

**ENERGY-EFFICIENT HOMES IN ALASKA:
HISTORICAL AND CONTEMPORARY PERSPECTIVES ON
ADAPTATION AND INNOVATION**

By

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Abstract

Global climate change is largely caused by greenhouse gas emissions from anthropogenic sources. The building industry is responsible for over 40% of global carbon emissions. Almost half of the energy consumption in buildings is from space heating and cooling. The incorporation of energy efficiency in homes has a large potential to mitigate future climate change impacts while at the same time aiding household members to adapt to the effects of global change. This dissertation explores this potential in Alaska, where in addition to climate change impacts, residents are vulnerable to high oil prices affecting not only their energy security, but also their health, food security, and sense of place. This interdisciplinary dissertation explores the viability of Alaskan energy-efficient homes from social, economic, and environmental perspectives.

In the following chapters, I first use a conceptual model of energy security that is adopted from the food security literature to determine that a significant segment of Alaska is in an energy-insecure state. This is predominantly due to expensive fuel, overreliance on fuel imports, inefficient uses of heating fuel, and a legacy of inefficient homes.

Next, I provide a historical survey of Alaskan homes from pre-contact dwellings to modern era homes. Some of the pre-contact homes' energy efficiency features have been reintroduced in some modern homes, such as a small square-foot-to-occupant ratio, passive solar design, arctic entrance, round or octagonal building layout, using earth berming, sand dunes, and snow banks as natural insulation, permafrost lined cellars, subterranean building style, thermal mass, and shared stone walls between rooms.

Third, I discuss interviews conducted with homeowners of highly energy-efficient homes and other stakeholders in the building-, real estate- and financing industry, which reveal several barriers to the adoption of this building style innovation. The predominant barriers are lack of information and education on this building style by homeowners, designers, and builders; economic disincentive due to a low appraisal value; and a psychological mindset resisting change.

Finally, I use a case study of a highly energy-efficient home in Dillingham, Alaska to exemplify the carbon payback point. Using a life cycle assessment approach, I calculated that within 3.3 years the highly energy-efficient house has reached carbon parity when compared to a conventional counterpart house.

Collectively, I build on these findings to recommend improvements in education about the benefits of energy efficiency, an overhaul of the appraisal system, and a careful consideration of the psychological aspects of embracing innovations in an effort to facilitate wider adoption of highly energy-efficient homes in Alaska.

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¹ See Appendix A for the IRB letter of approval.

Chapter 1: Introduction

“What if we could make energy do our work without working our undoing? Could we have fuel without fear? Could we reinvent fire?”

Amory B. Lovins

“A 40-year Plan for Energy” TED Talk, May 2012

Scientific evidence gathered since the mid-19th century indicates a warming of the global climate system (IPCC, 2013). The main culprit fueling this warming is an unprecedented increase in greenhouse gas concentration in the atmosphere. Carbon dioxide concentrations alone have increased by 40% when compared to global pre-industrial levels. This escalation can be attributed to multiple anthropogenic factors; increased fossil fuel emissions and emissions from changes in net land use. The adverse effects of climate change impact not only atmospheric systems and ecosystems but the human population as well.

1.1 Global Impacts of Climate Change

On a global scale, oceans warmed by 0.11 °C from 1971-2010 (IPCC, 2013). Glaciers are shrinking, Greenland and Antarctic ice sheets are losing mass, and spring snow cover is decreasing in the Northern hemisphere (IPCC, 2013). Permafrost has warmed by 3 °C between 1980-2000 in Northern Alaska. Globally, sea levels rose by a mean 0.19m from 1901-2010 (IPCC, 2013). Not only do these changes affect human systems, but also hydrological, terrestrial, and marine ecosystems (van Aalst, 2006). Changes to hydrological systems, including but not limited to changing precipitation, permafrost thaw and melting snow and ice, are affecting water resources for drinking and agriculture, and impacting crop yields (IPCC, 2014a). Climate extremes such as floods, landslides, cyclones, heat waves, drought, and wildfires are bringing into question the vulnerability of ecosystems and exposure of humans to natural hazards. The upsurges in extreme weather events are predicted to increase human injury, illness, and death rates as well as create a higher risk of food, water, and vector-borne diseases (ibid). Furthermore, planned or forced migration and displacement of vulnerable population groups increases with the extreme weather events such as droughts and floods, and rapid landscape change like coastal erosion (Parenti, 2012). Malnutrition is another adverse effect of climate change, resulting

from lower crop yield and food production, due to changes in weather and soil erosion (Wheeler & von Braun, 2013). Violent conflicts can also be indirectly fueled by climate change as well as national security issues due to the transboundary effects of climate change, sparking natural resource competition or affecting the integrity of country borders (Parenti, 2012).

1.1.1 Climate Change Mitigation

Projections made by the Intergovernmental Panel on Climate Change (2013) are clear that it will require a substantial reduction in greenhouse gas emissions to mitigate climate change. Globally, the U.S. is responsible for 18% of world carbon dioxide emissions, ranking second, after China (U.S. Department of Energy, 2012). In 2010 the U.S. building sector accounted for 41% of primary energy consumption nationally, and 7% globally. This was higher than the contribution of the industrial sector at 30% and the transportation sector at 29%. In the U.S., the primary energy consumption by buildings has risen by 48% between 1980 and 2009, and consumption is expected to rise a further 17% by 2035 when compared to the 2009 level. This increase is projected to be due primarily to increased households, floorspace and population numbers in the U.S. Since the building sector has a comparatively large contribution to U.S. carbon emissions, a substantial reduction in this sector would have a significant impact on mitigating climate change.

