COLD CLIMATE HOUSING RESEARCH CENTER
CCHRC

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Monitoring and Verification of Sustainable Northern Shelter Building Performance
Anaktuvuk Pass Prototype House Final Report

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Monitoring and Verification of Sustainable Northern Shelter Building Performance *Anaktuvuk Pass Prototype House Final Report*

Cold Climate Housing Research Center

written by

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NATIONAL RENEWABLE ENERGY LABORATORY

Figure 1. The Anaktuvuk Pass prototype house. The house is earth bermed on the ends to take advantage of the thermal and wind shear benefits of a traditional sod house.

CCHRC created the Sustainable Northern Shelter program in 2008 to help develop sustainable rural housing in northern climates. CCHRC designers work with local residents and housing authorities to develop homes that reflect the culture, environment, and local resources of individual communities. The designs emphasize energy efficiency, affordability, and durability. CCHRC has developed several prototype homes that can be easily built and affordably reproduced within each community to provide much-needed housing. The first prototype home was built in Anaktuvuk Pass in 2009.

Anaktuvuk Pass

Anaktuvuk Pass is a Nunamiut community of 312 located in the Brooks Range, accessible only by plane. It is a very cold location with an average winter temperature of –14°F (-25°C) and summer temperatures averaging 50°F (10°C) (State of Alaska, 2011). Figure 2 shows the exterior temperatures for the past two years. Anaktuvuk Pass has approximately 17,180 °F·day heating degree days per year (compared to about 14,000 for Fairbanks and 6,500 for Chicago).

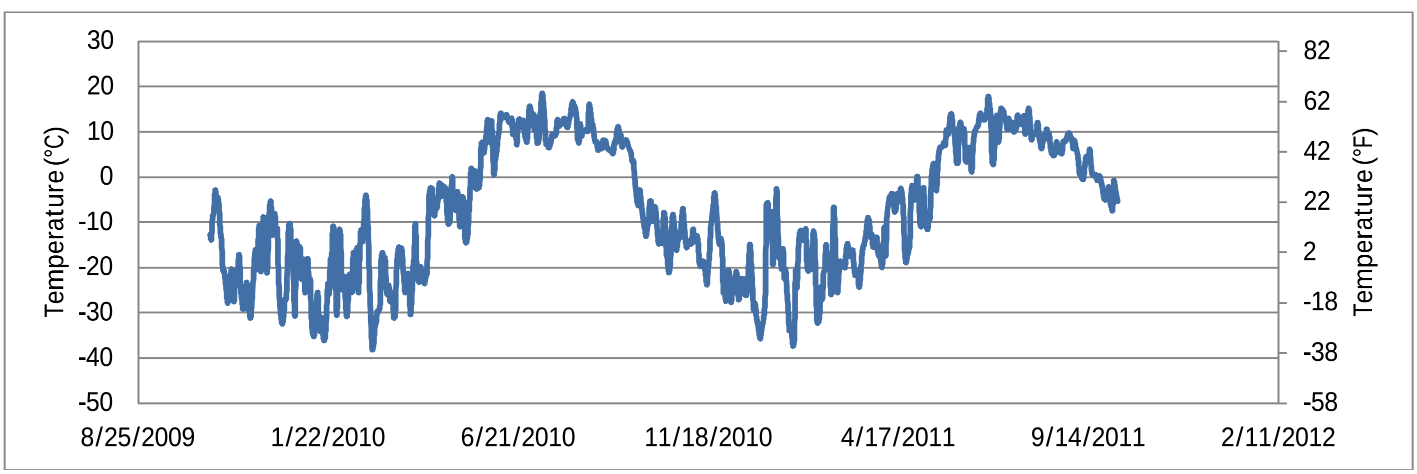

Figure 2. Exterior temperatures in Anaktuvuk Pass. Temperatures have ranged from -38 to 62°F (-38 to 17°C) over the past two years.

Anaktuvuk Pass has many frame-constructed homes built on pilings in the 1970s that are ill suited to the intense winds, local environment and living styles. Housing is characterized by overcrowding, poor indoor air quality and drafty living spaces.

Prototype House

In early 2008, CCHRC held a design charette in Anaktuvuk Pass to gather ideas from the community about what kind of housing suited its needs. The CCHRC design team developed a building site and floor plan based on these criteria. The design incorporated innovative building technologies, a traditional *qingok* (passive venting system), a roof truss system designed to hold solar panels, and spray polyurethane foam insulation sealed with a spray-applied elastomeric liner to insulate the walls, floor and roof and provide a weatherproof exterior finish.

The Anaktuvuk Pass prototype house is bermed with soil for insulation and a wind buffer. The foundation is made up of two feet of gravel fill topped with a synthetic waterproof membrane that supports the home's light frame that is filled with spray foam insulation. The house sits directly on the ground, unlike most of the homes in Anaktuvuk Pass that are on pilings. The frame is made of metal studs embedded in the foam that support half-inch sheets of plywood sheathing. Polyurethane foam insulation was sprayed onto the plywood from the outside (unlike typical construction where insulation goes on the inside) to a depth of nine inches, for an approximate R-value[1] of 50. All insulation was covered with an elastomeric coating for weather-proofing. The roof was also covered with nine inches of foam, topped with sod, and vegetated. The house was designed to have a temperature variation from the entry to the back bedrooms to allow for different uses. It was designed to have an area that could maintain cold temperatures for food storage, a cooler entry for gear storage, and a warm sleeping space. This report focuses on the data related to the indoor air quality and the energy efficiency on the Anaktuvuk Pass prototype house.

Space Heating

The primary heat source in the home is a Toyotomi OM-22 Oil Miser Direct Vent Oil Heating System. The Oil Miser is AFUE-rated to be 85% efficient, is thermostatically controlled, and has programmable temperature settings and a "shut-off" safety mode. The Toyotomi is rated to provide 8,000 to 22,000 BTU/hr. The secondary heat source is a Vermont Castings Dutchwest Wood Stove. The wood stove is intended as a supplemental heat source in the event that power goes out or the Toyotomi is not operational.

