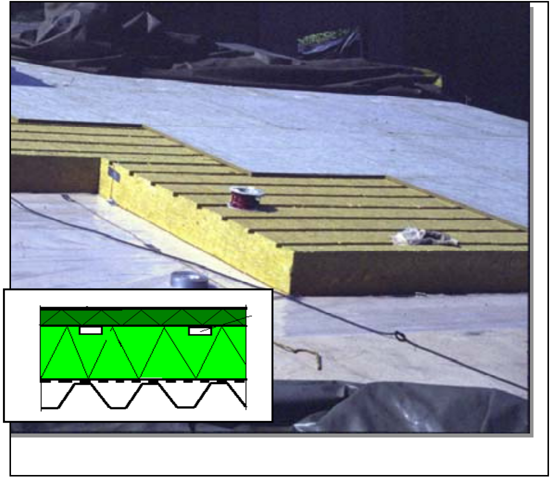
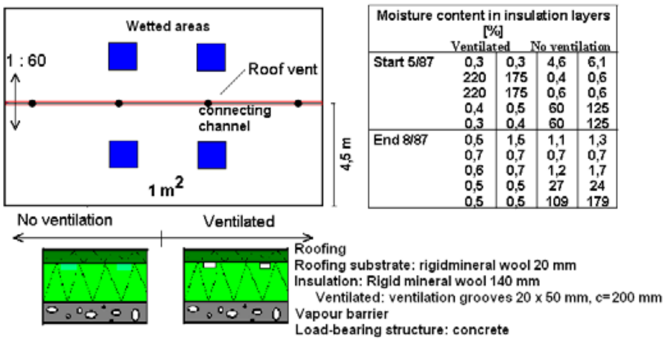


Figure 1. Low-sloped roof cross section. Ventilated insulation layer.

2 PREVIOUS FIELD AND EXPERIMENTAL WORK

Salonvaara and Nieminen [2002], field-tested the performance of an ventilated insulation system for 6 roofs in Finland (area varying from 200 m^2 up to 5 000 m^2). A laboratory hot box apparatus (Kouhia and Nieminen, 1999) was also used to further quantify the performance of the grooved roof ventilation system and to show the thermal consequences of ventilation. The authors measured moisture contents, temperatures and ventilation rates from the test roofs.

Results showed that a wetted low-slope roof can dry out in a sufficient time. Figures 2 and 3 show that ventilation rates varied between 0.005 and 0.1 m^3/h per m^2 depending on the ventilation details, size of the ventilated area and location of the roof and building



Moisture content in insulation layers [%]	Ventilated		No ventilation	
Start 5/87	0,3	0,3	4,6	6,1
	220	175	0,4	0,6
	220	175	0,6	0,6
	0,4	0,5	60	125
	0,3	0,4	60	125
End 8/87	0,5	1,5	1,1	1,3
	0,7	0,7	0,7	0,7
	0,6	0,7	1,2	1,7
	0,5	0,5	27	24
	0,5	0,5	109	179

Figure 2. An example of a drying test at VTT's test house. Wet insulation was installed into the roof, and drying of the roof was monitored by samples. Altogether 40 samples were taken from the wetted areas and other parts of the roof at the end of the test. The tables shows the measure moisture contents in May and August in the ventilated and non-ventilated areas of the roof.

Figure 3. Wetting of a test roof of about 1000 m^2. Initial moisture content in this test case was 20% of dry weight through the whole insulation layer. The roof dried out during one summer.

2.1 Thermal performance

In the previous work, laboratory and field measurements showed that low ventilation rate do not significantly affect the thermal performance of the roof. It was found that as the insulation layer increased the effect of ventilation on the thermal losses becomes less important. Field measurements showed that the measured average increase in heat flow was close to 3 % compared to the non-ventilated part of the roof for an insulation thickness of 180mm.

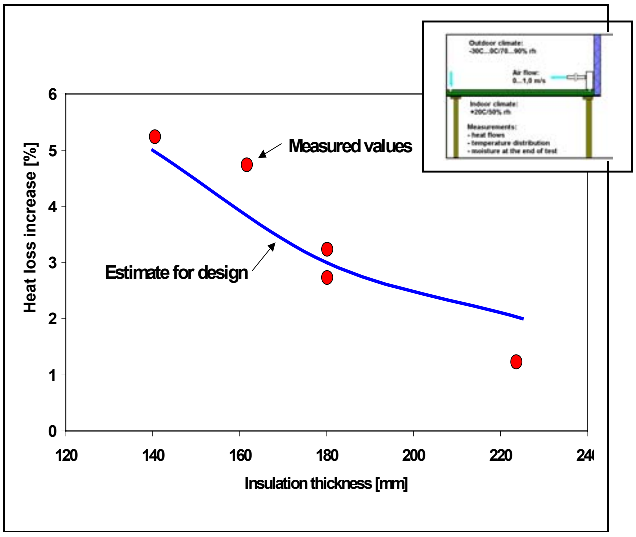


Figure 4. The effect of ventilation on the heat loss of a low-sloped roof according to insulation thickness. The measured values are 24 hour averages of a winter day.

