Cold Climate Case Study: High-Efficiency North Dakota Twin Homes

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ABSTRACT

This paper describes a housing project in Grand Forks, North Dakota, that had the goal of achieving up to 50% energy savings over the 1993 Model Energy Code. Estimated combined gas and electricity utility savings over a computer model base case ranged from 25% on the Phase I homes to 35% on Phase II homes. The increased savings in Phase II came from the use of extruded polystyrene (XPS) foam sheathing and tankless gas water heating, which had simple paybacks of 8.3 and 13.3 years, respectively.

INTRODUCTION

The Eastern Dakota Housing Alliance has completed 8 of 20 planned multi-family and single-family dwellings on Selkirk Circle in Grand Forks, North Dakota. Four twin-home (duplex) units were completed in March of 2003 (Phase I) and four more identical units were completed in February of 2004 (Phase II). Four additional units (Phase III) are due for completion by mid-summer 2004. Design assistance and performance testing were provided by the Building America Industrialized Housing Project with the goal of achieving up to 50% energy savings over the 1993 Model Energy Code.

To approach this level of savings, various envelope and equipment upgrades were assessed through DOE2 computer simulations. Base case, Phase I, and Phase II homes were modeled including input from envelope and duct leakage testing. Annual combined gas and electric utility savings estimates ranged from 25% on Phase I homes to 35% on Phase II homes over the base case unit built to local minimum standards. A cost comparison of standard and improved systems was also performed.

The use of extruded polystyrene (XPS) rigid foam sheathing and tankless gas water heaters were two features, considered innovative by local standards, providing much of the increased energy savings of the Phase II homes over Phase I. The decision to use insulated sheathing was driven by a tripling in the price of plywood during the summer of 2003, making it comparable to the price of R-10 XPS foam. Whole house tankless gas water heaters, far more popular overseas than in the U.S., were costly to purchase and install compared to typical gas or electric choices, but they provide substantial savings. The size of a small suitcase, these units saved valuable space in the compact Selkirk home design and are claimed to last 20 years or more..

Figure 1 *Selkirk Twin Homes, Grand Forks, N.D.*

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Table 1. Minot, North Dakota, TMY2 Weather Summary

Heating Degree-Days	97.5% Heating Design	2.5% Cooling Design
9,407	–20°F	89°F

Table 2. 2003 Utility Rates*

Electric ($/kWh)			Natural Gas Avg.
Jun - Sep	Other Months	Average	($/therm)
0.0657	0.0578	0.0604	0.748

* Xcel Energy

Table 3. Twin Home Specifications

	Base Case	Phase I	Phase II
Conditioned Area (with basement)	1840 ft^2	Same	Same
Above-grade Walls	R-19 Wood Frame	R-19 Wood Frame	R-15 Wood Frame + R10 sheath
Basement Walls	R-11	Same	Same
Vented Attic	R-49	Same	Same
Windows	U-0.34, SHGC-0.33	Same	Same
Gas Furnace	60 KBtu, AFUE-78	60 KBtu, AFUE-92	60 KBtu, AFUE-92
Air Conditioner	1.5 ton, 10 SEER	Same	Same
Thermostat	Standard	Programmable	Programmable
Ventilation	None	70% efficient HRV	70% efficient HRV
Water Heater	40 gallon, EF 0.88 Electric	40 gallon, EF 0.62 Natural gas	Tankless, EF 0.83 Natural gas
Lighting	10% Fluorescent	85% Fluorescent	85% Fluorescent
Appliances	Standard	Energy Star	Energy Star
Infiltration (ACH50)	5.0	2.8	2.4

Figure 2 *Twin home unit.*

BUILDING SIMULATION SOFTWARE

The software called EnergyGauge USA® (Parker et al. 1999) provides an input interface for performing hourly computations with the DOE2.1E simulation engine. The nearest TMY cities to Grand Forks include Fargo and Minot, North Dakota. The more severe weather in Minot (similar latitude to Grand Forks) was chosen for the annual simulations (Table 1).

Average energy rates were obtained from the serving utility for annual cost and economic comparison calculations (Table 2).