The Intergovernmental Panel on Climate Change has named energy efficiency measures as a key climate change mitigation strategy (IPCC, 2014b). Specifically, in the building sector, the usage of more efficient heating and cooling methods, improved insulation, passive and active solar design for heating and cooling, and integrated building designs are stated as key mitigation technologies and practices. The research presented in this dissertation contributes to knowledge about these technologies and practices, through a focus on energy-efficient homes in Alaska from a sustainability perspective. Sustainability in the specific context of an engineered building system encompasses not only environmental resource consumption and waste generation, but also considers human needs and economic value (Fiksel, 2003). The arctic is often described as the climate canary (Duyck, 2012; Foley, 2005, Larsen et al., 2008) because global change effects are most strongly felt in that area, forcing the inhabitants to adapt before other population segments are faced with the urgency to do so. A subsection of Alaskan builders and homeowners are exploring highly energy-efficient home design for various motivations, from wanting to adapt to existing conditions to a desire to influence future abatement of carbon emissions. This research investigates building infrastructure, to provide both rural

and urban community members in Alaska with information on energy-efficient choices that they can make.

As I explore in the next chapters, possible benefits of the adoption of energy-efficient home building in Alaska include not only monetary savings, but also reduction in carbon emissions and improving people's capacity to adapt to climate change. This research further delves into the details of building, financing and operating highly energy-efficient homes, and also calculates when carbon parity is reached, since typically these types of homes require more building materials than conventional homes. Furthermore, the legacy of incorporating energy efficiency features in dwellings in Alaska is explored through a look at vernacular homes, reviewing cultural and social influences. Vernacular architecture refers here to a building style that accommodates a households' needs and values as well as adaptability to external stressors. This research furthers the discourse on the viability of a strategy to abate carbon emissions from the building industry and explores the feasibility of highly energy-efficient homes as an adaptation option from a social perspective.

1.2 Built Environment

Buildings consume energy from a variety of avenues, from multiple sources. The production and assembly of the building materials, transportation to the building site, construction, operation of the building, decommissioning and disposal of waste materials all contribute to the life-cycle energy of a building, or the emissions footprint if the impact is translated into emissions equivalent (Li et al, 2012).

1.2.1 Buildings and Energy

Understanding the life-cycle emissions of a building can help in the evaluation of building design choices. To begin with, the building materials themselves embody a significant amount of energy (Li et al., 2012). Production of raw materials, such as stone, wood or metal, requires energy in the form of infrastructure, machinery, and human capital. Energy is required for transportation to and for the operation of factories to process raw materials and assemble them into building materials. Since buildings can be composed of over 2,000 separate components and 60 basic materials, the building materials' energy impact is noteworthy in a building's energy equation (Kohler & Moffatt, 2003). Construction of a building requires transportation of building materials to the site, construction

infrastructure, machinery, and human capital. Furthermore, during the construction of a single-family house anywhere between 2-7 tons of waste is generated, the disposal of which must also be accounted for in term of building energy requirement (U.S. Department of Energy, 2012). Yearly, the U.S. construction industry produces 30-35 million tons of waste from construction, renovation, and demolition of buildings.

Operation of a building requires energy for a variety of purposes (figure 1.1). In the most recent version of the U.S. Department of Energy’s Building Energy Data Book, among all the energy end-uses in U.S. buildings, including water heating, lighting, cleaning, cooking, electronic devices, and ventilation, space heating and cooling made up almost 50% of energy use (U.S. Department of Energy, 2012).

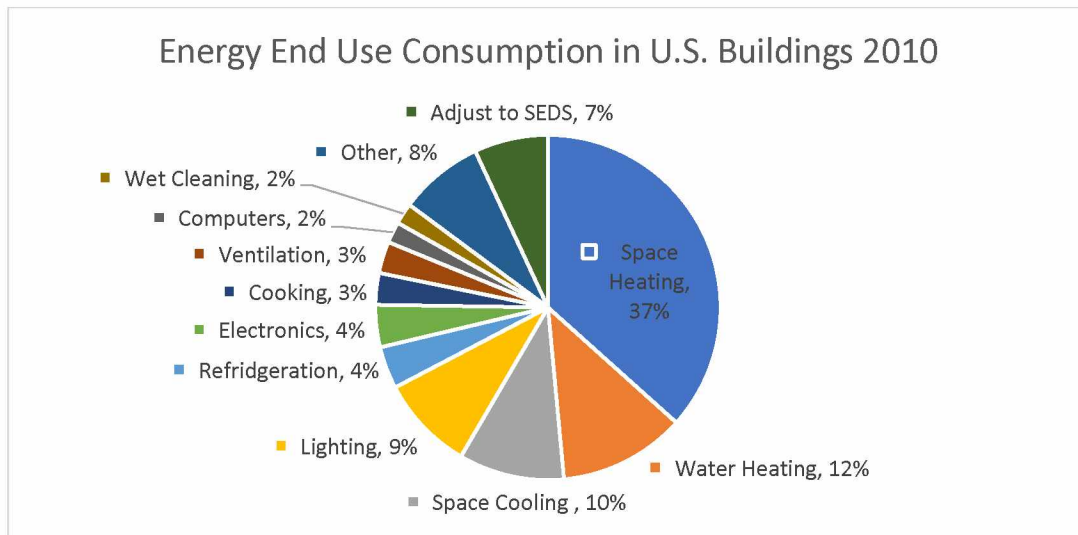


Figure 1.1: U.S. Buildings consumed energy broken down by end uses in 2010 (SEDS: EIA’s State Energy Data System). Sourced from the Building Energy Data Book 2011 (U.S. Department of Energy, 2012).