3 DESCRIPTION OF CURRENT RESEARCH

From the work described in the previous section, it becomes clear that adding ventilation grooves in the insulation, provides an alternative mode of drying for a roof system. To allow drying to occur, good air tightness must be maintained at the interior side of the roof. These roof systems are specific in that they are required either by the designer application or local codes authority to install a vapor retarder on the interior side of the roof.

Roofs are an integral and important part of a building envelope. Both energy efficiency and durability must be addressed during the design stage. This requires investigating the performance of the roof under ideal (perfect) and real conditions. It is expected that all roofs at some point in time will allow some water penetration. If the roof design has no capability to handle even small quantities of moisture ingress, then the roof design is very limited. The work performed so far has investigated the performance of ventilating roofs in cold climates, such as found in Northern USA, Canada and Finland. The direct extrapolation to other climates is not obvious. There is very little information on the performance of such roofs in mild and hot and humid climates.

In this paper the authors have numerically investigated the performance of a similar set of roof systems in a hot and humid climates climate. The drying performance of the roofs subjected to hourly exterior climatic loads were investigated for a period of approximately one year.

4 NUMERICAL PERFORMANCE ANALYSIS

An insulated roof section with ventilated grooves was examined by using a three-dimensional heat, air and moisture transfer calculation model, the newly upgraded VTT hygrothermal model (ASTM MNL 40, Salonvaara and Karagiozis [1994], Salonvaara [2000]). A 2-D cross section of the simulated roof is shown in Figure 9. A 10 m long and 0.5 m wide section with 1 ventilation groove on top of the insulation was calculated with 0, 0.023 and 0.046 m/s ventilation air flow rate. These flow rates are equal to the ventilation rates 0, 0.02 and 0.04 m^3/roof-m^2h, respectively, when the distance between the grooves is 0.5 m. The initial moisture content in the bottom of the roof insulation corresponded to 5 kg/m^2 excess moisture per roof area. The insulation thickness was 100 kg/m^3 with the assumed air permeability of $30 \cdot 10^{-6}$ m^3/m,s,Pa. The simulation period was approximately one year starting in October

1. The climatic conditions for Houston, TX were used in the analysis.

4.1 Drying of a roof section through ventilated grooves

The loss of moisture in the roof section as a function of time and ventilation rate was calculated for the 3-dimensional wall section with the 3D-model for a period approximately a full year. Thirty years of hourly weather data from the National Climatic Data Center (NCDC) were analyzed and a moisture year was chosen for the simulations. A 2-D cross section of the simulated roof segment is shown in figure 5.

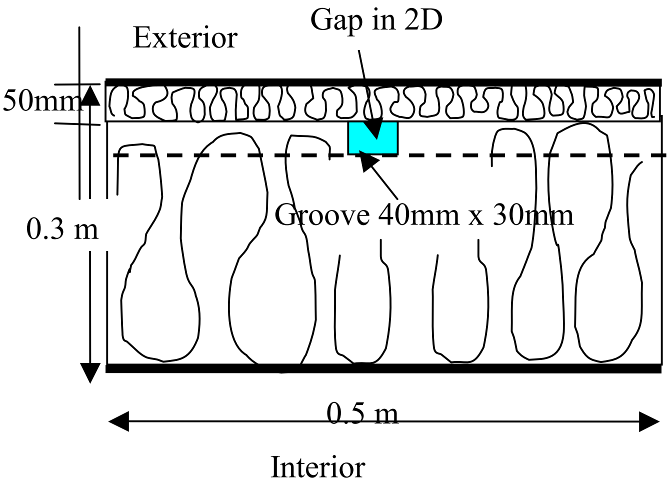


Figure 5. A schematic figure of the simulated roof section. The length of the simulated roof section was 10 m.