Electrical Use

The electrical appliances and fixtures were designed to be as energy efficient as target construction costs would allow. Of the regularly used electrical appliances the refrigerator and the water heater draw the most electricity, although the washer and dryer can get heavy use as well. The prototype house also has an outside sewage treatment plant (STP) which requires a constant electric draw for its UV lamps and heaters to both keep the effluent warm, and to treat it; while not a large electrical draw it is constant at about 145 kWh a month. The combined lighting for the house only uses 675 W when all lights are on. The electrical appliances, fixtures, and lighting installed in the house are identified in Tables 1 and 2. This list does not take into account the additional electrical appliances that the occupants may have added.

[1] All R-values in this document are in imperial units of $ft^2 \cdot °f \cdot h/Btu$.

Table 1. Electrical appliances.

Appliance	Power specification
Toyotomi OM-22 - *oil fired heater*	preheat = 275W, burning = 46W
Lifewater XSTP500UVP - *sewage treatment system*	230W
Flojet 4524-500 - *water pump*	154W @ 45 psi
Rheem Marathon 20 gallon – *water heater*	2000W
Sanibest 013 – *grinder pump*	990W
Whirlpool Duet - *clothes washer*	not specified
Whirlpool Duet – *clothes dryer*	not specified
2 Panasonic FV-40NLF1 – *air distribution fans*	132W x 2
Hotpoint - *electric range*	10,100W (@ 240V)
General Electric - *refrigerator*	1650W (Maximum)

Table 2. Light fixtures locations, types, and power consumption.

Location	No. of Fixtures	Number/Type Bulbs per Fixture	Total Power (W)
Garage	3	2/48" LED	90
Cold Storage Room	1	4/48" LED	60
Kitchen Sink	1	1/24.25" LED	15
Kitchen	1	4/48"LED	60
Entry	1	4/24.25" LED	60
Bedroom	3	3/CFL	162
Bathroom	2	2/CFL	72
Can Lights	12	1/LED	156

Ventilation

Ventilation needs to meet several goals in a home: bringing in fresh air to maintain healthy interior living conditions, maintaining healthy interior moisture, and reducing the energy costs of maintaining comfortable living conditions in homes. The original ventilation design (Figure 3) in the Anaktuvuk Pass prototype had fresh air supplied through a single passive intake duct located on the front of the house. This air passed through ducts above the arctic entry and then entered the living room through a vent above the oil heater and wood stove. Air exited the house by one of two routes. One was through a qingok located in the kitchen. The qingok is passive vent that works on stack effect, and can be opened and closed as needed. Air also exited through the ventilation fan for the Lifewater Sewage Treatment Plant (STP). The fan drew air out of the bathroom and fed it to the STP unit, which is located outside of the house. Fresh air was moved to the bedrooms by a distribution fan located in the attic. The fan drew air in from a vent above the Toyotomi (adjacent to the fresh air intake vent) and delivered it to each of the bedrooms.

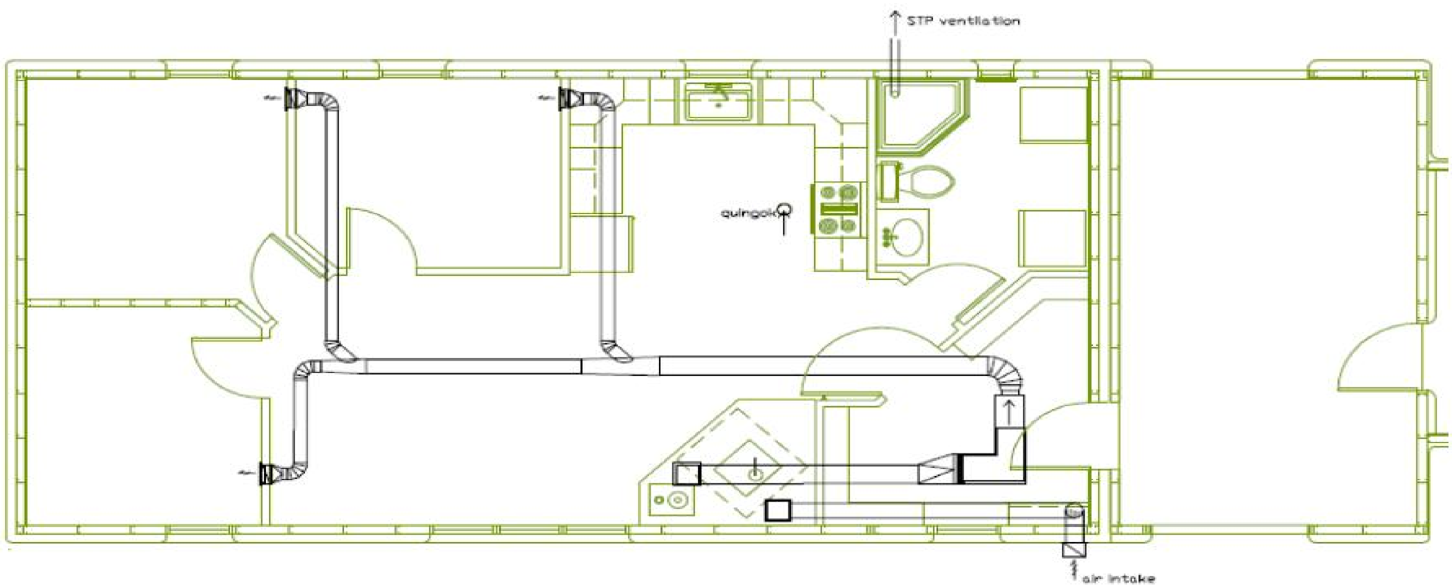

Figure 3. Prototype ventilation design. The original ventilation system was mostly passive with one small fan pulling air out of the house for the sewage treatment plant.