BASE CASE CHARACTERISTICS

A base case home was simulated to provide a point of comparison for annual energy use and payback analysis. This home used the same geometry as the actual homes but with envelope construction and equipment types normally used by builders in the Grand Forks area (Table 3).

Building Envelope

The base case above-grade walls consist of 2 × 6 wood studs, 16 in. on center to allow for R-19 batt insulation. The wall exterior is OSB sheathing, building paper, and vinyl

Table 4. Measured Phase I Envelope Tightness

Twin Home Unit	1	2	3	4	Average
CFM50	737	728	574	716	689
ACH50*	3.00	2.97	2.34	2.92	2.81
Notes:*ACH50 = CFM50 × 60/volume (basement zone depressurized along with main living space)					

siding. On the interior, a vapor barrier of 6-mil polyethylene is installed behind the gypsum wallboard to minimize moisture diffusion from the conditioned space into the wall cavity. High-grade windows are the norm for Grand Forks area builders. The modeled base case window is a double-pane, vinyl framed, argon-filled, horizontal slider with a low-e coating, providing a U-value of 0.34 and a solar heat gain coefficient (SHGC) of 0.33. The assumed base case infiltration is set at 5.0 ACH50 (1,227 CFM50).

The basement (608 ft^2) is upgradeable as a future living space with two windows set below grade level (in wells) for each of two bedrooms. Cement basement walls are insulated to R-11 with 2 × 4 framing on the interior. The basement ceiling is uninsulated and allows ample air communication with the living space above, causing the basement zone to function as a conditioned space.

Equipment

Space heating is provided by a gas furnace located in the basement, with an efficiency of 78% AFUE. Cooling is provided by a 10 SEER air conditioner sized at 1.5 tons (18 KBtu) nominal. Setpoints of 68°F in winter and 78°F in summer were assumed for the DOE2 simulations. Ductwork is primarily located in the basement, completely within the building's air barrier. Supply ductwork consists of uninsulated metal, and return ducts are loosely constructed pathways to the bedrooms and main body, utilizing building cavities. Total duct leakage is substantial in systems of this design, but leakage to outside is minimal and considered to be zero here.

Electric water heaters (EF 0.88) are routinely used in this area according to the builder. Natural gas price spikes in the last five years was one reason cited for the continued use of electric water heating in the Grand Forks area.

PHASE I MEASURES

Building Envelope

Careful attention to air sealing was the only difference over the base case envelope design in Phase I. Upgraded casement-style windows replaced the base case horizontal sliders to improve envelope tightness. These argon-filled, vinyl-framed units are otherwise identical to those assumed in the base case home with a 0.34 U-value and 0.33 SHGC. Blower door tests of the Phase I units show an average leakage rate of 2.8 ACH50 was attained based on 689 CFM50, as shown in Table 4, including the basement.

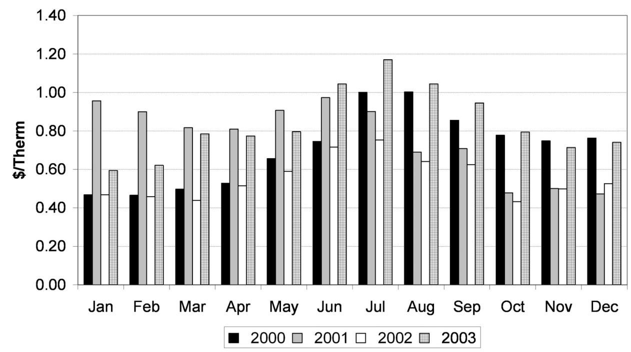

Figure 3 *North Dakota natural gas pricing.*

Equipment

The 78% furnace was replaced with a 92.6% AFUE, sealed combustion, condensing gas furnace. Combustion air is drawn from outside, completely sealing it from the inside space and minimizing the chance of leaking combustion products to the conditioned space. A programmable setback thermostat further reduces energy demand with assumed swings of 5°F in winter and 3°F in summer assumed for the DOE2 models. Savings were obtained by replacing the electric water heater with a power-vented natural gas model. This is not an exceptionally efficient gas unit (EF 0.62) but the power-venting feature provides a measure of combustion safety.