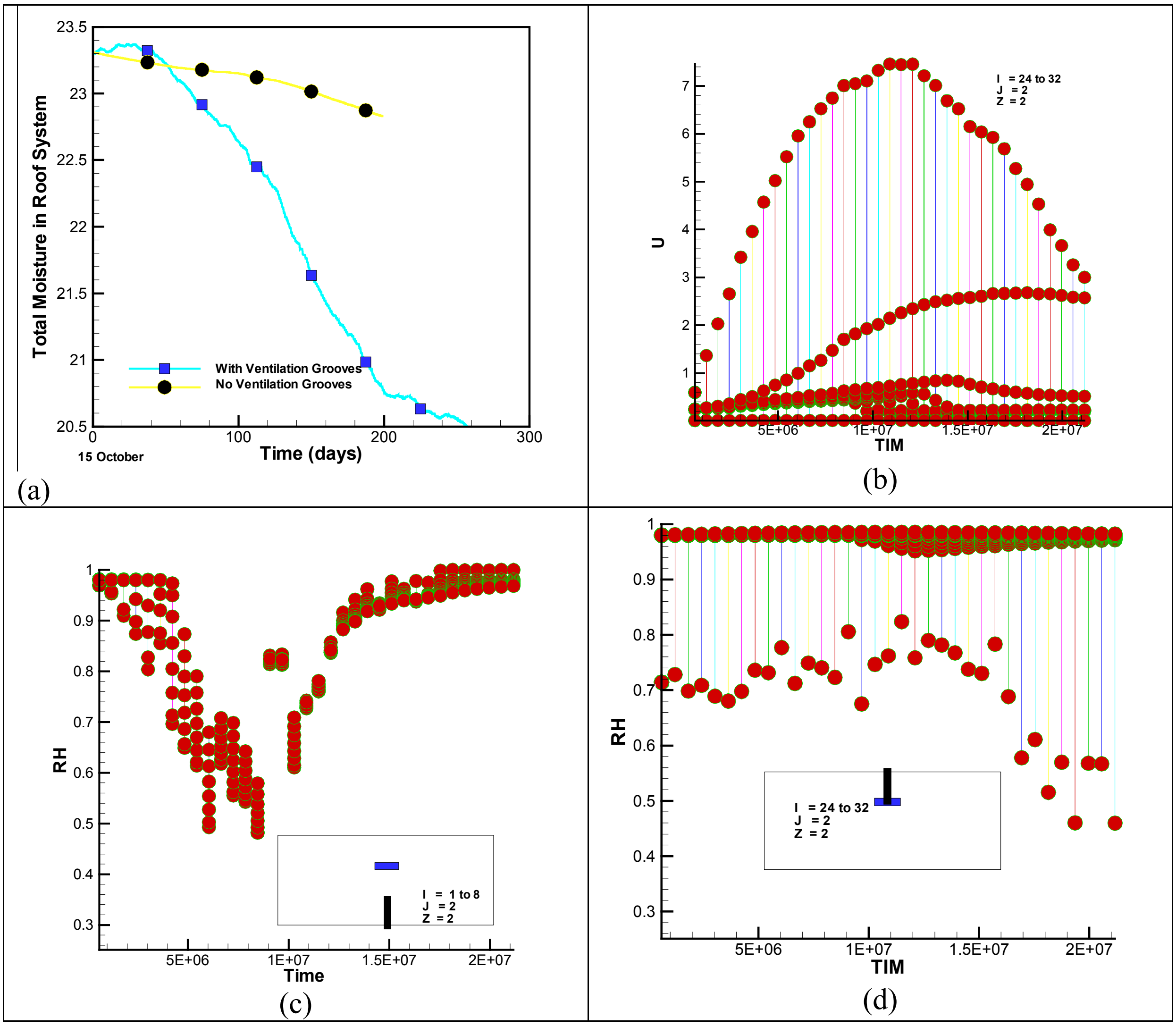
4.2 Drying out of initial moisture. Drying rate of the roof section depends on the airflow rate, increase in temperature on the exterior side of the roof due to solar radiation and also on the air permeability of the insulation layer. The development of the total moisture content as a function of time is shown in Figure 6a for the simulated period. Two cases are plotted out in Figure 6a corresponding to a roof system with and without ventilation grooves. Both systems had a vapor retarder installed at the interior surface of the roof. The roof with the ventilation grooves exhibits a significant difference in drying performance.With the exception of the first two weeks, a continuous drying performance is exhibited by the ventilated roof system. The initial hump is explained by the seasonal moisture ingress during an initially humid period. In the case without the ventilation grooves, water is migrating out of the roof system, however at a very slow pace. The drying out potential is very limited in the non-ventilated case as moisture is trapped between the two vapor retarders. In figure 6b the moisture content is plotted out for the ventilated system at a spanning mid-center through the ventilation groove and the exterior surface of the roof. The transient behavior of the elements close to the exterior surface of the roof shows the yearly cycle effects (cold and summer conditions). In Figure 6c and 6d the temporal and spatial distribution is shown during the 10th week since October 1. Here the relative humidity distribution shows the strong 2-D effects close to the exterior and interior side of roof. The roof seems to have higher moisture accumulations near the exterior and is drying out close to the interior for this instant in time (00:00, midnight). In Figure 7 the 3-D snapshot in time is depicted for the ventilated and non-ventilated roof assembly. The influence of ventilation is depicted in Figure 7a to 7c, while 7d has no ventilation. Results show that there are localized gradients in moisture distributions in the insulation layers, these gradients are more substantial at the inlet of the grooves. Depending on the wind-speed and orientation of the building and wind the flow direction can occur at either opening. However, the ventilated grooved case increased the drying out potential of the roof system compared to the non-ventilated roof system. During a warm day when the sun warms up the roof (afternoon) the airflow through the roof insulation dries out moisture. The ventilation air reaches it maximum moisture content already within the first two meters of flow path through the ventilation groove. When the airflow rate doubles (V2) the air gets saturated after approximately 3 m from the eaves. During the night the ventilation air can in slightly humidify the roof when the outdoor air is more humid than the dry insulation inside the roof after a warm day. The spacing between the grooves affects the drying rate and the moisture distribution around the grooves. The spacing of 0.5 m allows the groove ventilation to dry out approximately half of the moisture that the gap ventilation dries out (Figure 7a). The relative humidity distribution after 3 days of drying shows the uneven pattern of drying due to the oversized spacing of grooves. When the groove spacing is reduced to 0.2 m, the difference between gap and groove ventilation becomes insignificant. Ventilation can also increase the moisture contents in the dry insulation layer after summer drying during cold seasons .However, this wetting occurs only yp to the humidity level of the exterior air.