It was quickly apparent from the monitoring data (Figure 4) that the passive system was not bringing enough fresh air into the house and the house was retrofitted with more ducting and a larger exhaust fan in June of 2010. After the installation, temperatures in isolated sections of the house, such as the bathroom, indicated a continued lack of circulation. This is something that the prototype had hoped to address with its undercut doors. More ducting was added in January 2011 to supply more warm air into those rooms. A new combined heat and ventilation system was added to the house in December 2011 to further improve the ventilation.

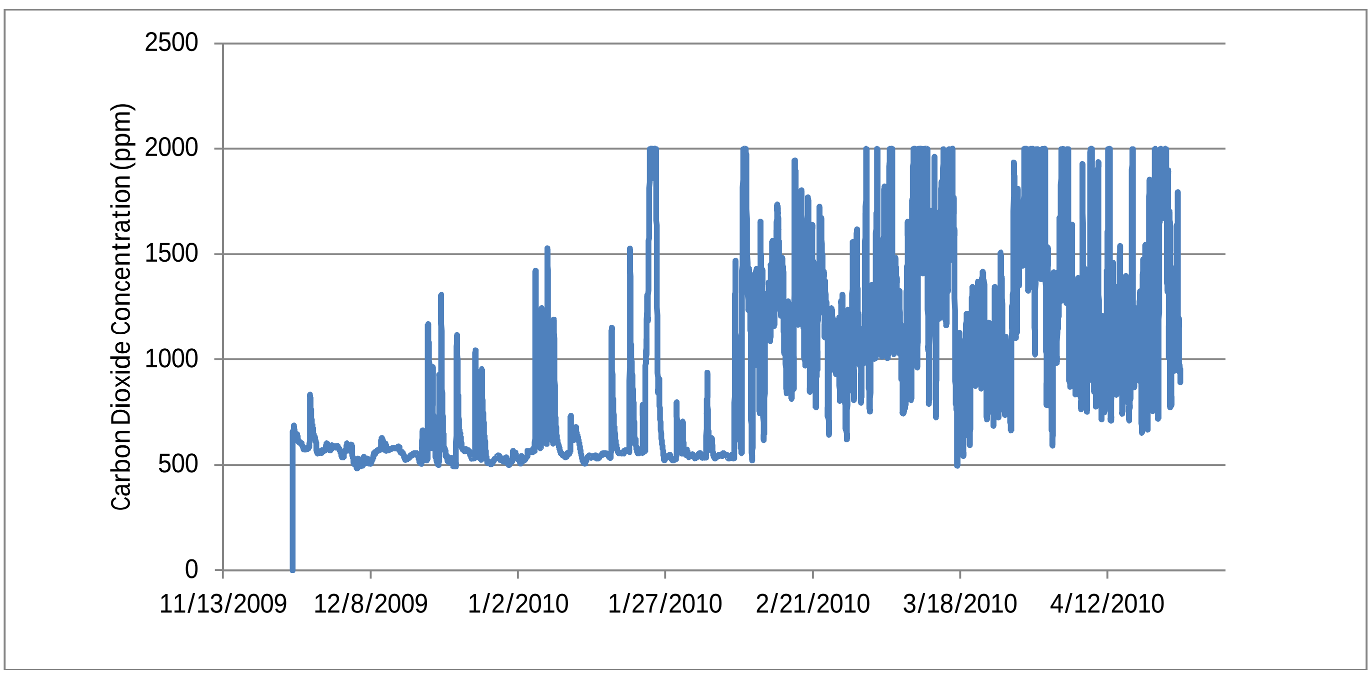

Figure 4. Carbon dioxide levels in the house. The CO_2 concentration maxed out the sensor capacity at 2000 parts per million (ppm); it should stay below 1250 ppm (700 ppm above ambient) to indicate that there is enough fresh air entering the space (ASHRAE, 2007).

Monitoring

Cold Climate Housing Research Center (CCHRC) is monitoring the prototype home in Anaktuvuk Pass. The data collection systems are intended to help demonstrate operations of the prototype designs, evaluate the integration of various building systems, and to recommend design improvements.

Equipment and Methods

There are three Campbell Scientific (CSI) CR1000 data acquisition systems in the prototype house. The three systems are monitoring a variety of systems in the house to develop a comprehensive understanding of the house's performance. The data is logged at two minute, hourly and daily intervals and sent back to CCHRC via a wireless antenna (CSI RF450) that connects to the Nunamiut School's internet connection. An array of sensors (Table 3) was embedded into the prototype house following construction in October 2009.

Table 3. Energy and ventilation sensors.

Sensor	Location	Purpose
Relative humidity	Living room, bedroom, garage, bathroom, and cold storage	Indoor air quality
Carbon dioxide (CO_2)	Living room and bedroom	Indoor air quality
Temperature	Qingok, STP intake, fresh air intake	Indoor air quality
Temperature	Living room, bedroom, garage, bathroom, floor, attic, and cold storage	Occupant comfort
Fuel level	On fuel tank	Energy use
Stove pipe temperature	On stove pipe	Energy use
Current transducer	Circulation fan, heater, STP, and bathroom fan	Energy use
Power meter	Grid power, solar power, and wind power	Energy use

All of the sensors provide an analog signal which is converted via a CRBasic program to useable data. The humidity, temperature and CO_2 are all self explanatory, providing average conditions in the house at regular intervals. The current readings from the fans are used to estimate the total power use of the ventilation system. By estimating the voltage to be 115V, this system overestimates the total power slightly by ignoring the power factor and fluctuations in the incoming voltage.

The fuel level and stove pipe temperature readings are used to determine the heating demand of the house. A thermocouple on the stove pipe records when the woodstove is fired. Monitoring for sharp temperature increases in the pipe provides a simple on/off signal for the woodstove. That on/off signal can be used to estimate how much fuel the woodstove is offsetting. The fuel level sensor is a pressure transducer placed at the outlet of the fuel storage tank. As the level of fuel in the tank changes the sensor records the changes in the pressure at the bottom. The pressure reading is divided by the specific weight of heating fuel (0.379 lb/in^2)to get the height of the fuel in the tank. The volume is then determined using the height of fuel and the dimensions of the tank. The hourly estimate of the fuel volume allows for the calculation of the fuel taken from and added to the tank.

