

Making Steel Framing as Thermally Efficient as Wood

Most Current Developments from ORNL

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Abstract

In many world regions like North America and Scandinavia wood framing is dominant technology for residential buildings. During last two decades several companies around the world started to promote a low-gage steel framing for residential and commercial buildings. Steel framing has many advantages over wood framing; strength, low weight, dimensional stability, resistance to termite damage, almost 100% recycleability, etc .. However because of several reasons an application of steel as a framing material in US residential building market is relatively low. Steel industry has noticed much more success on commercial building market which is not as rigorous regarding thermal efficiency and energy conservation.

Steel framing has one significant disadvantage over wood; Steel members conduct heat extremely well. This effect is known as thermal bridging, and it can sharply reduce a wall's effective R-value. The simplest and most common way to overcome this problem is to block the path of heat flow with rigid foam insulation. Adding rigid foam insulation not only increases the whole wall's R-value, but it also reduces the temperature difference between the center of the cavity and the stud area, which cuts down on the possibility of

black stains forming from dirt getting asymmetrically attracted to cold spots on a wall's surface. However, rigid foam insulation is an expensive solution.

Several material configurations were developed in the past to increase thermal effectiveness of steel-framed structures. This paper is focused on most common options of thermal improvements of steel framed walls. They were as follow:

- diminishing the contact area between the studs and exterior sheathing materials,
- reducing the steel stud web area,
- replacing the steel web with a less conductive material, and
- placing foam insulation in locations where the thermal shorts are most critical.

Researchers at Oak Ridge National Laboratory (ORNL) have utilized both hot box testing and computer simulations in aim to optimize thermal design of steel stud walls.. While examining several material options, ORNL's BTC was also striving to develop energy-efficient steel stud wall technologies that would enable steel-stud walls to beat the performance of traditional 2 x 6 wood stud walls. Several, most current, ORNL developments in steel framing are presented below.

Introduction

Steady-state thermal design calculations are most common practice in residential building energy design today. Steady state R-value or U-value are normally used as a measure of thermal performance of building envelope. The whole building energy consumption is rather rarely utilized for the evaluation of the wall systems. One of the reasons is that for an average North American residential building, energy consumption related with wood-framed walls typically do not exceed 25% of the total building energy consumption. The only problem associated with such assumption is that some changes in building envelope material configurations may generate substantial changes in the whole building energy performance. Also, very often, the improvements in building thermal envelope are indicated by increased R-value, however it is not common to verify these improvements by detailed whole building energy consumption analysis.

The main objective of this paper is to document the most common thermal improvements in several steel-framed wall technologies. The improvement results are analyzed based either on the R-value comparisons or on whole building energy consumption reduction.

During last two decades several material configurations were investigated to increase thermal effectiveness of steel framed structures. These options have included diminishing the contact area between the studs and the sheathing, reducing the steel stud web area, replacing the steel web with a less conductive material, and placing foam

insulation in locations where the thermal shorts are most critical.

In an effort to find more cost-effective solutions, researchers at Oak Ridge National Laboratory (ORNL) have utilized both hot box testing and computer simulations. While examining several material options, ORNL's BTC was also striving to develop energy-efficient steel stud wall technologies that would enable steel-stud walls to beat the performance of traditional 2 x 6 wood stud walls. They achieved their goal. In time period between 1994 and 2001 several novel steel stud technologies were developed at ORNL. Some of them represent a new way of designing a shape of steel framing members, when other developments are based on reconfiguration of the existing building materials. Series of hot box tests performed in ORNL confirmed theoretical predictions for some of these building envelope systems. For more complex technologies, ORNL is looking for industrial partners who would help in commercialization of their novel steel framing designs.

Insulating Sheathing - Effective, But Not Cheap Way of Increasing Wall R-value

It is widely known that installing exterior insulating sheathing is one of the simplest ways to improve a thermal performance of wall systems. Thermal efficiency of the usage of insulating sheathing was previously analyzed by several authors [Barbour et al -1994, Kosny -1995-A, Strzepek -1980, Trethoven -1988]. It can also improve building airtightness. Foam sheathing can be located on either the exterior or interior wall surfaces. It is important to

remember that in case of wood or steel framed walls insulating sheathing is changing mean temperature for the cavity insulation. That is why, different nominal thermal conductivities of the cavity insulation has to be assumed for different sheathing locations and for walls without sheathing. Framing effect is a very convenient measure of the sheathing thermal efficiency. It represents the R -value reduction generated by the framing members (in case of framed wall technologies - studs and tracks) [Kosny 1995-B].

In conventional wood stud walls (aluminum siding, 1/2-in. insulation sheathing ($R = 1.32$), 3 1/2-in. wood stud, R-11 batts, 1/2-in. gypsum board) upgrade of the wall using 1-in. EPS sheathing brings about 3.5 hft²F/Btu increase in R -value. Assuming that for wood-framed houses the whole wall R -value is about 8% lower than the clear wall R -value [Christian, Kosny 1995], 1-in. of EPS sheathing gives in average 7.3% of savings in the whole building energy consumption [Kosny 2001].