The carbon dioxide emissions from space heating and cooling in U.S. residential buildings in 2010 were 533.5 million metric tons (U.S. Department of Energy, 2012). Reducing this heating and cooling energy consumption through energy efficiency measures, such as improved insulation or air tightness, could help reduce these carbon emissions. The Energy Information Administration (EIA) surveyed residential households in 2001 asking respondents to judge their house based on insulation quality and drafts felt indoors (Hojjati, 2004). The airtightness of homes not only reduces drafts but also significantly increases heating efficiency in winter. Similarly, the quality of insulation used in homes relates to heating efficiency as well as to indoor thermal comfort. Of the roughly 107 million nationally surveyed households, 48.3% reported feeling a draft in their home and 19% either had no insulation or

thought their house was poorly insulated. Unsurprisingly, newer construction homes, built after 1990, had the largest percent of households that indicated their home was well-insulated (63.4%) and was not drafty at all (65.7%). In contrast 27.9% of occupants of homes built before 1950 indicated that their home was well insulated and only 39.6% did not feel a draft in their home. While newer construction homes seemingly improve upon air tightness and insulation quality, there still appears to be a range of homes that are lacking these two essential elements to increased heating efficiency.

1.2.2 Buildings and Health

Health of building occupants and communities within which buildings exist are also tied to the energy consumption of buildings. Over the past decade both physical health and mental health have been linked to the built environment (Hood, 2005). Both the external and spatial aspects of buildings play a part in the indoor contributing health factors. For example, spatial analysis relates to health impacts of occupants by assessing a home's proximity to public services (such as hospitals, schools, grocery stores, public parks), housing segregation, condition and availability of sidewalks, or bike paths. Reducing heavy traffic, especially from diesel trucks, in residential neighborhoods can have a positive effect on asthma incidence and other respiratory illnesses. Zoning residential areas to limit industrial pollution can be another factor contributing to positive health outcomes.

If a house is not cared for and maintained it can lead to a state of dilapidation, resulting in lead exposure, and increased indoor triggers of respiratory illness, including mold, moisture, dust mites or rodents. Additionally, indoor air quality in commercial and residential buildings alike influences the health of its occupants. Using building materials that contain toxic chemicals, including paint, that leach chemicals over time further contributes to indoor air pollution (U.S. Consumer Product Safety Commission, 2017). Indoor air quality can play a large role in occupants' health, as humans spend approximately 90% of their time indoors. Influences to indoor air quality include home heating choices, poorly-, unvented, or not properly combusted fuel sources such as kerosene or heating oil, stoves, fireplaces, gas stoves or space heaters. Heating methods that are well ventilated and properly maintained improve indoor air quality, however, they contribute to outdoor air pollution. In cold temperatures sealing a home for airtightness improves indoor temperatures but can also lead to improperly ventilated homes and increased moisture and mold build-up (Younger et al., 2008). Long-term poor indoor and outdoor air quality have been correlated to increased cardiovascular and respiratory illnesses and increased mortality incidents for both types of illnesses (Anderson et al., 2012).

Because most conventional buildings last between 50-75 years, the emissions of buildings during operation have a long lifespan. Building designs are legacies that impact future generations; 20% of residential homes in the U.S. in 2005 were built prior to 1950. Their design choices still affect the region today (U.S. Department of Energy, 2012). Reducing building-related emissions would lead to fewer health impacts as well as overall carbon mitigation.

In high-latitude climates, the amount of fuel a home requires to maintain comfortable indoor temperatures is a contributing factor to occupant health. In regions where fuel prices are high, fuel poverty can negatively affect wellbeing. Fuel poverty, or energy insecurity as it is also described, is the inability of a household to meet the World Health Organization's minimum indoor temperature standards, 21 degrees Celsius in living rooms and 18 degrees Celsius in all other rooms (WHO, 2007). Living below these indoor temperature conditions is considered unsafe and adverse to human health, generating significant health risks (WHO, 2007; Liddell & Morris, 2010). In a study conducted by Liddell and Morris (2010) the potential for fuel poverty of a household is traced back to household income, or the ability to afford a baseline thermal efficiency of a home. The scale of energy-efficient improvements or updates made over the lifetime of a house significantly impacts affordability of home heating and the choice of home indoor temperature, which in turn has potential for positive impacts on mental and physical health of the occupants.

1.2.3 Buildings and Environmental Impacts

Voluntary green building programs are urging building design towards energy efficiency to reduce greenhouse gas emissions (Kwok & Rajkovich, 2010). The building industry and associated stakeholders are increasingly paying attention to the negative environmental consequences of buildings (Bayer et al., 2010). The immense impact a building can have on the environment, regionally and globally, is an important consideration during all building stages, from sourcing building materials, the design and construction process to how the materials are disposed of at the end of the building's life. With the projection of over 14 million new homes to be built by 2030 (U.S. Census Bureau, 2005) the need for professionals as well as homeowners to conduct an environmental impact assessment of buildings is ostensible. Determining the carbon payback point as well as comparing the carbon emissions in all building phases of the house to a conventional counterpart house provides researchers, homeowners and building professionals information on building homes to meet climate-change concerns.