CCHRC has been working closely with GW Scientific and the homeowners to monitor the house. The homeowners have been in the house for almost two years and have been actively interested in the monitoring and upgrades to the house.

Ventilation Analysis

The air quality in a home is complicated to monitor and involves several parameters that need to be carefully balanced. The optimum humidity zone for human health is between 40% and 60% relative humidity (Sterling, 1985). This optimum band minimizes bacteria growth and virus spread that will occur at both very low and very high humidity; it also minimizes fungi and dust mites that thrive in high humidity. The optimum zone also reduces respiratory infections that come from low humidity and asthma that can be caused by very low and very high humidity. However, the optimum humidity zone for human health is not optimum for building health and the high humidity levels are detrimental to building durability. Relative humidity of 40% in the interior space can mean 80% or higher relative humidity inside the wall cavity depending on outside air temperature and wall construction. In an effort to balance healthy people and healthy buildings the recommended interior relative humidity is 30% to 50% for Alaska (Seifert, 2007).

In addition to having healthy humidity levels, changing the air in the house for fresh air is also important. A tight home has far less air exchange with the outside relative to older leaky homes. This allows for the build-up of stale air in the house. The stale air keeps noticeable odors from cooking and human activity in the house and can harbor higher concentrations of volatile organic compounds (VOCs) that may off gas from furniture, carpet, tile, and other items in the home. Carbon dioxide (CO_2) concentration is a marker that is simple to monitor and gives a good indication of air exchange. ASHRAE (2007) specifies that maintaining a steady state CO_2 level less than 700 parts per million (ppm) above ambient should ensure that sufficient fresh air is supplied to the space.

Keeping CO_2 levels low and humidity healthy can be conflicting goals, especially in the winter when fresh air introduced into the house will have very little moisture in it. On particularly cold days the interior humidity can drop drastically (Figure 5).

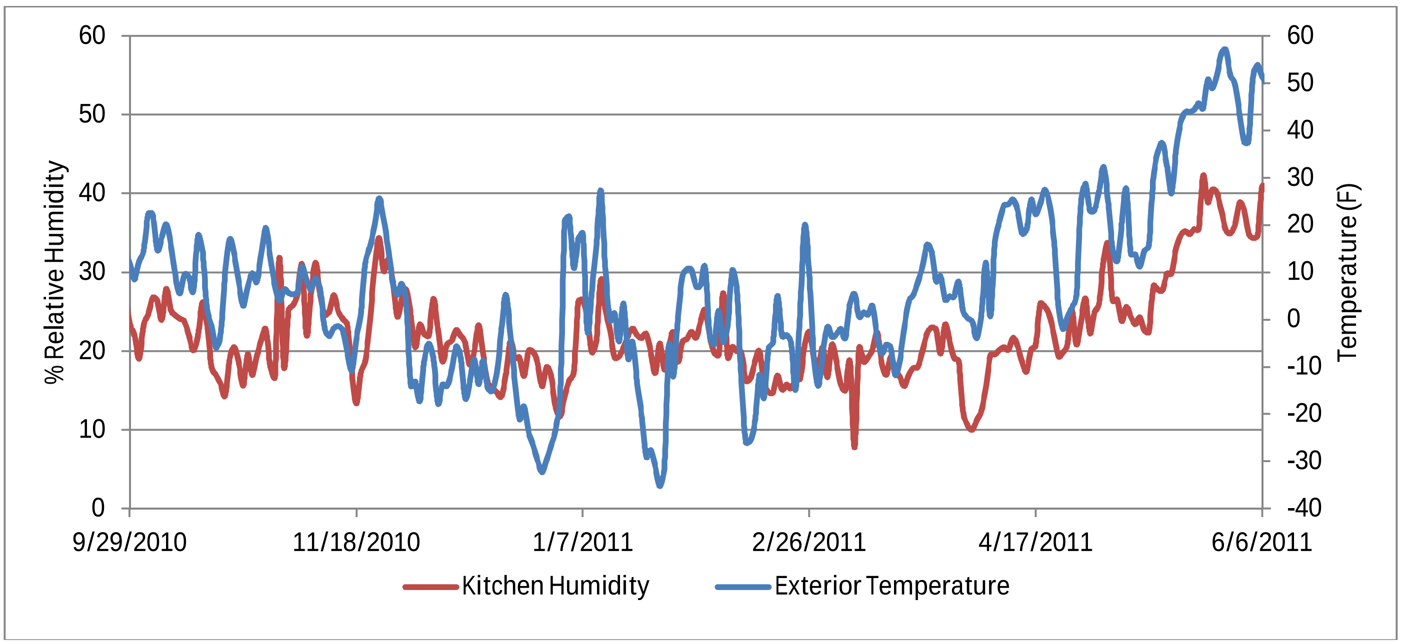

Figure 5. Winter interior humidity and exterior temperature. As the exterior temperature dropped in the winter the interior humidity also dropped; as temperatures started to rise in the spring the humidity also started to rise.