The most known application for the insulating sheathing is in case of steel stud walls. Several steel stud configurations were examined by authors [Kosny et al 1997]. From the technological point of view 2-in. (5.1-cm) of exterior foam sheathing is the thickest practical sheathing option used by builders in North America. For this thickness Framing Effect value f is close (13%). The f -values increase with a decrease in the thickness of the insulating sheathing. For a 3-5/8" (9.2-cm.) stud wall with 1/2" (1.3-cm.) thick layer of EPS sheathing, f is about 25%. For a 3-5/8" (9.2-cm.) stud wall with 1" (2.5-cm.) thick layer of EPS sheathing, f

is about 22%. For a 3-5/8" (9.2-cm.) stud wall with 1/2" (1.3-cm.) thick layer of plywood sheathing f value is 38%. For 6" (15.2-cm.) stud walls, f values are 12-15% higher than the comparable 3-5/8" (9.2-cm.) stud walls.

The R -value for steel stud wall containing 3-5/8" (9.2-cm.) studs, with 24-in. o.c. (61-cm.) is about 7.9 hft²F/Btu (1.4 m²K/W). The R -value for the same wall with installed 1-in. (2.5-cm) of EPS sheathing is 13.9 hft²F/Btu (2.45 m²K/W). Assuming that for steel-framed houses the whole wall R -value is about 25% lower than the clear wall R -value, 1-in. of EPS sheathing gives in average 6.7 % of savings in the whole building energy consumption [Kosny 2001].

Also, additional EPS sheathing reduces the temperature difference between the center of cavity and the stud area. The reduction in the temperature difference between the metal stud and the center-of-cavity diminishes the possibility of "ghosting" - an aesthetic problem caused by the attraction of the dirt to cold areas of the wall surface. In this light, using of insulating sheathing can be recommended as an efficacious way of the improving the thermal performance of steel stud walls.

Four ways of reducing the contact area between stud flange and the sheathing

A contact area between the stud flange and the sheathing material can be simply reduced by the change of the shape of the stud flange. Four most popular ways of reducing the contact area between studs and the sheathing are discussed below. Designers of steel-framed walls utilize ridges in stud flange area,

dimples, wood and metal spacers, and foam tape on the face of stud flanges .

Sometimes, these modifications are realized in the stage of the production of metal studs another time they are made at the building side during the construction. Reductions of the stud flange contact areas are made by the outward extrusion of the small protuberances (dimples) or ridges in the stud flange surfaces. Sheathing material in such walls is not supported exactly by the stud flange, but by the surface of these protuberances on the flange area. Also, distant spacers can be used to reduce the thermal bridge effect in metal stud walls [Barbour et al-1994, Kosny - 1997, Kosny 1998]. The authors assumed that, the effectiveness of the usage of furring strips in metal stud walls could be higher if they are made of the less conductive materials (like wood or plastic).

Vertical ridges reduced contact area between studs and the sheathing material by about 95%. In Table 1, the 6-in. stud wall, 1/2-in. ridges yield a 16% increase in R-value if compare with conventional 6-in. stud wall. In the case of 3 1/2-in. stud wall with 1/4-in. ridges, an increase of about 9% is noted. The thermal effectiveness of the 1/2-in. and 1/4-in. ridges are similar.[Kosny 2001]

An additional two walls were simulated to examine the thermal effect of the

usage of studs with the extruded dimples (0.1 -in.) on the flange surfaces [Kosny et al- 1997]. Extruded dimples reduced contact area between studs and the sheathing material by 89%. Traditionally constructed 3-1/2 in. steel stud wall was simulated to enable comparisons. All walls, used 3.5-in. studs with 16-in. o.c. The wall cavity was insulated with R-11 batts. Simulation results are presented in the Table 2.

The thermal effect of the application of spacers was examined on four walls. The thermal breaks were created by installing horizontal steel or wooden furring strips. They separated the steel stud from the exterior sheathing, and created air cavity. Thermal effectiveness of spacers is analyzed in Table 3. It can be observed that for all walls with distance spacers, the increase in wall R-value is close to the R-value of the additional air space.

In addition to the wall constructed with 1/2 in. plywood, 3-5/8 in. studs, R-11 insulating batts, and 1/2-in. gypsum board, a 3/4-in. wide and 5/16-in. thick silicone foam was attached to the exterior surfaces of stud flanges. For this wall, an increase of R-value caused by silicone foam is 0.5 hft²F/Btu, and Framing Effect = 34.3% [Christian, Kosny 1996]. As show in Table 3 for a similar wall configuration, installing wooden distance spacers decreased Framing Effect to about 28%.

Table 1.

Thermal performance of the wall containing studs with vertical distance ridges.

Wall construction	Test R-value [hft²F/Btu]	Simul. R-value [hft²F/Btu]	Improve- ment [hft²F/Btu]	Improve- ment [%]	Framing Effect [%]
6-in. studs, 20 g.a., 24 in. o.c.	9.58	9.50			50.2
As 6-in. stud wall, stud with two 1/4-in. distance ridges.	10.44	10.46	0.96	10.1	45.1
As 6-in. stud wall, stud with two 1/2-in. distance ridges.	11.12	10.63	1.13	11.9	44.3
3 1/2-in. studs, 20 g.a., 24 in. o.c.	—	7.17			38.0
As 3 1/2-in. stud wall, with two 1/4-in. distance ridges.	—	7.81	0.64	8.9	32.5
As 3 1/2-in. studs wall, stud with two 1/4-in. distance ridges.	—	7.89	0.72	10.6	31.8

Table 2.