4.3 Thermal performance. The heat flows for a few days through the interior surface of the roof are plotted for the non-ventilated case and the ventilated grooved cases in Figure 8. The ventilation through the grooves increases the heat loss through the roof only slightly. Drying the roof and the insulation - on the other hand - decreases the heat loss by improving the thermal effective thermal conductivity of the insulation layer. For the first 4770 hours since October 1, ventilation seems to lower the heat load of the roof slightly more than what it increases the heat loss. This is due to cooling of the roof by ventilation

5 SUMMARY AND CONCLUSIONS

Building envelope designer have many design options for good moisture performance of roof systems. A designer may use or omit a vapor retarder on the interior surface of a roof system. If one chooses to include a vapor retarder, the roof must include some features to allow moisture to dry out from the assembly. This moisture may be due to initial construction moisture or an unintentional water penetration occasion.

This preliminary study has found that the drying potential of low-sloped roofs can be significantly improved by using groove ventilation. Grooves in the insulation layer ensure the even distribution of airflow over the whole roof area. According to laboratory tests and simulations the effect of ventilation on the heat loss is insignificant and less than 5% depending on the insulation thickness and ventilation rate. Airflow rate approximately 0.1 m^3/m^2h has been found to allow for drying of typical initial moisture contents in roofs during one summer.



(a) (b) (c) (d)

Figure 6. (a) Total moisture content as a function of time (Figure 6a) for 3-dimensional case with and without ventilation.
(b) The moisture content in the insulation layers along the length of the ventilation groove at 10 weeks (Dec. 15)
(c) The relative humidity distribution after 10 weeks (Dec. 15).
(d) The relative humidity after 10 weeks of drying at another cross section (Dec 15)