1.3 Alaska - the Canary in the Coal Mine

Vulnerability of humans to the impacts of climate change is driven by multiple interacting variables and circumstances (Bankoff et al., 2004; Oliver-Smith, 2004; Adger, 2006). Typically, there are social, cultural, economic, political, and ecological drivers and determinants of vulnerability, including disparate power relations and equity issues. Vulnerability in the context of this dissertation is described as a function of the exposure and sensitivity of a system to external stress (Adger, 2006). The arctic region, which includes a large portion of Alaska, has a high vulnerability to external stress, including climate change impacts, oil price fluctuations, transportation disruption and other socio-, economic, or political divergences. Due to the strongly felt impact of warming temperatures, affecting sea ice melt, thawing permafrost, and changes in cold weather cycles, the arctic is considered particularly sensitive to the effects of climate change (Duyck, 2012). Local temperatures increase at a faster rate than in other areas of the globe (IPCC, 2007), having proportionally large repercussions since the majority of sea ice is present in the arctic, and affecting the lifestyle of the arctic inhabitants in some population segments and communities drastically. In Alaska, some climate change impacts have the potential to disrupt the entire transportation system (Larsen et al., 2008). For example, thawing of permafrost can cause roads to buckle making them impassible. Sea-level rise can damage harbors and adjacent infrastructure, such as receiving docks. An increase in floods could lead to damaged bridges, roads and airplane landing strips, and an increase in wildfires could directly damage built infrastructure and make some roads impassible. A disruption in imported goods leads to impacted food and energy security in the state.

1.3.1 Energy Security in Alaska

Energy security in Alaska is closely interconnected with other areas of wellbeing, such as food security, physical and emotional health, subsistence lifestyle, and maintaining population levels in rural villages. Both rural and urban Alaska are dependent on fuel and food imports. The Alaska Farm Bureau estimates that if transportation of goods to Alaska were halted, for example due to a transportation disruption, there would be 3-5 days before grocery store shelves would be completely empty, including canned and packaged food, and fresh produce (Alaska Center for the Environment, 2008). Delivering fuel from the refineries throughout the state depends on open transportation routes (EIA, 2016). Most of rural Alaska is not located on a road system, leading to a high dependency of fuel delivery for all aspects of livelihood from heating and electricity generation to fueling transportation modes and food

delivery by either barge or plane (Szymoniak et al, 2010). Alaska ranks third in the nation for per person energy demand (EIA, 2014). The high-energy needs are related to the extreme climate and the remote location. Rural communities rely heavily on diesel for power generation and for space heating needs (EIA, 2016). Alaska ranks second, after Hawaii, in electricity generated by petroleum liquids in the nation, adding to the carbon emissions load of the state. The environmental costs of consumption of fossil fuel in Alaskan communities are riddled with externalities, not only adverse health impacts but also environmental degradation caused by emissions and spills from diesel engine operation. Chapman (1996) estimated this cost of environmental degradation to be \$3/gallon, further escalating the cost associated with burning fossil fuels.

1.3.2 Effects of Energy Consumption on Food Security and Health

Food systems and health are closely conjoined with energy consumption in rural Alaska. Not only does an increase in fuel cost affect heating capacity of homes but also impacts food security, especially in rural Alaska where subsistence lifestyles depend on snowmobiles, four-wheelers, and boats (Loring & Gerlach, 2009). Furthermore, high fuel prices lead to an elevated cost of imported goods, due to increased transportation and food production costs (Brinkman et al., 2014). Decreasing reliance on subsistence food sources is leading community members to consume larger amounts of imported foods. On average, food sold in local grocery stores travels 1,500 miles before reaching Alaska (Meadow, 2009). Studies have been conducted investigating the decreased nutritional value of food items that are sold in rural villages, which are predominantly pre-packaged to have a longer shelf life. Additionally, fresh produce especially loses nutritional value during the long import journey north (Gerlach et al, 2011; Meadow, 2009; Fazzino & Loring, 2009; Reed 1995). The lack of nutritious foods impacts health, leading to high incidence rates of obesity, diabetes, cancer, and heart and respiratory diseases. The cost of imported foods sold in village stores is relatively high, as much as 600-1,000% that of food sold in the contiguous U.S. (Gerlach et al, 2011; Reed 1995). High fuel consumption at increased fuel prices coupled with the high cost of food may be linked to rural outmigration to urban centers (Martin et al., 2008). Coupled with climate change impacts to village infrastructure, such as increased risk of flooding, sea level rise, coastal erosion, thawing permafrost, and amplified hazardous weather patterns, the safety of homes, utility infrastructure, and inhabitants are all impacted (Hamilton et al., 2016; Penn et al, 2017). Despite net out-migration rates in Alaskan communities that are especially vulnerable to these effects, the birth rates are above replacement levels (Hamilton & Mitiguy, 2009; Hamilton et al., 2016)

resulting in growing arctic communities. Typically, families and individuals with higher financial capital are able to out-migrate, leaving behind a socio-economic vulnerable subset of the population (Hamilton et al., 2016). Energy-efficient homes, both new buildings and retrofits, will play an even greater role in enhancing climate change adaptation in these communities.

1.3.3 Residential Housing Legacy

The legacy of constructing houses inappropriate to the sub-arctic and arctic climate in Alaska can be traced back to the first settlers and has been perpetuated in the modern era through governmental agencies such as the Bureau of Indian Affairs and the Department of Housing and Urban Development (Stefansson, 1913; Slaughter, 1982). Design choices, engineering practices and construction materials not customized for the Alaskan climate and culture have increased household and community vulnerability to global change. Academic researchers are in agreement that rural Alaskan communities need support to adapt to changing conditions and what is more, community members themselves are reaching out and asking for assistance (Gerlach et al., 2011; Chapin et al., 2006; Ford, 2008; Walker et al., 2004). Alaskan residents are aware of the high usage of fossil fuels that living in the arctic and sub-arctic climate demands. The financial burden of a high cost of oil coupled with concerns over their personal contribution to the carbon balance leads many to seek out alternative options (see Chapter 3 for further discussion). Energy-efficient home designs can be relatively high in cost, and are certainly more costly than conventional homes. Additionally, perceived modern designs can detract from the cultural considerations of what a home should look and feel like, and the sense of place it provides. One of the reasons for failed buildings in Alaska that are not maintained or utilized, is the emotional attachment to a home is not taken into consideration by the design and construction companies (Cooke, 2014).