Recent fluctuations in the price of natural gas complicate payback calculations for both the furnace and water heater upgrades. The 2003 average local rate ($0.748/therm) was obtained from the serving utility for the economic calculations. In the ten years prior to 2000, gas prices were relatively stable with a slight rise in the middle of the year when heating demand is reduced. This trend roughly continued after 1999, but a substantial increase in winter prices seen in 2000-2001 (Figure 3) would have a considerable impact on furnace upgrade savings, making the high-efficiency unit look much more favorable against the base case when prices increase. For the gas water heater, on the other hand, increasing prices would reduce its cost-effectiveness relative to the base case electric model, which is powered by a historically more stable commodity that was 26% cheaper than the national average of $0.0813/kWh in 2003 (EIA 2004).

Considerable effort was focused on replacing incandescent fixtures with fluorescent lighting, yielding a simple payback of 6.5 years. The typical 10% fluorescent fraction was increased to 85% with a combination of linear and compact fluorescent light (CFL) fixtures. The only locations

Table 5. Measured Phase II Envelope Tightness

Twin Home Unit	1	2	3	4	Average
CFM50	736	474	685	495	598
ACH50*	3.00	1.93	2.79	2.02	2.44
Notes:*ACH50 = CFM50x60/volume (basement zone depressurized along with main living space)					

Figure 4 *XPS foam at corner.*

with standard edison-socket fixtures are hallways, bathrooms (with dimmers), and kitchen can lights (also with dimmers).

An Energy Star dishwasher and horizontal-axis clothes washer provide an annual savings of $37 by reducing electrically generated hot water an estimated 10 gallons per day. The typical 60 gallons of hot water use per day was reduced to 50 with an estimated savings of 8 gallons from the horizontal-axis washer (Tomlinson and Rizy 1998) and 2 more gallons from the dishwasher. Savings from reduced water and detergent use are not included. The Energy Star refrigerator saved an estimated $34 (1,100 kWh/yr vs. 450 kWh/yr) in electrical energy but $10 of this is lost per year due to increased heating demand (approximately 14 therms).

A heat recovery ventilator (HRV) mounted in the basement provides controlled mechanical ventilation with an energy penalty estimated at $45/year. The unit contains an 80-watt fan that introduces 75 CFM of outside air while exhausting a similar amount at a heat transfer efficiency of 70%. Attempting to meet the new ASHRAE 62.2 standard (ASHRAE 1999) would require 42 CFM of continuous ventilation. For these simulations, however, the old ASHRAE guideline of 0.35 ACH was used, calling for a continuous rate of 25 CFM. The HRV can operate either continuously or on an intermittent 20 minutes on, 40 minutes off, cycle. Intermittent operation was simulated to meet the old guideline.

PHASE II MEASURES

The Phase II structures had only two new measures over those used in Phase I: XPS foam board sheathing and tankless gas water heaters. The use of rigid foam exterior insulation was considered early in design discussions but was not implemented until Phase II when plywood prices nearly tripled. This measure allowed the construction of 2×4 walls that were insulated with a blown fiberglass product to achieve R-15. Two inches of extruded polystyrene (XPS) (R-10) was installed except in areas where ½ inch plywood bracing was required. These corner-braced areas received 1-1/2 inches (R-7.5) of insulated sheathing (Figure 4), making up roughly one-third of the exterior wall area and resulting in an average value of R-9.2 for use in the DOE2 simulation. The remaining wall construction (siding, vapor barrier, etc.) matched the phase I details.

The unfaced XPS foam sheathing has a perm rating of 1.1 and is considered a vapor retarder at the wall exterior. This is in addition to the interior vapor barrier (6-mil poly) installed behind the gypsum wallboard at the wall interior. Installation of two vapor barriers in this manner leaves the wall vulnerable to moisture accumulation should water unintentionally enter the cavity. There will be only a slight ability for the wall to dry to the outside. Another recommendation calls for removing the interior vapor barrier and relying on two coats of latex paint on the interior to limit diffusion from the conditioned space into the wall. This option allows the wall to dry to some extent in both directions but was not chosen by the builder.