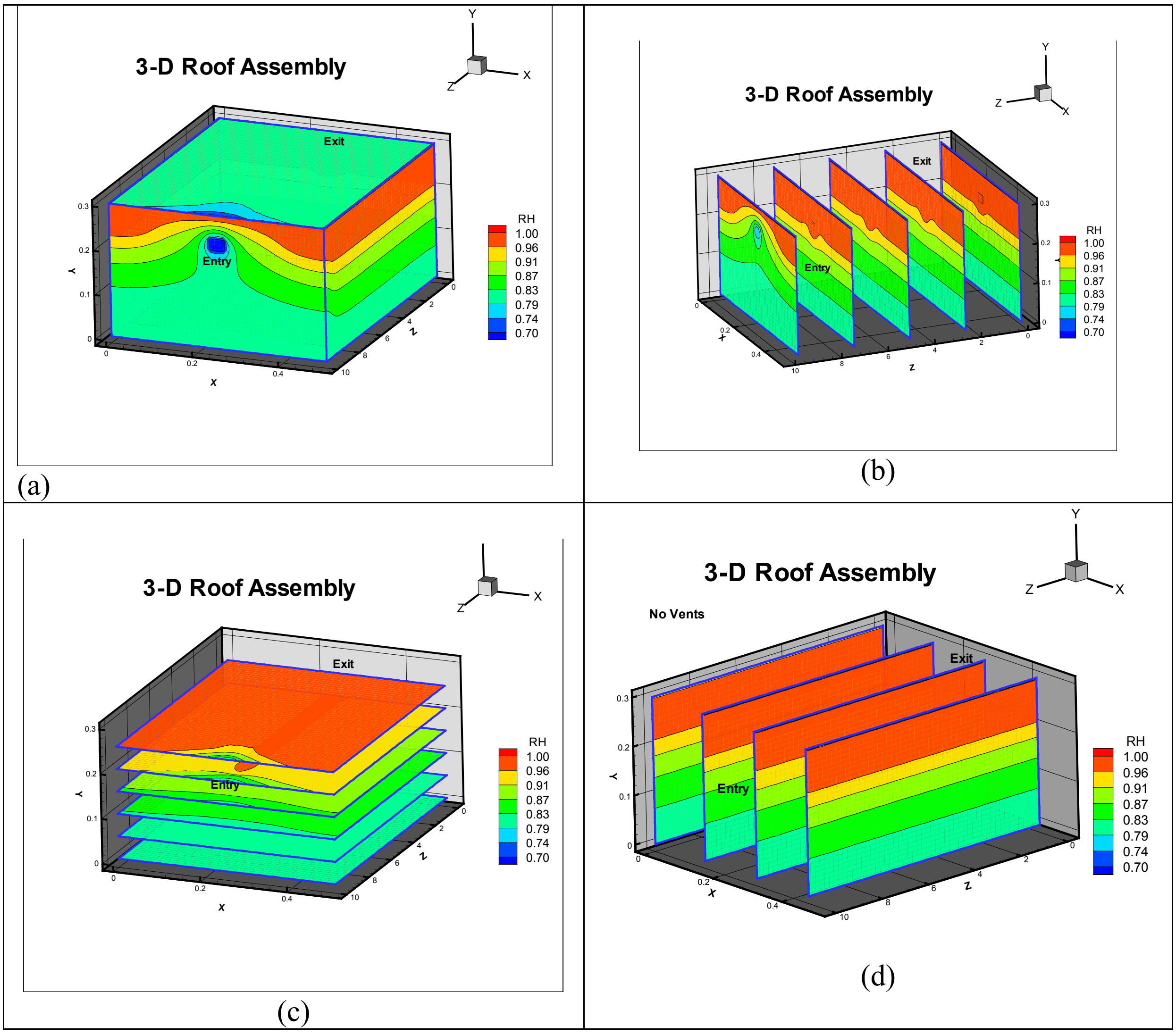


Figure 7. (a) 3-D face RH distribution (Dec. 15).
(b) RH distribution in the ventilated roof system (Dec. 15) Direction of airflow is from left to right.
(c) RH distribution in the ventilated roof system (Dec. 15) Direction of airflow is from left to right.
(d) RH distribution in the non-ventilated roof system (Dec. 15) No airflow).