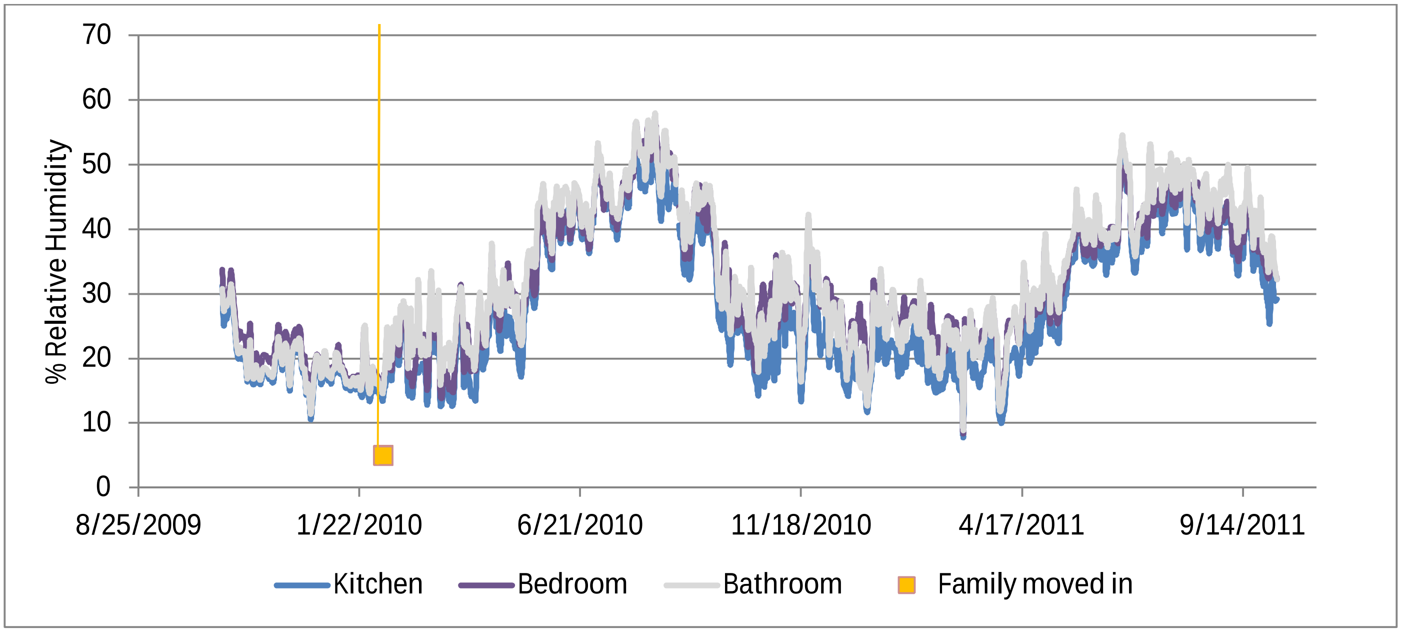

Figure 6. Interior relative humidity for the Anaktuvuk Pass prototype house. The relative humidity is dependent on the interior temperatures and the amount of moisture in the outside air.

Figures 6 and 7 demonstrate the difficultly of balancing air exchange with healthy humidity. The CO_2 levels in the house should remain below 1250 ppm, yet they are exceeding 1500 ppm on several occasions, indicating that more air exchange would be beneficial. However, the humidity is already below the healthy range in the winter and more air exchange would lower the humidity more. A combined heat and ventilation system that will incorporate a heat recovery ventilator (HRV) and an in-line duct heater was installed in the house in December 2011; this system is expected to improve the indoor air quality by allowing for more effective control of the ventilation.

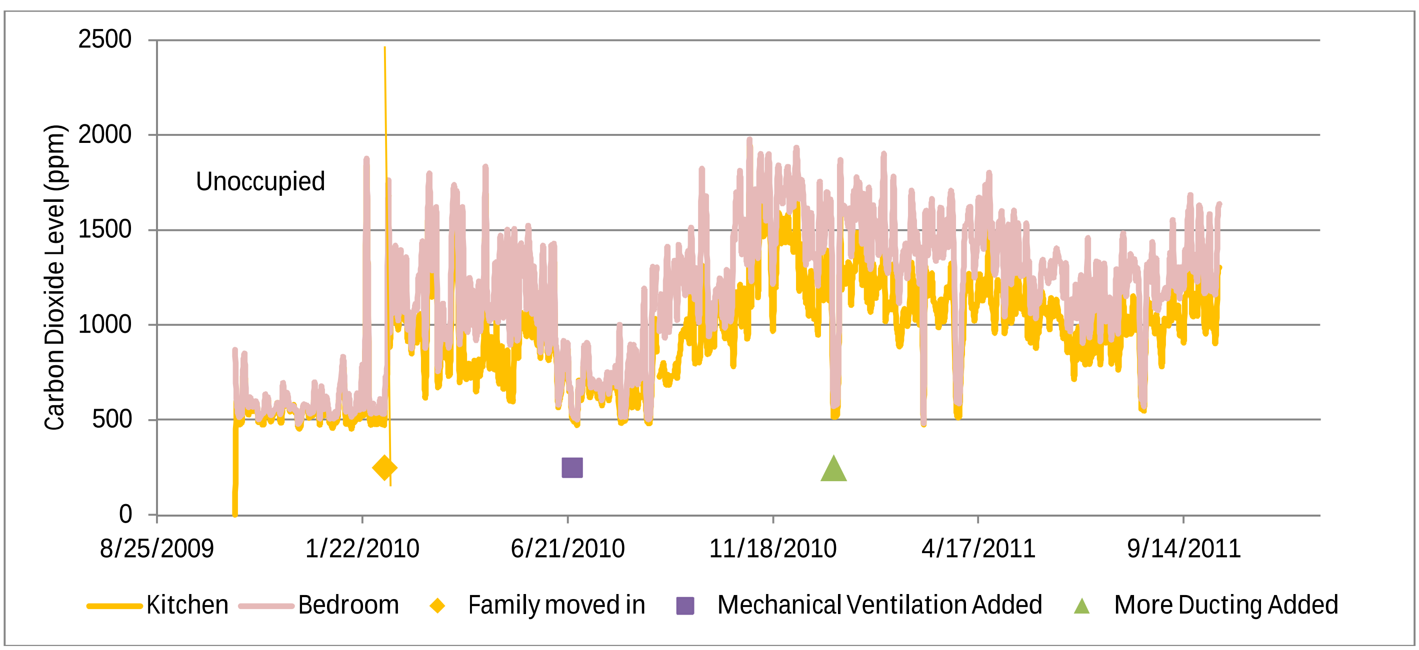

Figure 7. Interior carbon dioxide levels for the Anaktuvuk Pass prototype house. The interior CO_2 levels are higher than the ASHRAE recommended values of 700 ppm above ambient (1,250 ppm); however a new heating and ventilation system to be installed in December 2011 should increase the air changes in the house and improve air circulation throughout the house.