The external stressors exerted on households in Alaska contribute to a reduced adaptive capacity of households (figure 1.2).

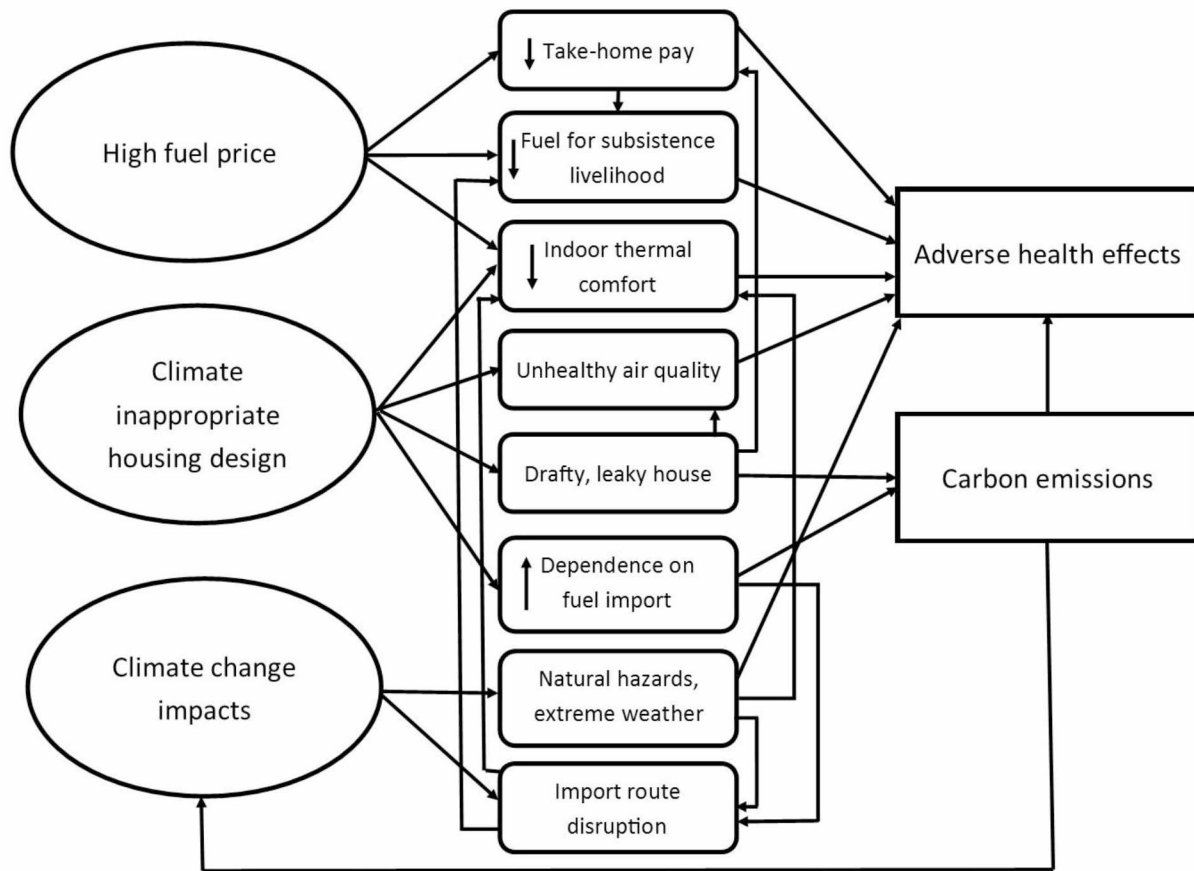


Figure 1.2: External stressors exerted on households living in conventional homes in Alaska.

As figure 1.2 shows, conventional Alaskan households are confronted with numerous external but related influences. The high price of oil leads to reduced household budget to spend on food or other essential household items, and also reduces subsistence livelihoods that can be dependent on gas powered modes of transportation. Climate-inappropriate house designs lead to leaky homes that are not well-insulated, thus requiring more fuel to be burned to maintain indoor thermal comfort, leading to indoor and outdoor air pollution and negative health impacts. Housing legacies in Alaska can also be partially attributed to inappropriate heating stoves fueled by resources that are not sustainable or available locally, thus leading to a dependence on imported fuel. Climate change affecting transportation routes leads to a high vulnerability of households. The feedbacks are reinforced by the high amounts of fuel burned per household, emitting more carbon emissions that in turn exacerbates climate change and adds directly to lowering air quality, adversely impacting human health.

1.3.4 Adaptation Strategies

The strategies that people employ to adapt to the external stressors illustrated in figure 1.2 vary based on the make-up of the household's available capital, cultural and historic contexts, environmental conditions, as well as decision-making and political power (Smit & Wandel, 2006). The International Panel on Climate Change recognizes that adaptation and adaptive capacity are very similar in their definition (IPCC, 2014a). Their working definition of adaptive capacity and adaptation are, respectively, the potential, ability, or capacity for a system to cope with changes in the climate and environment, and, the long-term effects of those changes. For the purposes of this dissertation, Alaska, especially in rural regions, is highly vulnerable to changing conditions (Hossain et al., 2016). Several influences limit the adaptive capacity of households. High poverty rates, limited employment opportunities, reliance on subsistence lifestyle, high dependence on imported food and fuel and a colonial legacy limit the inhabitant's capacity to adapt and apply alternative coping mechanisms if the original ones fail, such as relying on imported fuel for home heating. When exploring home design options for adapting to climate change in Alaska, it is important to take into consideration not just the mechanics of the building design, the material choices and the interaction with the ecological systems, but also pay attention to the social structures, such as the demographics of households, their willingness and ability to pay for energy-efficient features of a home and the emotional connection to a home that is important in the upkeep and maintenance of the home.