Thermal performance of the wall containing studs with extruded distance dimples.

Wall construction	Simul. R-value [hft²F/Btu]	Improve- ment [hft²F/Btu]	Improve- ment [%]	Framing Effect [%]
Plywood, traditional 3 1/2 -in. studs, 16-in. o.c. R-11, gypsum board.	8.07			39
Plywood, traditional 3 1/2 -in. studs 16-in. o.c. with distance dimples, R-11, gypsum board.	8.77	0.7	8.7	33

Steel Stud Web - A Key to Thermal Efficiency.

A very intensive heat transfer through steel stud web is causing a lot of problems in steel-framed constructions. There are two ways of improving of

thermal performance of such construction

a reduction of the stud web area

and

- replacement of the steel web by less conductive material.

Table 3.

Thermal performance of the wall containing distance spacers.

Wall construction	Test R-value [hft ² F/Btu]	Improvement [hft ² F/Btu]	Improvement [%]	Framing effect [%]
½ in. plywood, 3-5/8 in. studs, R-11, ½-in. gypsum board.	7.9			38.2
½ in. plywood, 7/8-in. metal furring, 3-5/8 in. studs, R-11, ½-in. gypsum board.	9.3	1.4	17.7	27.2
½ in. plywood, 6- in. studs, R-19, ½-in. gypsum board.	10.1			47.1
½ in. plywood, 7/8-in. metal furring, 6- in. studs, R-19, 7/8-in. metal furring, ½-in. gypsum board.	12.4	2.3	22.8	35.0
½ in. gypsum board, 3-5/8 in. studs, R-11, ½-in. gypsum board.	7.8			36.3
½ in. gypsum board, 1x2-in. wood spacers, 3-5/8 in. studs, R-11, ½-in. gypsum board.	8.8	1.0	12.8	28.1
½ in. gypsum board, 6-in. studs, R-19, ½-in. gypsum board.	9.6			49.8
½ in. gypsum board, 1x2-in. wood spacers, 6-in. studs, R-19, ½-in. gypsum board.	10.4	0.8	8.3	45.7

The thermal effect of the reduction of the stud web area caused by stud holes in the stud web is analyzed below. As shown on Figure 1, four wall configurations are used during modeling: The first one is traditional design with full stud web. The second one (shape A) is also traditional stud but with punched 1.5x4 holes with 24-in. o.c..

The next two (shapes B and C) represent so called expanded channel design. The amount of the reduction of the section area of the center of the stud web was as follows for considered shapes of studs:

- shape A - 16%,
- shape B, and C - 87.5%

Stud web area was reduced by 11% in shape A stud walls, 63% in shape B stud walls, and 39% in shape C stud walls. The efficiency of similar studs was previously tested by J.R.Sasaki [1971]. Sasaki reported 50% reduction of thermal bridge effect compared with regular metal studs walls. Results of the analysis of the effectiveness of the usage of the punched studs are displayed in Table 4.

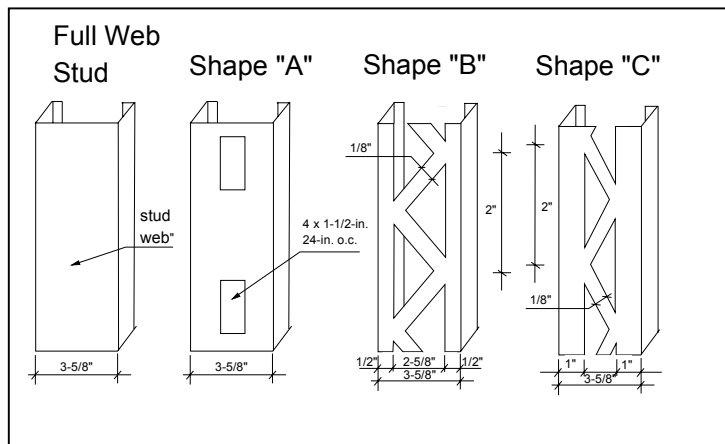


Figure 1. Steel studs with reduced stud web area.

Table 4.

Thermal performance of the wall containing studs with reduced width area.

Wall construction	Simul. R-value [hft²F/Btu]	Improve-Ment [hft²F/Btu]	Improve-ment [%]	Framing Effect [%]
Gypsum board, traditional 3 5/8 -in. studs, R-11, gypsum board.	7.28			41
Gypsum board, shape A 3 5/8 -in. studs, R-11, gypsum board.	7.43	0.15	2.1	39
Gypsum board, shape B 3 5/8 -in. studs, R-11, gypsum board.	9.89	2.61	35.9	19
Gypsum board, shape C 3 5/8 -in. studs, R-11, gypsum board.	9.38	2.1	28.8	23

It is clearly seen that walls with reduced stud web are much more thermally efficient from the walls with traditional studs. Lowest values of Framing Effect were noted for walls containing shape B and C studs. Assuming that walls containing studs B and C have similar thermal performance, stud C seems to be more efficient because it is stronger (stud's web area was reduced about 50% less than in case of wall containing shape B studs). The simulation results for the expanded channel studs, are similar to that reported by J.R. Sasaki [1971]. In walls containing this type of stud, the thermal bridge effect was reduced by about 50%.