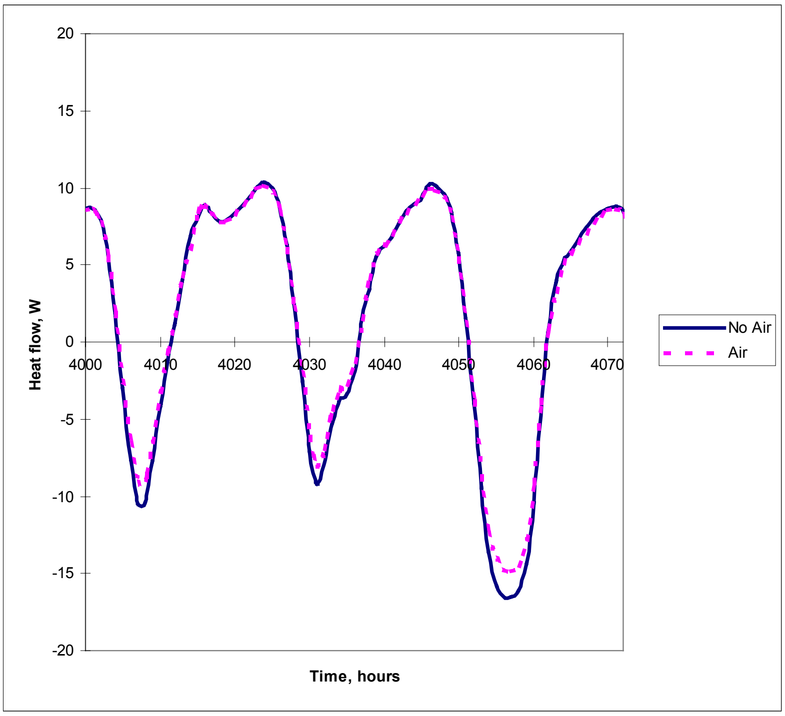


Figure 8. Heat flow through the ventilated and non-ventilated roof for a few days. Negative flow is toward the interior (heat load)

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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

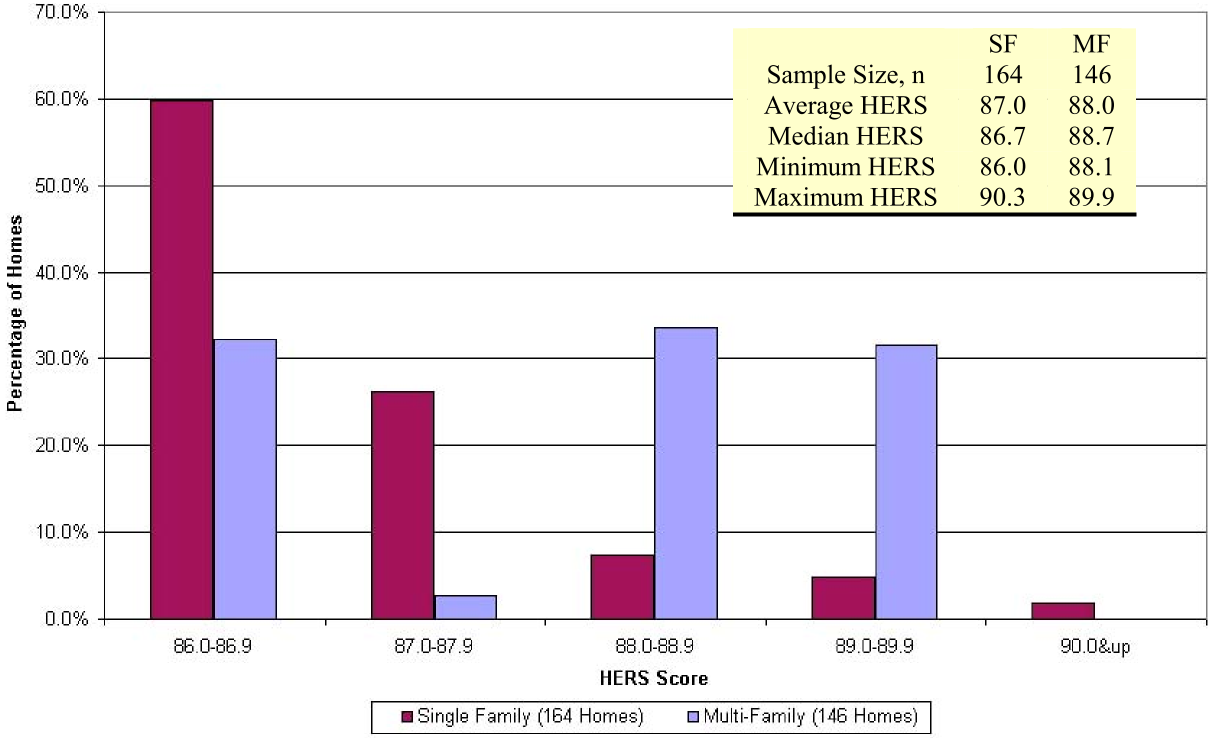
Figure 4 Butterfly Damper for OA control

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.