Another consideration when introducing fresh air in the winter is the need to keep the house comfortable. There is no way to get around the need for fresh air in a tight home, ideally the ventilation system will have some sort of heat recovery. Without heat recovery the house will require more energy to heat. In fact, part of the jump in fuel use between the two winters in the prototype house (Table 4 on following page) from 191 gallons to 241 gallons may be due to the addition of the exhaust fan and ducting to the ventilation system. There is no heat recovery in the current system. A mechanical heat recovery ventilation system does require electrical energy, but the minimal electrical energy is usually made up in fuel savings. The current system in Anaktuvuk Pass without heat recovery has used 426 kWh electricity since December 2010 (Figure 8) compared to the HRV in Quinhagak that has used 195 kWh and has heat recovery.

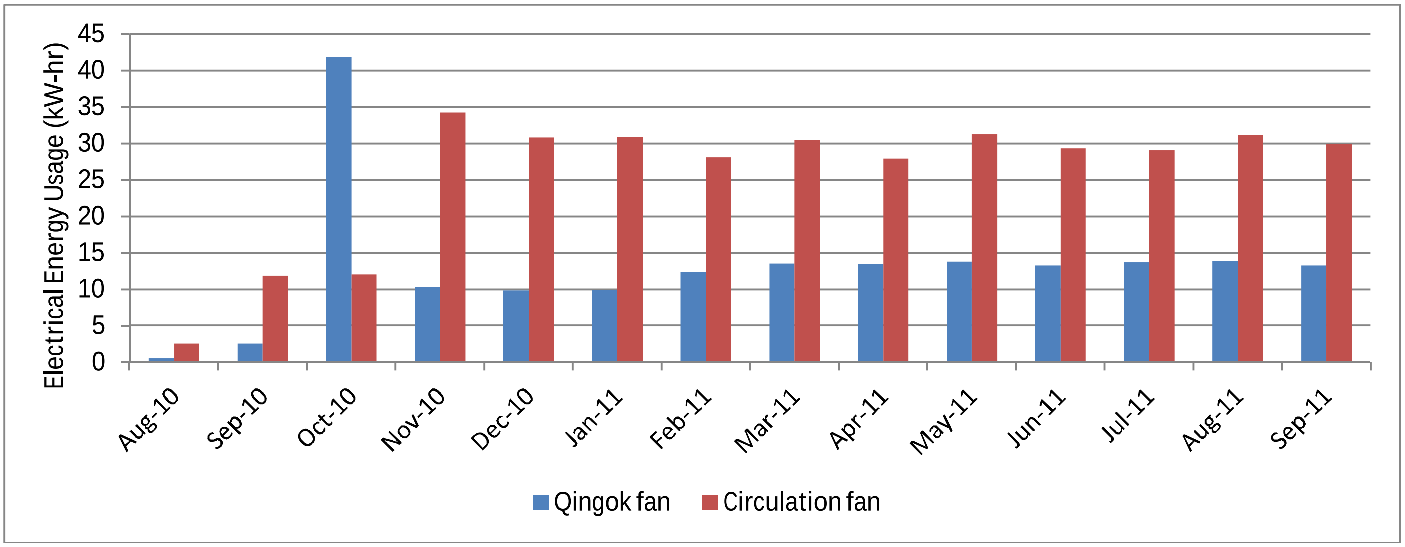

Figure 8. Electrical energy used by the ventilation system in the Anaktuvuk Pass prototype house. The qingok fan energy spike in October 2010 is a result of figuring out the best control setting to supply the best amount of fresh air at the least electrical cost.

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Heating Demand

Typical home heating usage in rural Alaska is not well known. The 2009 Alaska Housing Assessment puts Anaktuvuk Pass in its rural 2 category which has a median house size of 1056 square feet that consumes an average of 880 gallons of heating fuel a year (Alaska Housing Finance Corporation, 2009). This estimate is for small remote communities all over the state, so Anaktuvuk Pass with its colder climate may average even more. Several homes of comparable size in Anaktuvuk Pass that were rated under Alaska Housing Finance Corporation's (AHFC) Building Energy Efficiency Standards (BEES) for new construction were estimated to consume 327 gallons of fuel per year (Alaska Housing Finance Corporation, 2011). These BEES rated homes are rare in Anaktuvuk Pass, in that they were built in 2001 with special attention to energy efficiency. They do not represent the typical heating use in Anaktuvuk Pass. (AHFC finances approximately 40% of all new residential construction in Alaska. A requirement for AHFC financing is meeting BEES. The BEES are a number of Alaska-specific amendments to IECC 2009.)

The tight envelope of R-50 insulation should make the heating load for the house around 52.2 MMBtu for the year (AkWarm 2.1.2.1[2]). The model estimates that the house will use 193 gallons of #2 diesel oil. When the model is compared to the actual use for two separate years it underestimates the fuel use for the second year. This is due to the changes in the ventilation system that require more heating than the original model intended. Even with the increase in

[2] AkWarm 2.1.2.1 is the energy modeling program for Alaska Housing Finance Corporation's BEES and energy retrofit programs.

the second year, the house used 27% of the fuel a typical rural house would use, and used 25% less fuel than the BEES homes use.

Table 4. Gallons of heating fuel used summarized by date.

	Dates	Gallons
Family moved in Feb. 7, 2010 (dipstick measurement)	Dec. 22, 2009 to May 15, 2010	86
Spring use (dipstick measurement)	May 15, 2010 to June 27, 2010	29
Summer, fall and early winter	June 27, 2010 to Dec .22, 2010	76
Total first year	Dec. 22, 2009 to Dec. 22, 2010	191
Late winter 2011	Dec .11, 2010 to April 3, 2011	115
Spring and summer 2011	April 3, 2011 to October 1, 2011	66
Fall and winter 2011	October 1, 2011 to Dec. 11, 2011	60
Total second year	Dec. 11, 2010 to Dec. 11, 2011	241
Total since construction	Dec. 22, 2009 to Dec. 11, 2011	432

The fuel use in the prototype house has increased from its first winter. The house was unoccupied for a portion of the first winter and the homeowners have increased the set point on the heat system. Additionally the ventilation was reconfigured to exhaust more air and expanded to a previously unheated space, thus bringing in more cold air. This next winter will see another change in the heating fuel use as the new heat and ventilation system comes online. The new system is expected to be more efficient than the old system.