Very optimistic prognoses for the application of the punched studs can be driven from the results of the above study. However, the lower structural integrity of such studs has to be taken in

to account. More theoretical and experimental research is necessary in this area.

In Scandinavia, a new design of stud web is proposed for steel studs. As shown on Figure 2, the web area is divided by several courses of slots. They significantly reduce effective heat conduction area on the stud web. Currently, a series of hot box tests on steel stud walls containing slotted studs have been ordered by NAHB in ORNL BTC. The preliminary test results for two walls are presented in Table 5. The first wall is conventional 2x4 steel stud wall with R-13 batt insulation. In the second wall conventional studs and tracks were replaced by slotted structural members.

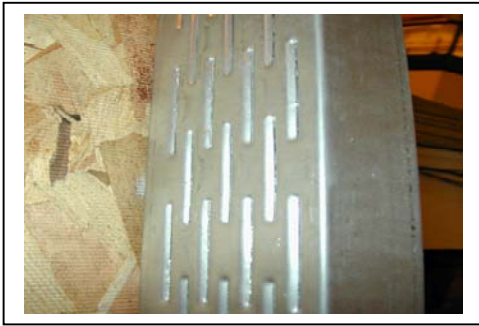


Figure 2. Steel stud with the slotted stud web.

Another way of minimizing of steel stud web heat transfer is replacement of the steel web by less conductive material. It can be plywood or OSB. A novel stud design developed by the Florida Solar Energy Center (FSEC) is analyzed

below. As shown on Figure 3, FSEC combined wood/metal studs consist of two metal flanges and connecting web made of OSB or plywood. The FSEC wall cavity can be insulated by R-11 or R-13 fiberglass batts. For tests, the exterior surface of the wall was finished with ½-in. thick layer of gypsum board to simulate EIFS (exterior insulated finish system). The interior surface of the wall was finished with ½-in. thick layer of gypsum board. Several FSEC stud walls were tested and simulated by the author [Kosny et al -1998]. Conventional steel stud wall was used in this analysis for comparison. Some results of the effectiveness analysis of usage of FSEC steel/wood studs are presented in Table 6.

Table 5.
Thermal performance of the wall containing slotted studs.

Wall construction	Tested R-value [hft ² F/Btu]	Improvement [hft ² F/Btu]	Improvement [%]	Framing Effect [%]
OSB, traditional 3 1/2 -in. studs, R-13 batts, gypsum board.	8.1			42
OSB, slotted 3 1/2 -in. studs, R-13 batts, gypsum board.	10.1	2.0	25	27

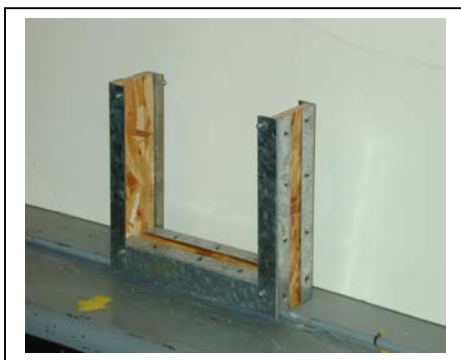


Figure 3. FSEC steel/ wood stud.

Table 6.
Thermal performance of the wall containing FSEC studs.

Wall construction	Simul. R-value [hft ² F/Btu]	Improve-ment [hft ² F/Btu]	Improve-ment [%]	Framing Effect [%]
Gypsum board, traditional 3 5/8 -in. studs, R-11, gypsum board.	7.5			37
Gypsum board, FSEC 3 5/8 -in. studs, R-11, gypsum board.	10.4	2.9	39	12.9

Local Stud Insulation System – ORNL Stud Snuggler.

A usage of insulating foam profiles covering steel studs can be considered as another way of the reduction of the contact area between studs and the sheathing. Additionally, such insulation reduces transverse heat transfer which takes place through stud flanges. This kind of heat transfer increases heat losses in metal framed structures. It was measured and reported by H. Trethoven [1987]. Developed by the author covering foam shapes add highly efficient thermal insulation only in locations where it is strongly needed (steel stud areas). At the same time, the wall cavity is insulated by traditional fiberglass batts. This reduces thermal bridge effects on relatively low cost. Steel stud wall containing 1-in. thick

foam shapes covering studs, was designed and tested by the authors [Kosny -1997]. This stud insulation is pictured on Figure 4. Results of the experimental analysis of this wall are displayed in Table 7.

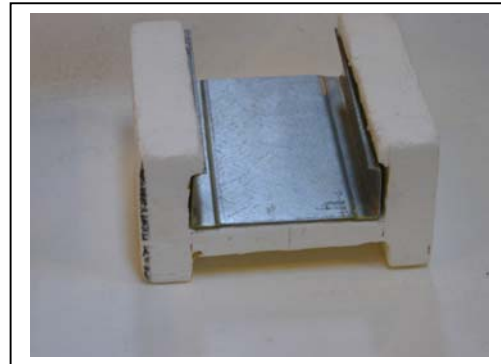


Figure 4. ORNL Stud Snuggler - steel stud covered by 1-in. thick foam profile.

