BUILDING ENVELOPE, DUCT LEAKAGE AND HVAC SYSTEM PERFORMANCE IN HUD-CODE MANUFACTURED HOMES

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ABSTRACT

Between 200,000 to 300,000 manufactured homes are built to the US Department of Housing and Urban Development's Manufactured Home Construction and Safety Standards *(MHCSS*) in the US each year. This paper compares building envelope, duct leakage and HVAC system performance measured at standard construction HUD-code homes with energy efficient manufactured homes built under EPA's Energy Star and USDOE's Building America programs.

These comparisons show that significant improvements in energy efficiency and HVAC performance are achievable at minimal and/or no incremental cost to the homebuyer. Areas of improvement include building envelope air leakage control, duct design, installation and material selection, and HVAC system design and controls.

Computer analysis for two different climates was conducted on a prototypical home built to minimum HUD standards and to Energy Star specifications. The analysis utilizes input data from envelope and duct leakage field testing. The analysis results provide an estimated range of energy use, energy savings, and utility cost savings. A wide range of assumptions are made about ventilation system operation.

Cost savings is translated into additional home mortgage "purchase power". Energy savings resulting from using the energy efficient construction methods and materials are shown to be cost-effective. If adopted at the national level, these improvements may result in millions of dollars in utility savings to homeowners, reduce national residential energy consumption, and decrease greenhouse gas emissions, while providing improved occupant comfort and control of the indoor environment.

KEYWORDS

Air infiltration, duct leakage, energy, indoor air quality, HUD-code, manufactured housing.

INTRODUCTION

The construction and installation of US manufactured homes must meet requirements contained in the HUD Manufactured Home Construction Safety Standards (MHCSS.) The MHCSS addresses structural, fire safety, and energy efficiency issues, and has requirements for adequate ventilation. The MHCSS supersedes local and state building codes. HUD provides interpretive bulletins to the MHCSS.

The National Fire Protection Association (NFPA) recently updated standards that may significantly improve energy and IAQ performance of manufactured homes (NFPA501-2002.) HUD will review and consider adopting NFPA501-2002 standards for the MHCSS.

Research associated with energy efficient manufactured home programs, such as Energy Star, Building America Industrialized Housing Project (BAIHP), and NIST modeling and field research[24] indicates that:

- The assumption of air changes per hour (h^{-1}) for infiltration is problematic given the dynamics of occupants, climate, HVAC system type, and building envelope and duct system location and tightness.
- The flow rate capacity of bath fans in most HUD code homes is typically less than half that required by MHCSS (21 l/s [50 CFM]) unless performance tests were periodically conducted, as required in the Building America program.
- Forced air-systems in most HUD code homes have leaky ductwork, typically doubling infiltration rates when the HVAC system operates.
- Forced air-systems in most energy efficient homes where performance testing and improved duct mastics and duct leakage tests were employed typically have half the duct leakage as typical HUD-code homes that use duct tape.
- Exhaust fans and supply duct leakage draw moisture into the home in hot humid climates.
- Energy use and duct leakage of ventilation systems connected to forced-air systems is considerable.

As a result of these findings, the following improvements were made to NFPA-501 2000 and 2002:

- Using envelope and ductwork fan pressurization and ventilation system flow rate testing to quantify the definition of “effectively sealed”. (NFPA501-10.14.5.1 & 10.14.10)
- Employing quality assurance protocols, systems, and materials that systematically tighten the building envelope and ductwork. (NFPA501-A.8.5.1.1)
- Using R-8 crossover ducts instead of R-4. (NFPA501-10.14.8)
- Defining de-pressure limits that may reduce fireplace back-drafting and moisture condensation problems. (NFPA501-4.3.2.1)
- Using quiet, durable, and energy efficient ventilation fans. (NFPA-501-4.3.2.4)
- Educating occupants on operation of ventilation system using homeowner manual, labels, brochures, and videos. (NFPA-501-4.3.2.6)
- Promoting the use of controls to optimize air change rates at minimum energy cost. (NFPA-501-4.3.2.5

FIELD TESTING

Table 1 lists overall house tightness, measured by blower door tests. Table 2 provides duct leakage using duct blaster testing. Table 3 provides measured ventilation system flow rate capacity. In the tables, current practice (CP) homes are representative of single and multi-section homes built to HUD-FMHCSS. Energy efficient (EE) homes are representative of homes built under programs such as the Super Good Cents/Energy Star and BAIHP. The Zero Energy Manufactured Home (+) is the USA’s most energy efficient manufactured home, employing spray foam insulation, a heat recovery ventilation system, renewable solar photovoltaic and water heating systems, and numerous Energy Star lighting, appliance, window, HVAC and building technologies.