Blower door tests of the Phase II units show an average leakage rate of 2.4 ACH50 was attained based on 598 CFM50, as shown in Table 5, including the basement.

An instantaneous gas water heater with an energy factor of 0.83 provided an estimated annual savings of $42 over the phase I gas model. Savings over the base case 40-gallon electric water heater are estimated at $94, providing a 13-year simple payback. The manufacturer claims a 20- to 25-year lifespan.

Groundwater temperatures in Grand Forks routinely reach below 40°F during the winter months, which would drop hot water output below 4 gallons per minute (GPM) at a 120°F supply temperature according to manufacturers' performance data. The new homeowners were notified that, while hot water would always be available, some changes in usage habits might be required to allow for reduced capacity. No homeowner complaints were reported during an exceptionally cold 2003/2004 winter season in Grand Forks, which saw a new all-time record low of –44°F on January 30, 2004 (NOAA 2004). Impromptu discussions with homeowners during envelope testing (April 29-30, 2004) indicated general satisfaction with the units to date.

Table 6. Economic Assessment of Phase I Measures

Energy Measure	Annual Savings	Installed Cost	Simple Payback	First Year Cash Flow**
Reduce infiltration to 2.8 ACH50	$90	$325	3.6	$68
Upgrade to 92% direct vent furnace	$52	$600	11.5	$11
Switch to programmable thermostat	$23	$130	5.7	$11
Upgrade to Energy Star appliances*	$61	$730	12.0	$12
Change to EF-0.62 power vented water heater	$52	$520	10.0	$16
Increase from 10% to 85% fluorescent lighting	$31	$200	6.5	$17
All measures	**$309**	**$2,505**	**8.1**	**$135**
Heat recovery ventilation at 75 cfm, 33% RTF	($45)	$1,400	N/A	$134
All measures with HRV	**$264**	**$3,905**	**14.8**	**$1**

Notes:
* Energy Star appliances include refrigerator, dishwasher, and h-axis clothes washer
** First year cash flow based on 30 year fixed rate mortgage with interest rate of 6%, down payment of 5%, and discount rate of 5%. A general inflation rate of 3% per year was applied to the upgrade cost of measures replaced at end of lifetime. Final value of equipment is determined by linear depreciation over lifetime. Interest paid on mortgage is considered tax deductible using a tax rate of 28%. Energy costs escalate at 3% per year. A property tax rate of 0.8% was applied to the energy upgrade cost and is inflated at 3% per year.

Table 7. Economic Assessment of Phase II Measures

Energy Measure	Annual Savings	Installed Cost	Simple Payback	First Year Cash Flow**
Upgrade walls to (R10 sheath + R15 FG batt)	$72	$600	8.3	$31
Reduce infiltration to 2.4 ACH50	$106	$325	3.1	$82
Upgrade to 92% direct vent furnace	$40	$600	15.0	-$1
Switch to programmable thermostat	$18	$130	7.2	$6
Upgrade to Energy Star appliances*	$60	$730	12.2	$12
Change to EF-0.83 tankless gas water heater	$94	$1,250	13.3	$10
Increase from 10% to 85% fluorescent lighting	$31	$200	6.5	$18
All measures	**$421**	**$3,835**	**9.1**	**$158**
Heat recovery ventilation at 75 cfm, 33% RTF	($43)	$1,400	N/A	$134
All measures with HRV	**$378**	**$5,235**	**13.8**	**$24**

Notes:
* Energy Star appliances include refrigerator, dishwasher, and h-axis clothes washer
** First year cash flow based on 30 year fixed rate mortgage with interest rate of 6%, down payment of 5%, and discount rate of 5%. A general inflation rate of 3% per year was applied to the upgrade cost of measures replaced at end of lifetime. Final value of equipment is determined by linear depreciation over lifetime. Interest paid on mortgage is considered tax deductible using a tax rate of 28%. Energy costs escalate at 3% per year. A property tax rate of 0.8% was applied to the energy upgrade cost and is inflated at 3% per year.