Table 7.

Thermal performance of walls containing 1-in. thick foam shapes covering steel studs.

Wall construction	Tested. R-value [hft²F/Btu]	Improve- ment [hft²F/Btu]	Improve- ment [%]	Framing Effect [%]
Gypsum board, traditional 3 5/8 -in. studs, R-11batts, gypsum board.	7.9			38.2
Gypsum board, traditional 3 5/8 -in. studs, 1-in. foam profiles on studs, R-19 batts, gypsum board.	16.3	8.4	106.3	13.0

As show on Figure 4, foam insulation is placed only in the location of strong thermal shorts generated by the steel stud. With its simplicity, high R-value (R-16), low Framing Effect (13%), and low cost, such wall can be a very good example how proper thermal designing can create an effective steel stud wall performing as well as wood frame wall.

Experimental results presented in Table 7 document excellent thermal performance of the steel stud wall containing local stud insulation. The whole building energy savings for 1500 ft² one-story rancher were as well optimistic. The usage of Stud Snuggler may bring in average 7- 15% of energy savings [Kosny 2001]. Comparison was made against the house containing walls made with conventional 3-5/8-in. steel studs. It was assumed that for the wall system containing steel studs with local insulating foam profiles the whole wall R-value was only 10% lower than clear wall R-value.

The novel ORNL steel/wood hybrid wall as efficient as wood stud construction

In 1999 ORNL researchers, have designed a novel 6-inch steel-framed wall that can match the thermal performance of a 6-inch wood-framed wall at about the same cost. If consider additional call backs costs for traditional wood framing (cracking of walls due to low dimensional stability of wood) and insect protection costs, the new ORNL wall design is cheaper than conventional wood stud construction.

This design combines steel and wood components to make top and bottom plates. Yet all of the materials in this design are commonly available, requiring no special prefabrication or tools. As shown on Figure 5, the hybrid steel/wood wall uses standard 3.5-inch C-shaped steel studs set at 24 inches on center. T-shaped top and bottom plates are prefabricated from 2x6 and 2x4 dimensional wood. In additional studies composite wood, fiberglass profiles, and thermally broken steel profiles are also considered for these horizontal

members. The main goal is to eliminate all wood components because of the possible termite damage.

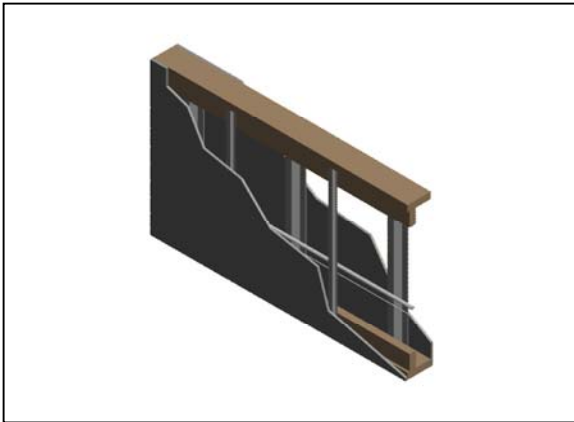


Figure 5. Wood/steel hybrid wall.

In the wall assembly used in Feb. 2001 for hot box testing, T-shaped top and bottom plates were prefabricated from 2x6 lumber with 2x4 perpendicular nailers set in from the exterior edges. These inset nailers created room for 1/2-inch steel hat channels, which were also installed at 24 inches on center and attached top and bottom to the nailers. Half-inch plywood or OSB was then screwed to the hat channels. This configuration created a complete thermal break and an almost perfect acoustic break as well. Unlike most other design approaches for residential steel framing, this one used no rigid foam insulation. An application of rigid foam sheathing to create a thermal break adds significant labor and material cost to steel-framed houses and makes them less competitive with wood framing. That is why, this newly developed wall does not require a usage of the foam sheathing to match the R-value of 2x6 wood stud wall.

Two hot box tests were conducted at ORNL in 2001 to see how the thermal

performance of the new steel-framed wall compared to a 2x6 wall framed entirely with lumber. The measured R-value of the steel-framed wall was 14.5, just 0.1-R off the wood-framed assembly. The hybrid wall's thermal performance would probably be even better if spray-in cellulose or foam were used in place of fiberglass, because it would fill in around the C-studs and hat channels better than fiberglass batts.

New shapes of steel studs – the alternative to dimensional wood

In time period 1999 - 2002, four configurations of light gage steel profiles and one steel track profile were developed in ORNL BTC. These profiles enable construction of 6-in. thick walls containing conventional fiberglass batt insulation. A series of very detailed three dimensional computer simulations yielded for wall assembled using these studs, R-values in the range between R-18 to R-19. The framing effect for these walls is only between 7 to 9%, when for similar wood framed construction framing effect is about 8%.