TABLE 1
House Tightness

Project Name*	Data Source	Sample	EE/CP**	Year Built	ACH***
BPA (2)	Eck	21	CP	65-80	14.3
RCDP-CTRL (2)	Davis	29	EE	89	8.8
RCDP-MCS (2)	Davis	131	CP	89	6.1
MAP (2-3)	Davis	162	EE	94	5.5
CS/OR (1-2)	EWEB	1253	CP	59-89	12.1
CSl/OR (2-3)	EWEB	187	EE	90-97	10.1
SGC/ID (2-3)	Ecotope	25	EE	97-98	4.6
SGC/WA (2-3)	Ecotope	11	EE	97-98	4.8
WSU/BA (3)	Lubliner	1	EE	96	2.4
FSEC/BA (1-2)	Chandra	6	CP	99	5.5-7.5
FSEC/BA (1-2)	Chandra	2	EE	99	5.5
FSEC/BA (1-2)	Cummings	21	CP	74-86	12.6
NY (n/a)	AEC	6	CP	94-95	10.2
NC (n/a)	AEC	8	CP	94-95	12
Vincent (1)	WSU/BA	25 (1)	CP	92	6.1
Vincent (1)	WSU/BA	25 (1)	EE	92	5.6
PNNL/BA (2)	WSU/BA	1	EE	00	3.6
KT (1)	FSEC/INEL	1	CP	00	6.45
KT-(2)	WSU/INEL	1	CP	01	6.3
KTSGC (2)	WSU/BA	1	EE	02	3.6
KT-ZEMH (2)	WSU/BA	1	+	02	1.9
SGC02 (2-3)	OOE/BA	14	EE	00	3.84
FSEC – NC (2)	FSEC/BA	1	CP	00	10
FSEC – NC (2)	FSEC/BA	1	EE	00	9
FSEC – FL (2)	FSEC/BA	1	EE	01	5.2
NIST (2)	NIST/BA	1	CP	01	9.43

*(#) = number of sections
**CP = Current Practice EE = Energy Efficient (+) Zero Energy
***ACH = air changes per hour (h^{-1}) at 50 PA

TABLE 2
Outside Duct Leakage

Project Name	Data Source	Sample Size	Efficiency*	l/s (CFM)
MAP	Davis	162	EE	49 (104)
SGC/ID	Ecotope	24	EE	50 (106)[1]
SGC/WA	Ecotope	25	EE	49 (103)[1]
WSU/BA	Lubliner	1	EE	47 (100)
FSEC/BA	Chandra	6	CP	33 (70)
FSEC/BA	Chandra	2	EE	19 (40)
Vincent	WSU/BA	25 (1)	CP	62 (132)
Vincent	WSU/BA	25 (1)	EE	14 (29)
PNNL/BA	WSU/BA	1	EE	45 (45)
INEEL 1x	FSEC/BA	1	CP	94 (200)[2]
INEEL KT 2x	INEEL/BA	1	CP	57 (120)[3]
SGC02	OOE/BA	65	EE	53 (112)
KT-SGC	WSU/BA	1	EE	71 (150)
ZEMH	WSU/BA	1	+	17 (37)
FSEC – NC	FSEC/BA	1	CP	68 (145)
FSEC – NC	FSEC/BA	1	EE	39 (83)
FSEC – FL	FSEC/BA	1	EE	21 (45)
NIST	NIST/BA	1	CP	104 (220)

*CP = Current Practice; EE = Energy Efficient; + = Zero Energy
[1] = median [mean not used]; [2] = total leakage; [3] = bias low due to high wind

TABLE 3
Measured ventilation system flow rate capacity

Project Name	Data Source	Sample Size	EE/CP*	Ventilation system Type**	l/s (CFM)
RCDP-CTRL	Davis	29	EE	IN	12 (25)
RCDP-MCS	Davis	131	CP	EXH	15 (32)
MAP	Davis	261	EE	EXH	26 (55)
SGC 97	Ecotope	36	EE	OUT	34 (73)
WSU/BA	Lubliner	1	EE	IN	14 (30)
WSU/BA	Lubliner	1***	EE	OUT	42(90)
Vincent Village	WSU/BA	50 (1)	EE	OUT	24 (50)
PNNL/BA	WSU/BA	1	EE	OUT	49 (104)
SGC02	OOE/BA	25	EE	OUT	31 (65)
KT-SGC	WSU/BA	1	EE	OUT	37 (78)
FSEC – NC	FSEC/BA	1	CP	OUT	24 (50)
FSEC – NC	FSEC/BA	1	EE	OUT	24 (50)
FSEC – FL	FSEC/BA	1	CP	OUT/IN	24 (50)
NIST	NIST/BA	1	CP	OUT	12 (25)
NIST	NIST/BA	1***	CP	IN	8 (16)

*CP = Current Practice EE = Energy Efficient
** OUT = Exhaust Fan; IN = Intake Duct
*** Same home as previous, using a different ventilation system

ENERGY AND COST SAVINGS ANALYSIS

Energy use and cost estimates were developed for a typical 146 m^2 (1568 ft^2) HUD code double section home located in Miami, FL and Seattle, WA climates, using Energy Gauge USA version 2.1. The analysis included both space conditioning, and whole house energy use.

Two thermal efficiency levels were analyzed for each climate: HUD and Energy Star. The specific envelope measures, air leakage targets, and mechanical systems for each efficiency level are provided in Table 4.