ESTIMATED ANNUAL ENERGY USE AND COST COMPARISON

Phase I and Phase II energy measures were evaluated progressively by adding one measure at a time to the base case home. Energy measures were added in the order listed in Tables 6 and 7 to arrive at estimated savings numbers for individual measures while allowing for interaction of the building systems.Major construction components or equipment were added first such as envelope measures and the gas furnace. Hot water saving, Energy Star appliances were added prior to the water heater upgrade to highlight their savings with respect to electrically heated water.

One row in Tables 6 and 7 shows the cumulative effect of all measures added to the base case home. Estimated saving in this row includes the cumulative effect of all measures incorporated together in the DOE2 simulation. The heat recovery ventilator (HRV) is broken out from the other measures to provide a meaningful simple payback and first year cash flow figures for the other cumulative measures. The HRV is considered an essential component for the indoor air quality of these homes, but comparing it to a base case home without ventilation means no relative savings are attained; thus, this measure is added in a separate row. With the exception of the HRV all measures show a positive cash flow on a 6%, 30-year fixed rate mortgage beginning in the first year.

Table 8. Simulated Performance Comparison of Base Case and Improved Homes

	Base Case		Phase I		Phase II	
HERS	85.2		89.7		92.2	
Total Annual Energy	**Cost**		**Cost**	**Savings**	**Cost**	**Savings**
	$1,079		$815	25%	$701	35%
	Cost	**Design Load (KBtu/h)**	**Cost**	**Design Load (KBtu/h)**	**Cost**	**Design Load (KBtu/h)**
Heating	$458	29.8	$366	33.4	$294	30.7
Cooling	$15	9.9	$11	10.6	$10	10.3
Hot Water	$245		$157		$116	
Total	$718		$534		$420	

Two alternate measures used in Phase II were XPS foam board sheathing and tankless gas water heaters, which were unfamiliar to the builder and plumbing subcontractor. This meant a larger labor premium was included in the installed cost than may be the case in the future if they continue to be used. The XPS foam in particular is being considered for other projects by the builder as plywood prices continue to remain high in the area.

A performance comparison of the base case and the improved structures is shown in Table 8. The increased heating design load in Phases I and II over the base case is caused by the addition of 75 CFM of ventilation introduced on a 20 minutes ON, 40 minutes OFF cycle, which the base case does not have. The DOE2 model predicts the need for very little cooling; however, many new homes in this area are being built with central air conditioning.

SUMMARY AND CONCLUSIONS

A total of eight twin home units (four each of Phase I and Phase II) have been built to date on Selkirk Circle in Grand Forks, North Dakota, with the goal of achieving up to 50% energy savings over the 1993 Model Energy Code. DOE 2 computer models of each phase plus a theoretical base case house built to local minimum standards were devised to determine energy savings and cost-effectiveness. Phase I and Phase II home models included input from envelope airtightness testing results. Estimated combined gas and electric utility savings ranged from 25% on Phase I homes to 35% on Phase II homes over the base case.

The increased utility savings of Phase II over Phase I come from two energy-saving measures unique for this area: extruded polystyrene (XPS) foam sheathing and tankless gas water heating. Simple paybacks for these measures were 8.3 and 13.3 years, respectively. Electric water heaters are the current norm in the Grand Forks area, but with electricity 26% below the national average and natural gas prices on the rise, simple payback on the tankless model was relatively long. In addition, fluctuating natural gas prices complicate the economic analysis. Initial concerns of how the tankless water heater would perform in this extreme climate were met with positive feedback through the first winter, which was colder than normal, including an all-time record low of –44°F set at the Grand Forks International Airport on January 30, 2004.

The low water vapor permeance of rigid XPS foam sheathing (1.1 perms) presents a dilemma in this climate where an interior vapor barrier (usually 6-mil polyethylene) is considered mandatory to minimize moisture diffusion from the conditioned space into the wall cavity. The installation of two vapor barriers leaves the wall vulnerable to moisture accumulation should water unintentionally enter the cavity. One recommendation calls for removing the interior vapor barrier and relying on two coats of latex paint on the interior to limit diffusion from the conditioned space into the wall. This option allows the wall to dry to some extent in both directions but was not chosen by the builder.

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