These new designs represent a innovative way of designing a shape of steel framing members. Majority of these new developments is based on reconfiguration of the existing building materials. The most radical changes are made in shapes of steel studs and tracks. They significantly reduce amount of heat transferred by these steel structural members. Series of hot box tests performed in ORNL confirmed theoretical predictions for some of these building envelope systems. For more complex technologies, ORNL is looking for industrial partners who would help in

commercialization of their novel steel framing designs.

Conclusions

There are various efficient means of reducing whole-building energy consumption in steel-framed buildings. Modifying the thermal envelope to optimize the material configuration and using the proper amount of thermal insulation will reduce first costs. Such savings can be easily achieved in the design stage when materials are chosen.

Due to intense heat transfer through steel components, steel framed structures require a very careful thermal designing. Adding rigid sheathing insulation to the wall is not always cost-effective. Some insulating techniques — such as modification of the contact area between steel members and exterior sheathing (dimples or ridges on the stud flange area) are not thermally efficient. ORNL experience showed that changes in stud web area (the main heat transfer shortcut) are much more effective. On the other hand, local insulation profiles located around steel studs or expanded-channel studs are effective ways of increasing the R-value of steel stud walls. Several steel profiles containing reduced web area are close in thermal performance to equivalent wood profiles. The thermal efficiency of wood stud walls can be reached and exceeded with steel-framed technologies. Newly developed ORNL wall technologies are very good examples of this. Though these designs seem full of promise, there are sizable hurdles to their acceptance in the marketplace. The biggest of these is conservative thinking in the steel and construction industries. Steel industry

has been oriented toward selling volume and trying to convince builders to replace wood framing members with steel one for one.

Of course, steel is not competitive that way. Steel is a very excellent material. It's very strong, dimensionally stable, rotproof, insectproof, fireproof, and recyclable. But it's also a thousand times more conductive than wood. It requires an engineering approach to succeed—one that capitalizes on steel's strength and eliminates the need for expensive rigid insulation."

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**Homes produced with airtight duct systems
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**HOMES BY THE FLORIDA HOME ENERGY
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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

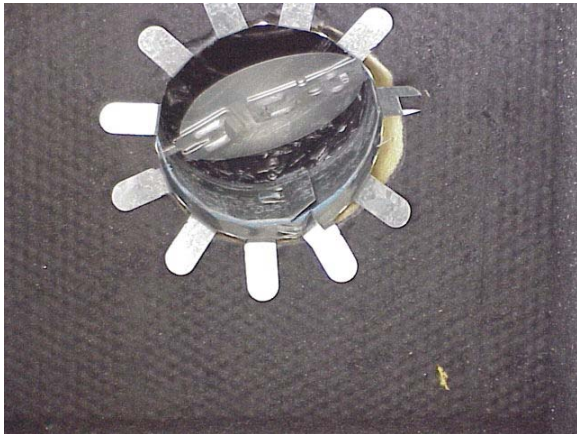


Figure 4 Butterfly Damper for OA control

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)