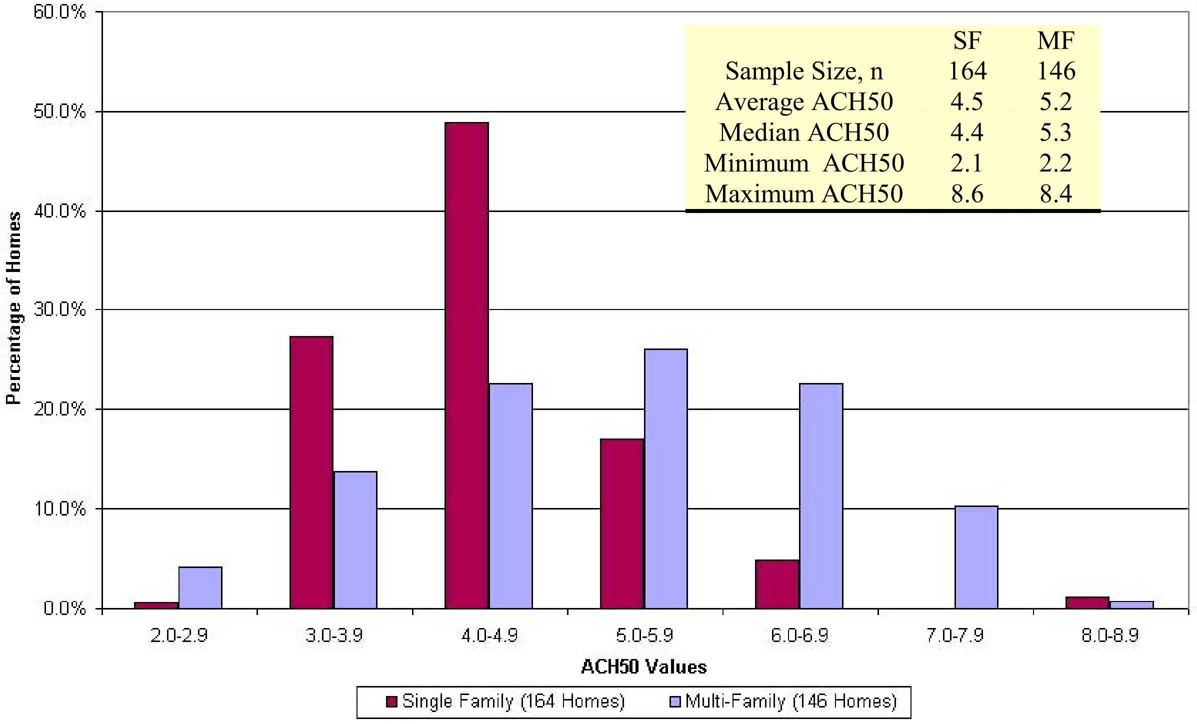
Table 2. Summary statistics on FL.H.E.R.O. Homes
n = sample size

	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)



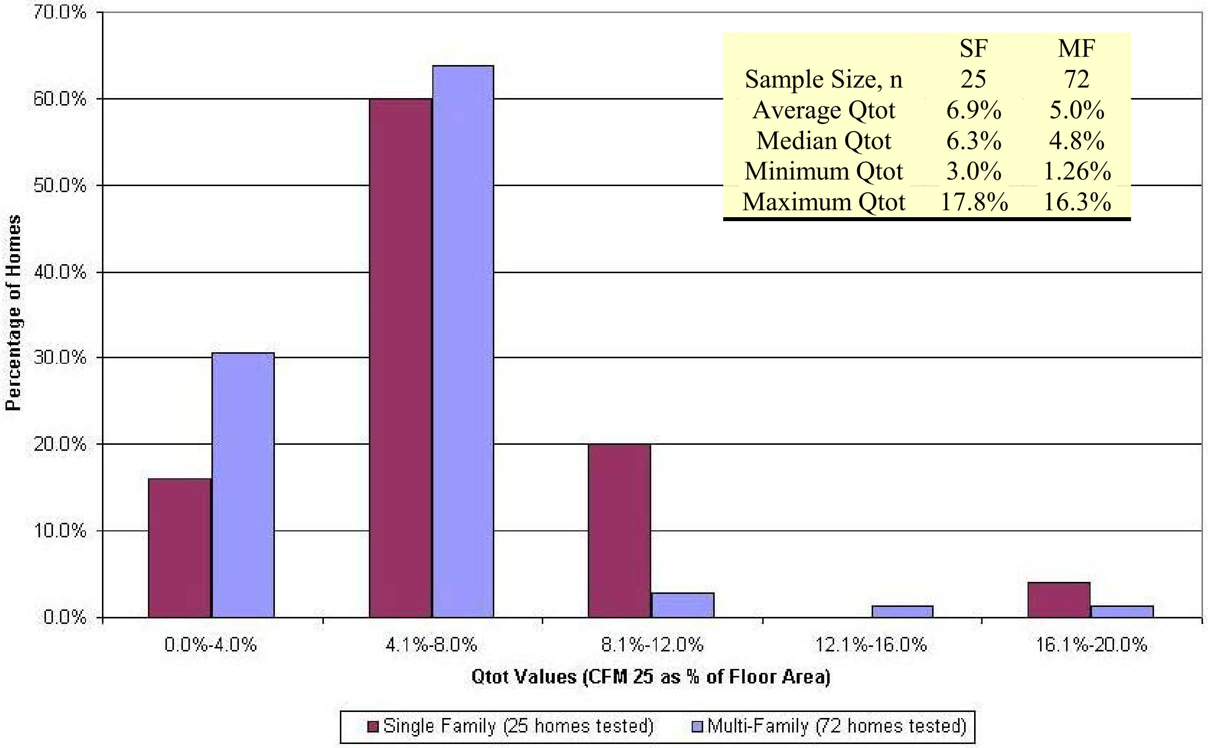
	SF	MF
Sample Size, n	164	146
Average HERS	87.0	88.0
Median HERS	86.7	88.7
Minimum HERS	86.0	88.1
Maximum HERS	90.3	89.9