The arctic is often viewed as the canary in the coal mine in light of climate change (Duyck, 2012; Foley, 2005, Larsen et al., 2008). Alaska is not only impacted by changes to the ecology as climate change progresses at faster rates than in the south, but is challenged with a vulnerable population. Because of this, the north can also be viewed as a test bed for how to address these challenges. For these reasons, Alaska as a research region is on the extreme end of the spectrum of not only adapting to but also mitigating adverse climate change impacts. I chose to research the viability of highly energy-efficient homes in Alaska because the research results represent the extreme end of the spectrum and can thus be applied to a wider geographical scale.

1.4 Research Goal and Methods

The overarching theme of this research is to explore how energy security relates to climate change mitigation and adaptation by Alaska residents. The research drills down into this large topic by focusing on the viability of energy-efficient home design features as a mitigation and adaptation technology, both in previous housing legacies as well as current and future trends, and how reducing energy demand addresses climate change mitigation and challenges to vulnerability in the North, as discussed above. This dissertation utilizes interdisciplinary research methods from both the social and natural sciences. Due to the complex nature of climate change and sustainability, tackling vulnerability reduction and adaptation questions involves drawing on multitudinous disciplines. Both quantitative and qualitative datasets are examined.

The main research question is: How do energy-efficient homes, particularly highly energy-efficient homes, provide a sustainable infrastructure from economic, environmental, and social/cultural considerations in Alaska? The term highly energy-efficient house in the context of this research denotes buildings that are close to having annual net zero fossil fuel requirements achieved through mass insulation, passive solar design, and a tight building envelope. Highly energy-efficient homes are on the far end of the spectrum of energy-efficient homes that reduce energy demand through technology. The research is based on an assumption that reducing fossil fuel needs for home heating by increasing energy efficiency will significantly lessen the dependence on imported fuel, thereby reducing community vulnerability by addressing energy security in the context of global change and carbon emissions abatement. In other words, this dissertation explores how highly energy-efficient homes contribute to the adaptive capacity of their occupants.

The objectives of this study correspond with chapters 2,3,4, and 5 in this dissertation. They are to:

- (1) evaluate the state of energy security in rural Alaska and how it relates to residents' wellbeing;
- (2) explore the evolution of home energy efficiency and vernacular architecture in Alaska;
- (3) assess affordability, barriers, and motivations for the adoption of highly energy-efficient homes in Alaska;
- (4) calculate the carbon emissions equivalent of the life-cycle of a highly energy-efficient house, enabling the determination of a carbon payback period when considering the carbon emissions saved from reduced heating fuel usage.

The objectives are achieved through employing case study research, historical records analysis, interviews, and life-cycle assessment.

Case study analysis is utilized in research to address contemporary phenomena situated in real-life context (Yin, 1989). Currently, there are a limited number of operational case study homes in Alaska. At the time I began this research process, the only known example of an operational highly energy-efficient home was in Dillingham, Alaska in the Bristol Bay region. Other highly energy-efficient homes in Alaska were still in the design phase or under construction. By the conclusion of the research phase, several additional highly energy-efficient homes became operational as well. The Dillingham case study house is representative of a home built in a rural community on the mainland that is only accessible by air or water (see figure 1.3).



Figure 1.3. Map depicting case study house location. Source: CNN.com

As part of assessing the social and cultural viability of highly energy-efficient homes in Alaska, I used historical records research to explore the historical legacy of Alaskan homes, starting with pre-colonial homes wholly not reliant on fossil fuels and ending with modern era home designs. Parallels or differences between these homes provide intellectual and cultural insight into the viability of the modern highly energy-efficient homes currently being built.

Furthermore, I conducted qualitative semi-structured interviews with key informants, homeowners, builders, architects, and other stakeholders as well as experts in the building, mortgage, and lending industry. Snowball sampling was used to widen the pool of interviewees.

Life-Cycle Assessment (LCA) is a quantitative cradle-to-grave calculation of environmental impacts from the input, operation, and waste output of products (Bayer et al., 2010; Huberman & Pearlmutter, 2008; ISO, 2006). For buildings, each phase of construction can be evaluated separately or combined in a whole-building analysis. The building phases commonly begin with material sourcing and manufacturing, construction, operation, and maintenance, and conclude with decommissioning or recycling where appropriate (Bayer et al., 2010; Assefa et al., 2007; Bribián et al., 2009). Understanding the environmental impacts of different building techniques can justify design decisions and long-term payback periods, thus allowing for a holistic view of design decisions. The case study analysis in this dissertation includes an LCA of the carbon emissions equivalent both expended and saved through the lifetime of the house. To calculate the carbon payback rate of the highly energy-efficient case study house, a model of a comparable house in Dillingham built according to minimum R-value recommended standards for the region is used for comparison. Access to quantifiable data is pertinent for policy creation is especially relevant for policy makers and intergovernmental bodies (Ginetti, 2011). In the realm of new energy efficiency legislation my hope is that this type of data will be of great value.