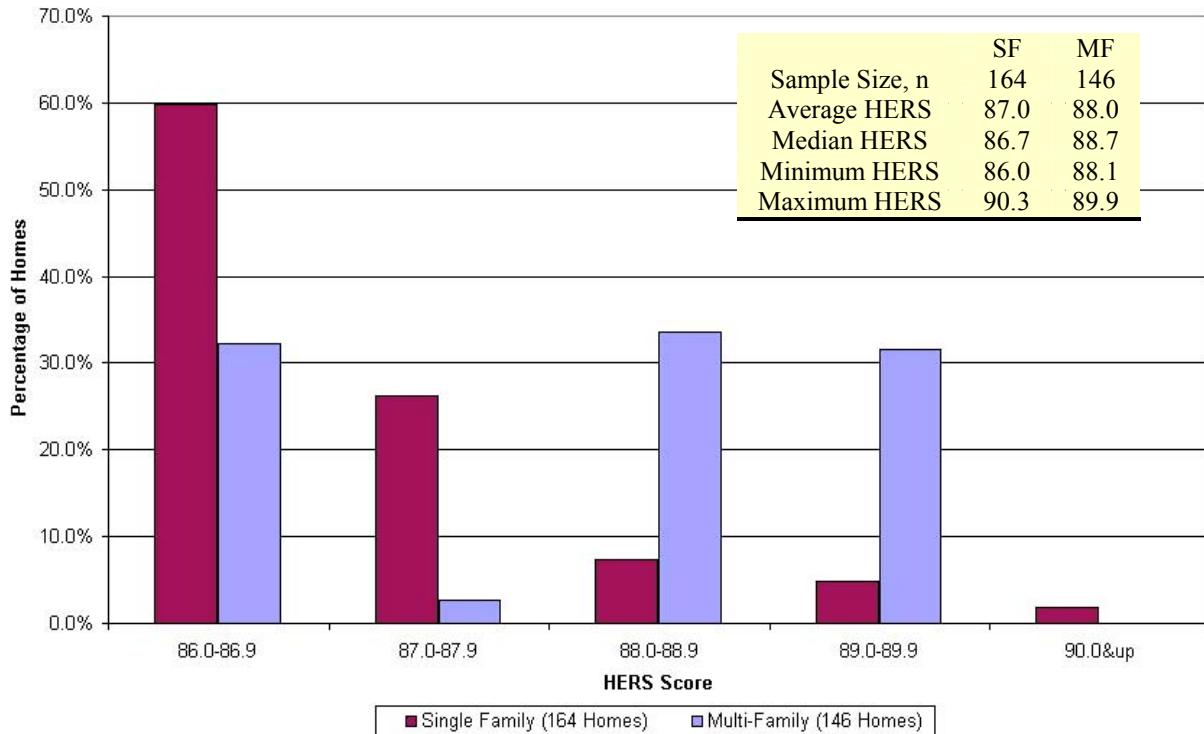


Figure 5 HERS Scores for FL H.E.R.O. Homes

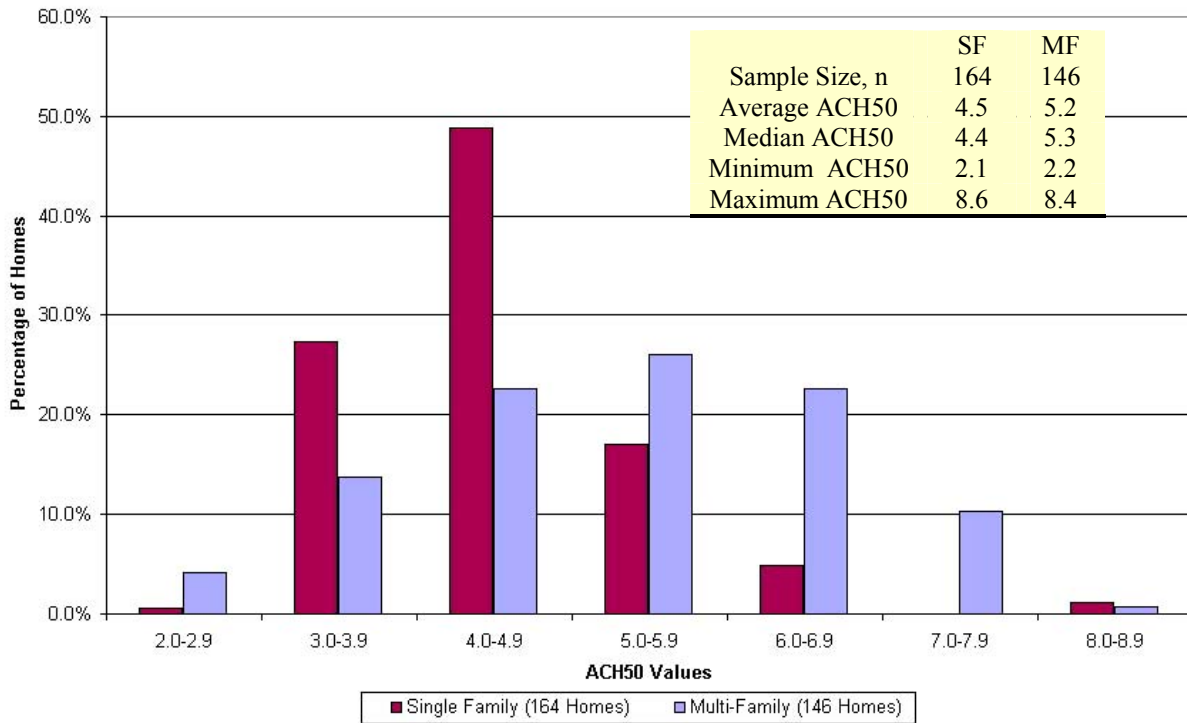


Figure 6 ACH50 Values for FL H.E.R.O. Homes

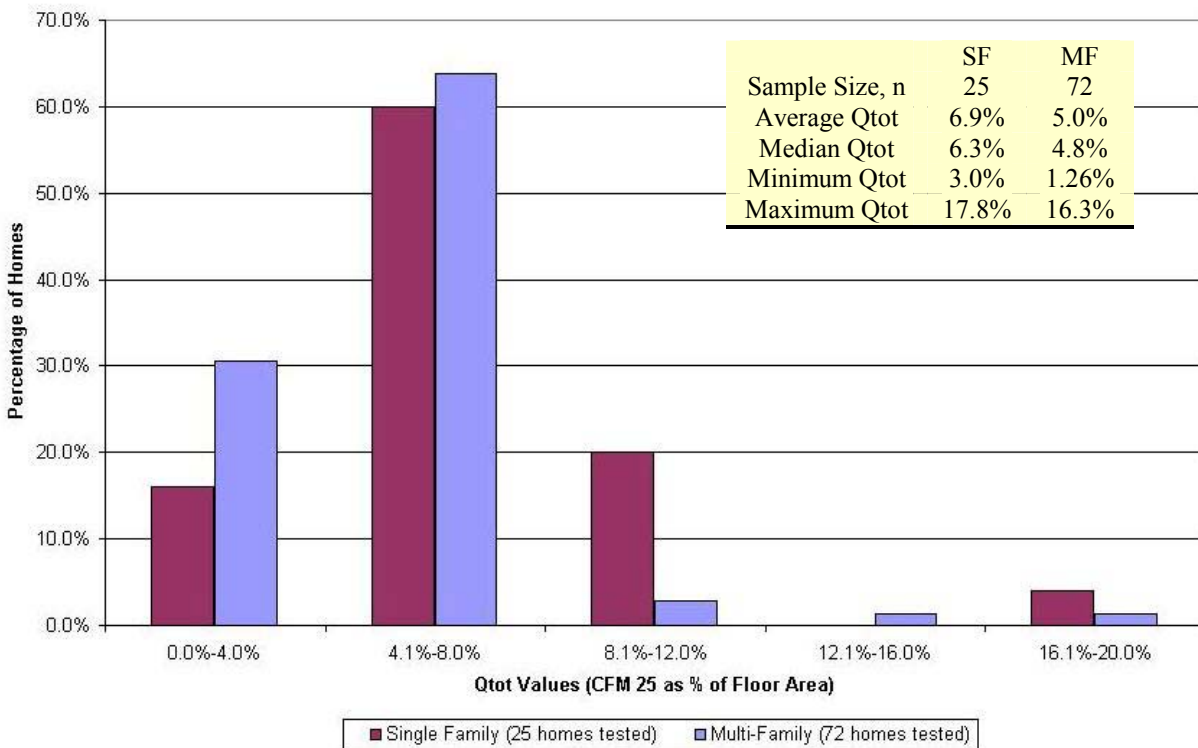


Figure 7 Qtot Values for FL H.E.R.O. Homes

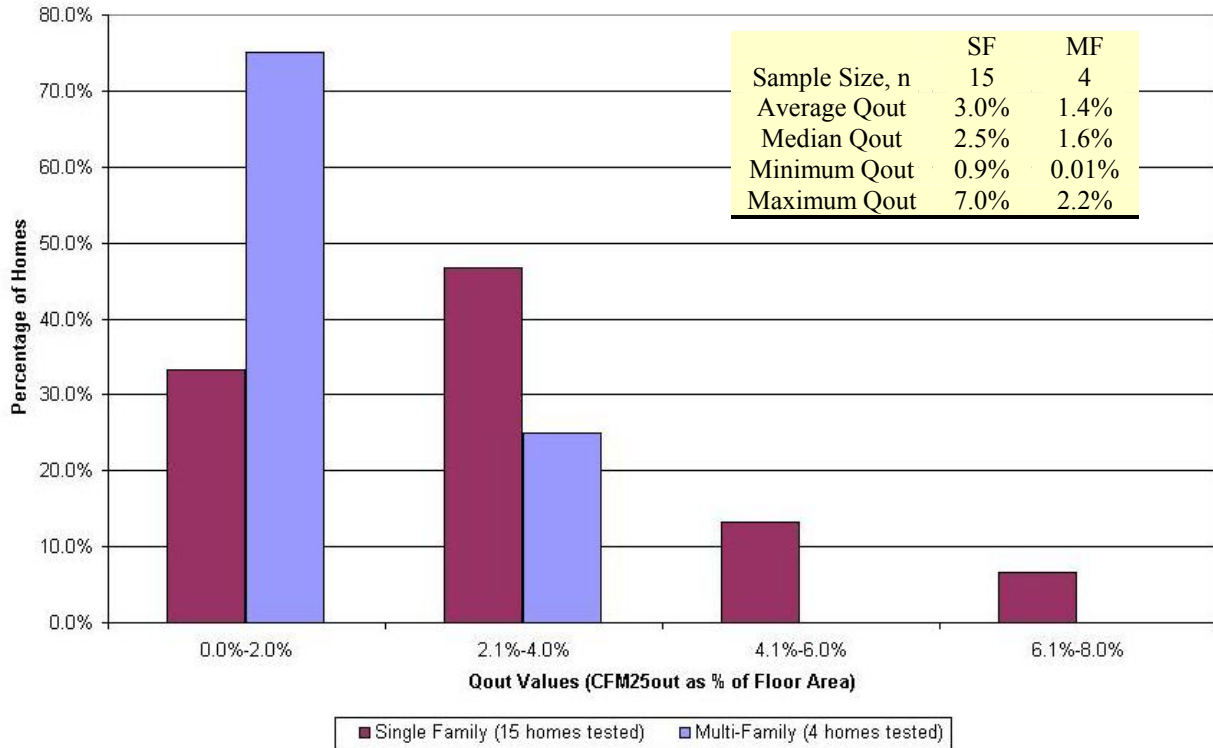


Figure 8 Qout Values for FL H.E.R.O. Homes

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/exum.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)

ACKNOWLEDGEMENTS

This research was sponsored, in large part, by the U.S. Department of Energy, Office of Building Technology, State and Community Programs under cooperative agreement no. DE-FC36-99GO10478 administered by the U.S. DOE Golden field office. This support does not constitute an endorsement by DOE of the views expressed in this report.

The authors appreciate the encouragement and support from George James, program manager in Washington DC and Keith Bennett, project officer in Golden CO.

Special thanks to Bert Kessler of Palm Harbor Homes, Mike Dalton of Stylecrest Sales, Mike Wade of Southern Energy Homes and David Hoak of Alten Design for the hundreds of hours they have each contributed to the success of BAIHP.

We are grateful to our sponsors, industry partners, collaborators and colleagues for this opportunity to make a difference.

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