Electrical Demand

Home electrical usage is strongly a function of occupant behavior. Anaktuvuk Pass was designed with the most efficient appliances that were affordable within the construction budget. The electrical usage in the house is shown in Figure 9. Prior to the family moving in February 2010 the total use for the house averaged 367 kWh a month. Since the house has been occupied it has averaged 1100 kWh per month. This average is above the Alaskan monthly household average of 661 kWh/month (U.S. Energy Information Administration, 2009).

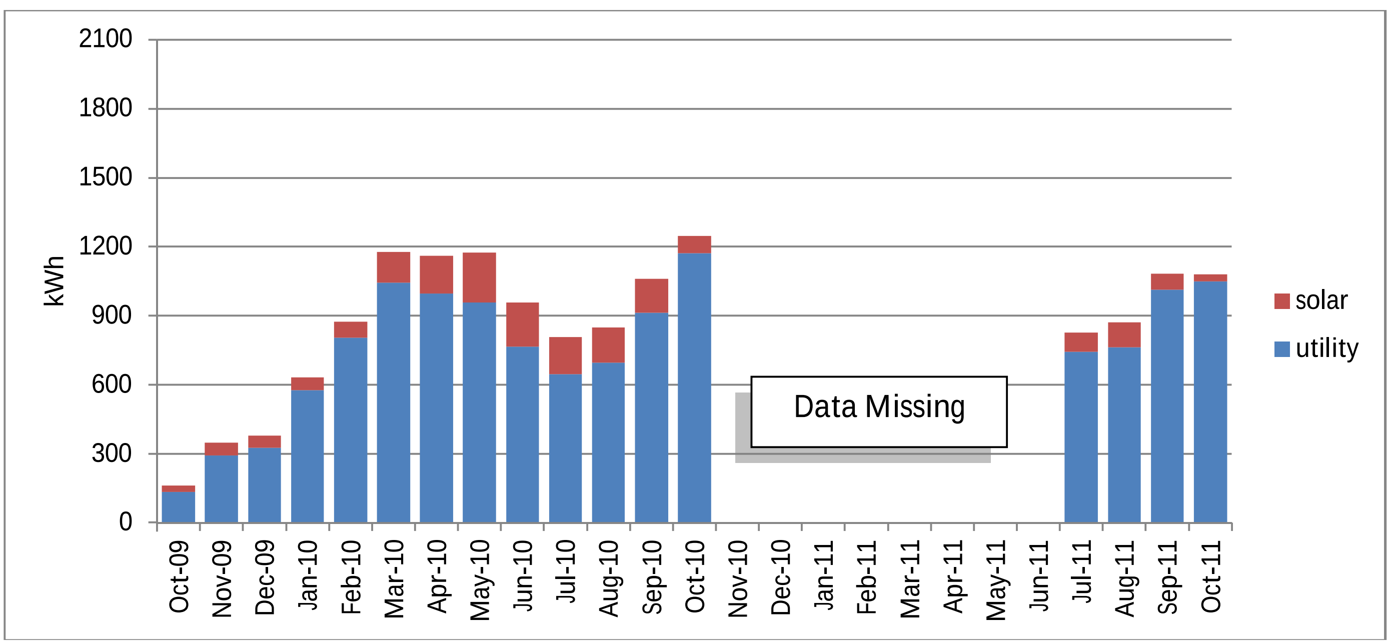

Figure 9. Electrical use for the Anaktuvuk Pass prototype house. The solar energy is included as part of the total monthly use, as it is also consumed by the house.

The prototype house has an array of 6 solar photo-voltaic panels that offset the grid power by about 7% of demand on a yearly average. In the summer that percentage approaches 20%and the solar array can produce more electricity than the house consumes. That electricity is sent back to the grid. Figure 10 shows the solar electricity produced in the course of one day in August, around noon the panels are feeding electricity back to the grid.

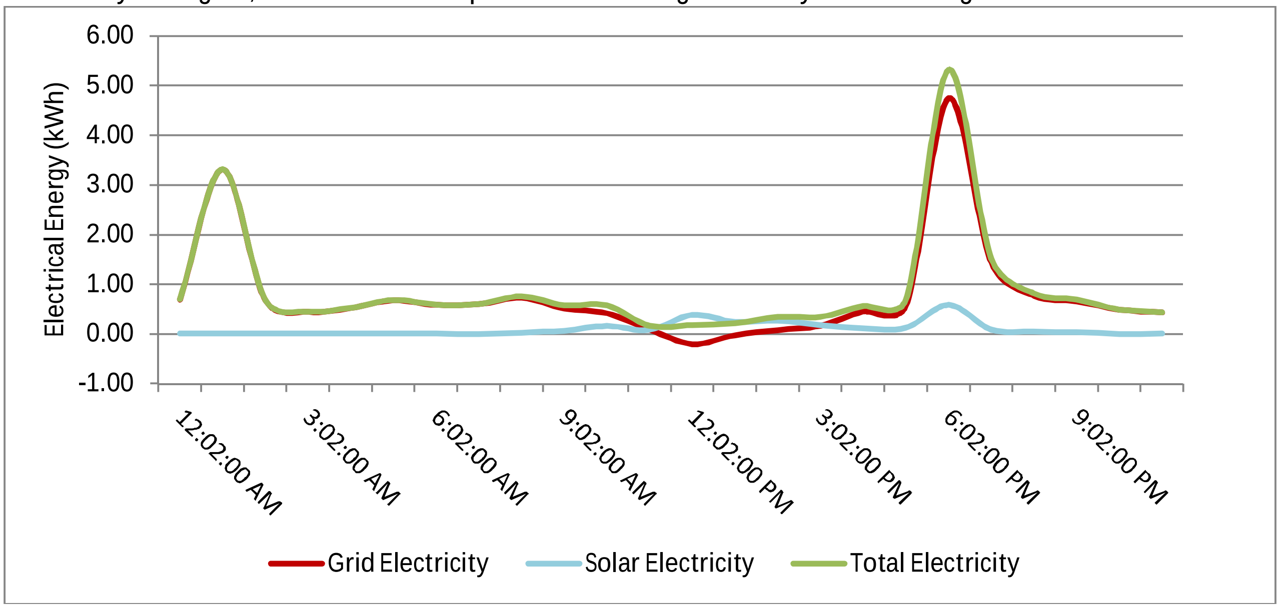

Figure 10. Electrical Usage for August 6, 2011. The electricity from the solar panels (blue line) rose above the amount of electricity used by the family (green line). The red line drops below zero because electricity is flowing into the grid from the house, instead of from the grid to the house.