1.4.1 Conceptual Framework

This research is nested in the larger theoretical framework of the sustainability triangulation of social, economic, and ecological research (Gibson, 2006). In this dissertation, I adapt Fiksel's (2003) definition of sustainability: an engineered system, a house, and its occupants "contributes to sustainability if it constrains environmental resource consumption and waste generation to an acceptable level, supports the satisfaction of important human needs, and provides enduring economic value" (p.5330). Rather than addressing each of the pillars of sustainability separately my dissertation surveys all three and recognizes the integrated relationship among them, including linkages and feedback loops. The research into cost and affordability of highly energy-efficient homes and the role of the mortgage and financing industry addresses the economic pillar of sustainability². The research of vernacular homes in Alaska, the motivations, perceptions of highly energy-efficient homes, and the needs of its occupants provides social science information, and quantifying carbon emissions in the life cycle of a highly energy-efficient house addresses the ecological pillar.

The framework integrates the nexus of energy-efficient home design, climate change mitigation technology, and the adaptive capacity of a household in the face of global change, including

² See Appendix D for a case study of the affordability of a highly energy efficient house in rural Alaska.

environmental, economic, and social change. Figure 1.4 draws the interrelated nodes and connections providing a bridge between these concepts. The connection is explored between energy-efficient homes contributing to carbon abatement, which furthers climate-change mitigation, which in turn can enhance adaptive capacity of households and communities. The increased adaptive capacity, especially in economic capital, could lead to a further uptake of energy-efficient homes, thus completing, and perpetuating the positive impact cycle.

In this research, human adaptation to external stressors is defined as a process or action taken to help cope with, manage, or adjust to change, either current or anticipated (Smit & Wandel, 2006). The components that make up adaptive capacity are forms of capital, either individually possessed or collectively: social, cultural, natural, political, and economic capital along with technology and infrastructure (Folke, 2006; Holling, 1973; Chapin, Folke & Kofinas, 2009). The amount, interplay, and relationship, including power relationships, between these forms of capital determine the degree of adaptive capacity. For example, if a household is endowed with a high amount of all forms of capital it may be expecting external stressors and is quite resilient to changes in its environment. In general, households or communities that have diversified capital resources can respond to changes or stressors quickly and easily, and are considered to have high adaptability (Denevan, 1983). While engineered systems, such as buildings, can be structured to address stressors, they cannot be designed to anticipate all future possibilities (Fiksel, 2003). Therefore, energy-efficient buildings are considered a contribution to active planned adaptation strategies, addressing some forms of adaptive capacity but not all (Loring et al., 2016). Energy efficiency is viewed not as a panacea to climate change and other global change conditions, but rather as a contribution to vulnerability reduction, not only of human systems but also ecological systems.

In the context of this paper, home design choices, such as heating method, insulation choices, or building materials, inform the adaptive capacity of the household (see figure 1.4). The design choices in turn affect the share of the household budget, for example the share used for heating fuel. Design choices also affect the indoor and outdoor air quality, which is linked to health conditions of occupants and community members. Indoor thermal comfort is related to both physical and mental health of occupants, and additionally facilitates an emotional connection to a home. Occupants are more likely to value a home that is year-round comfortable to inhabit. An emotional connection to a home in turn facilitates improved maintenance and upkeep of a home, which also enhances health conditions. In the event of a transportation route disruption, highly energy-efficient homes are able to maintain indoor temperatures for longer periods of time than conventional homes without the need for heating fuel.

Households with high adaptive capacity are less vulnerable not only to a changing environmental landscape but also changing social, and economic circumstances.

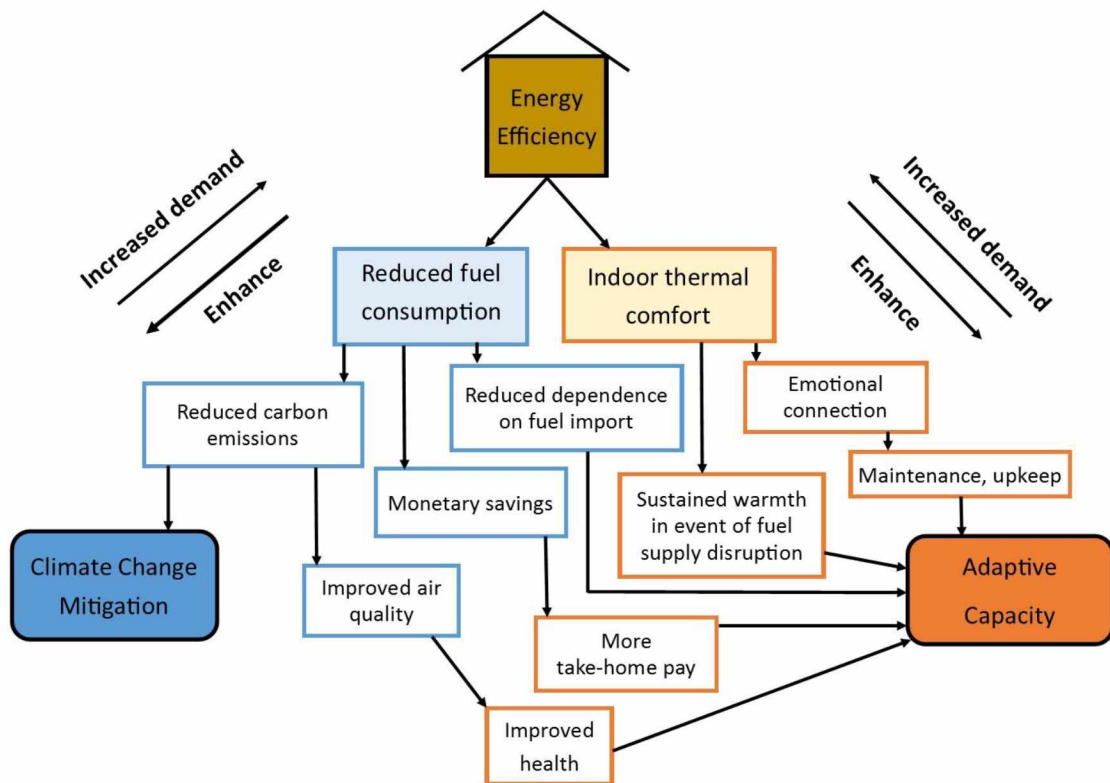


Figure 1.4: Nexus of energy-efficient home design, climate change mitigation and household adaptive capacity.