TABLE 4
Energy Gauge USA 2.1 inputs

	Miami		**Seattle**	
	HUD	Energy Star	HUD	Energy Star
Walls	1.9 m^2/°C/W (R-11)	2.3 m^2/°C/W (R-13)	3.3 m^2/°C/W (R-19)	3.7 m^2/°C/W (R-21)
Floor	1.9 m^2/°C/W (R-11)	1.9 m^2/°C/W (R-11)	3.9 m^2/°C/W (R-22)	5.8 m^2/°C/W (R-33)
Roof	3.9 m^2/°C/W (R-22)	5.3 m^2/°C/W (R-30)	5.3 m^2/°C/W (R-30)	6.7 m^2/°C/W (R-38)
Glazing	0.2 m^2/°C/W (R-1)	0.4 m^2/°C/W (R-2)	0.4 m^2/°C/W (R-2)	0.5 m^2/°C/W (R-3)
Duct Insulation	0.7 m^2/°C/W (R-4)	1.4 m^2/°C/W (R-8)	0.7 m^2/°C/W (R-4)	1.4 m^2/°C/W (R-8)
Envelope Tightness	8 ACH@50Pa	4 ACH @50Pa	8 ACH@50Pa	4 ACH @50Pa
Duct Leakage	57 l/s @25 Pa 120 CFM @25Pa	28 l/s @25 Pa 60 CFM @25Pa	57 l/s @25 Pa 120 CFM @25Pa	28 l/s @25 Pa 60 CFM @25Pa
Ventilation system	50 CFM @ 22W	50 CFM @ 350W	50 CFM @ 22W	50 CFM @ 350W
Heat Pump	SEER = 13	SEER = 10	SEER = 13	SEER = 10
Water Heater	EF = .88	EF = .93 (heat trap)	EF = .88	EF = .93 (heat trap)
HVAC controls	Std. thermostat	Set-back thermostat	Std. thermostat	Set-back thermostat
Lighting	90% incandescent	Energy Star lighting	90% incandescent	Energy Star lighting

Table 5 shows the Energy Gauge analysis of energy use, given two ventilation system operating scenarios: continuous whole house fan operation versus 2 hour per day typical bath and kitchen fan operation. Homes are assumed to use electric furnaces, with higher space heating and limited loads use in Seattle, and limited heating and significant AC loads in Miami.

TABLE 5
Energy Use of Energy Star and Minimum HUD-Code Homes

Miami, FL	**Energy Use (kWH/year)**		**Energy Cost (US $ per year)**	
	24 hr/day	**2 hr/day**	**24 hr/day**	**2 hr/day**
HUD- Space	9638	6712	$795	$554
HUD- Total	19515	16589	$1612	$1371
EStar – Space	4498	3689	$371	$304
EStar – Total	13169	12369	$1090	$1023
Total Savings	**6346**	**4220**	**$522**	**$348**
Seattle, WA	**Energy Use (kWH/year)**		**Energy Cost (US $ per year)**	
	24 hr/day	**2 hr/day**	**24 hr/day**	**2 hr/day**
HUD- Space	13349	8127	$1102	$671
HUD- Total	23773	18550	$1964	$1533
EStar – Space	7806	5455	$644	$451
EStar – Total	16844	14492	$1391	$1198
Total Savings	**6929**	**4058**	**$573**	**$335**

COST EFFECTIVENESS

Table 6 converts lower utility costs into additional mortgage purchase power from the Energy Star package.

TABLE 6
Mortgage purchasing power for Energy Star utility savings

Miami, FL	**24 hr/day**	**2 hr/day**
Monthly Savings	US $44	US $29
Savings for 30-year loan*	US $5011	US $3303
Seattle, WA		
Total Savings	US $48	US $28
Savings for 30-year loan*	US $5467	US $3189

*Assumes 10% interest rate

Data from the USDOE Building America Program indicates that the Energy Star package costs approximately US$ 11 per m^2(less than US $1 per ft^2), roughly US $1568 for the two-section prototype. In addition, nationally accepted manufactured appraisal guides indicate that energy efficiency options in manufactured homes retain their resale value[32]. There are also many utility incentive/rebate programs available for Energy Star homes, which further offset the cost of the energy efficiency options.

CONCLUSIONS

Comparisons of energy efficient and current practice HUD-code homes suggest significant improvements in energy efficiency and HVAC performance are achievable at minimal and/or no incremental cost to the homebuyer. Areas of improvement include building envelope air leakage control, duct design, installation and material selection, and HVAC system design and controls.

Computer analysis suggests that Energy Star homes, HVAC systems, lighting and appliance technologies are cost significant, and cost effective if utility saving is converted to increased mortgage "purchase power", and/or increased resale value is recognized. If adopted at a national level, these improvements would result in millions of dollars in utility savings to new homebuyers, reduce national residential energy consumption, and reduce power plant greenhouse gas emissions, while providing improved occupant comfort and control of the indoor environment.

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