The STP has a fairly consistent monthly electrical demand. It uses an average of 12% of the total house demand in a month. Figure 11 shows the STP electrical demand as part of the total house demand.

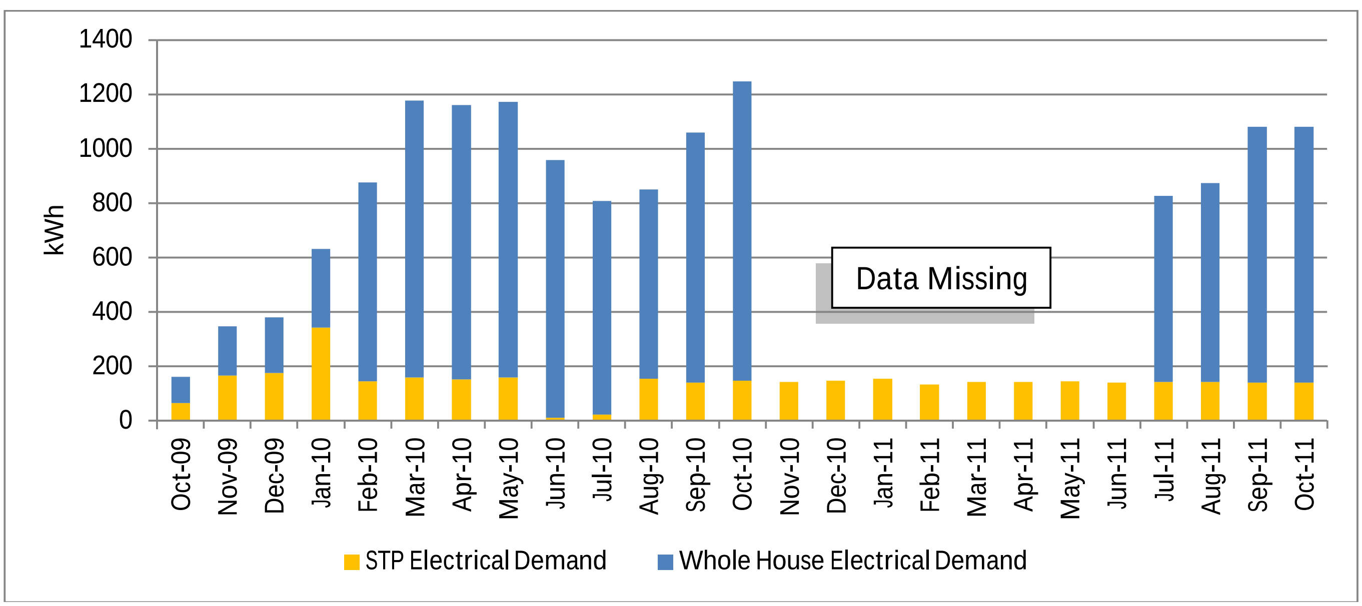

Figure 11. Electrical demand for the sewage treatment plant as part of the whole house demand. The STP electrical draw is not the sole reason that the Anaktuvuk Pass house uses so much more energy than the average Alaska house, but it does start to make up the approximate 440 kWh difference.

CONCLUSIONS

Energy efficiency is more and more important to homeowners as the price of energy increases. Conserving energy on a house by house basis can save Alaskans $406 million a year if each house is improved by 33% (Wiltse, 2011). In order to reach this level of improvement houses need to be better insulated and less drafty. The Anaktuvuk Pass prototype demonstrates that this level of efficiency in home heating can be made, even in the Arctic. The 73% reduction in fuel use from a typical rural home is the most telling demonstration of this improved efficiency. This heating fuel use is even expected to decline with the new heat recovery ventilation system.

With the advent of tighter houses there is the necessity to ventilate. A great deal of research is currently being done into optimized ventilation strategies for Alaska and other circumpolar regions. Balancing healthy humidity and proper air changes is a delicate dance, which will continue to improve with new technology and innovation. The Anaktuvuk Pass prototype has gone through three versions of non-heat recovery ventilation systems trying to achieve this correct balance. The fourth iteration installed in December 2011 includes a heat recovery unit which is expected to improve air quality and thermal comfort while lowering heating costs. CCHRC will continue to monitor the house to evaluate this new system.

With every new house (Tagiugmiullu Nunamiullu Housing Authority has built 5 based on the Anaktuvuk Pass model) there are innovations that improve the energy efficiency and occupant comfort.

Partners

The following organizations collaborated to help design, build and study the Anaktuvuk Pass prototype house:

- Village of Anaktuvuk Pass
- Burris Family, House Residents
- Cold Climate Housing Research Center (CCHRC)
- Tagiugmiullu Nunamiullu Housing Authority (TNHA)
- Ilisagvik College
- Alaska Housing Finance Corporation (AHFC)
- Denali Commission
- US Department of Energy, National Renewable Energy Laboratory (NREL)
- Canada Mortgage and Housing Corporation (CMHC)
- Geo-Watersheds Scientific (GWS)
- Yukon River Inter-Tribal Watershed Council (YRITWC)
- Nunamiut School, North Slope Borough
- Alaska State Museum
- EE Internet
- Remote Power Inc. (RPI)
- Lifewater Engineering Company (LEC)
- Campbell Scientific Inc. (CSI)

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