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



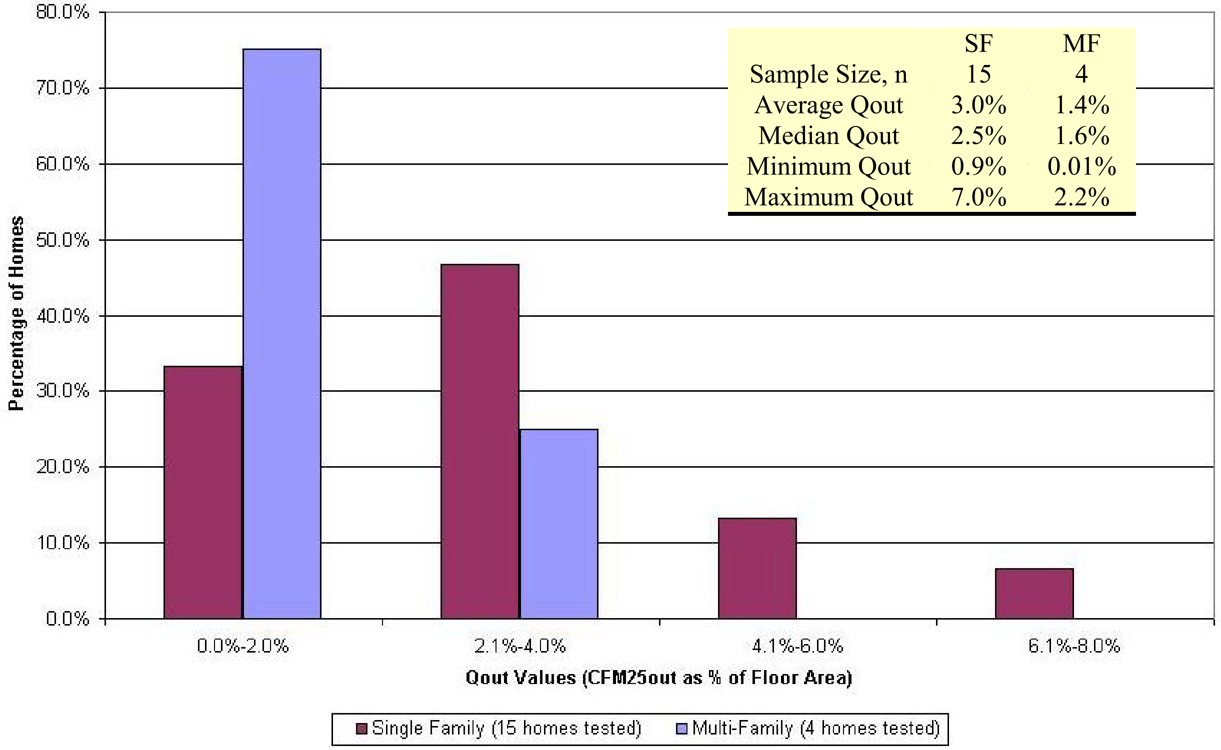
	SF	MF
Sample Size, n	164	146
Average ACH50	4.5	5.2
Median ACH50	4.4	5.3
Minimum ACH50	2.1	2.2
Maximum ACH50	8.6	8.4

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



	SF	MF
Sample Size, n	25	72
Average Qtot	6.9%	5.0%
Median Qtot	6.3%	4.8%
Minimum Qtot	3.0%	1.26%
Maximum Qtot	17.8%	16.3%

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



	SF	MF
Sample Size, n	15	4
Average Qout	3.0%	1.4%
Median Qout	2.5%	1.6%
Minimum Qout	0.9%	0.01%
Maximum Qout	7.0%	2.2%

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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