This analysis method and framework will be either wholly or in part modifiable for effective place-based responses to similar global change challenges in other regions of world (Ostrom, 2007; Loring et al., 2008). The analytical frames of reference will be portable to communities within Alaska, throughout the arctic region and even in other global latitudes. My hope is that this research will provide a framework for action research in geographic areas particularly vulnerable to global change that affects their energy security.

1.5 Chapter Outlines

Subsequent to this Chapter 1, the general introduction of this body of research, Chapter 2, “Defining energy security in the rural North—Historical and contemporary perspectives from Alaska,” provides background on the energy demand and supply equation of rural Alaska. The paper proposes a place-based definition of energy security that is applicable especially to the challenges faced in rural Alaska, and concludes that a significant segment of the population in rural Alaska is energy insecure.

Chapter 3, “The Evolution of Home Energy Efficiency in Alaska,” delves deeper into the socio-historical review of vernacular homes in Alaska, already touched upon in Chapter 2. Beginning with pre-colonial homes the paper surveys energy-efficient design features, space syntax, and the influence changing demographics has had and continues to have on home design choices in Alaska.

Chapter 4 “To Build or not to Build: Highly Energy-Efficient Homes in Alaska,” utilizes stakeholder interviews to drill down into the motivations, challenges and benefits of building and owning highly energy-efficient homes in Alaska. Particular emphasis is placed on affordability, both from an upfront cost perspective but also relating to financing options and resale value of these types of homes.

Chapter 5, “Conducting Life-Cycle Assessment to Determine Carbon Payback: A Case Study of a Highly Energy-Efficient House in Rural Alaska,” presents a case study of an operational highly energy-efficient house in Dillingham, Alaska. Using life-cycle analysis the carbon emissions associated with the life of the house are quantified enabling the determination of a carbon payback point, considering the savings in heating fuel when compared to a comparable conventional house.

The concluding chapter 6 summarizes the key findings from this dissertation, and provides broad recommendations based research findings.

1.6 References

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, 16(3), 268-281.

Alaska Center for the Environment (2008). Alaska Food, Farms, and Jobs Act. Retrieved from

<http://akcenter.org/sustainable-communities/local-food/policy/alaska-food-farms-and-jobs-act>

Anderson, J. O., Thundiyil, J. G., & Stolbach, A. (2012). Clearing the Air: A Review of the Effects of Particulate Matter Air Pollution on Human Health. *Journal of Medical Toxicology*, 8(2), 166-175. doi:10.1007/s13181-011-0203-1

- Assefa, G., M. Glaumann, T. Malmqvist, B. Kindembe, M. Hult, U. Myhr, and O. Eriksson. (2007). Environmental Assessment of Building Properties - Where Natural and Social Sciences Meet: The Case of Ecoeffect. *Building and Environment* 42: 1458-64. doi: <https://doi.org/10.1016/j.buildenv.2005.12.011>
- Bankoff, G., Frerks, G., & Hilhorst, D. (2004). Mapping vulnerability disasters, development, and people. Retrieved from <http://www.netlibrary.com/urlapi.asp?action=summary&v=1&bookid=108833>
- Bayer, C., Gamble, M., Gentry, R., & Joshi, S. (2010). *AIA Guide to Building Life Cycle Assessment in Practice*. Retrieved from Washington, D.C.:
- Bribián, Z. Ignacio, Aranda Uson Alfonso, and Sabina Scarpellini. (2009). Life Cycle Assessment in Buildings: State-of-the-Art and Simplified LCA Methodology as a Complement for Building Certification. *Building and Environment* 44, no. 12: 2510-20. doi: <https://doi.org/10.1016/j.buildenv.2009.05.001>
- Brinkman, T., Maracle, K. t., Kelly, J., Vandyke, M., Firmin, A., & Springsteen, A. (2014). Impact of fuel costs on high-latitude subsistence activities. *Ecology and Society*, 19(4). doi:10.5751/ES-06861-190418
- Chapin III, F. S., Gary P. Kofinas, Carl Folke. (2009). *Principles of Ecosystem Stewardship, Resilience-Based Natural Resource Management in a Changing World*: Springer Science+Business Media, LLC.
- Chapin III, F. S., Lovcraft, A., Zavaleta, E., Nelson, J., Robards, M., Kofinas, G., Naylor, R. (2006). Policy Strategies to Address Sustainability of Alaska Boreal Forests in Response to a Directionally Changing Climate. *PNAS*, 104, 16637-16643. doi:10.1073/pnas.0606955103
- Chapman, R. (1996). Hybrid Power Technology for Remote Military Facilities. *Proceedings for Power Quality Solutions/Alternative Energy*, 415-427.
- Cooke, A. (2014, March 21). Personal communication. [Viability of Highly Energy Homes in Alaska].
- Denevan, W. M. (1983). Adaptation, Variation, and Cultural Geography. *The Professional Geographer*, 35(4), 399-407. doi:10.1111/j.0033-0124.1983.00399.x
- Duyck, S. (2012). Which Canary in the Coalmine? The Arctic in the International Climate Change Regime. In T. Koivurova, G. Alfredsson, & W. Hasanat (Eds.), *The Yearbook of Polar Law* (Vol. 4, pp. 583-617). Leiden, Netherlands: Brill Editions.
- Energy Information Administration (EIA). (2014). *Alaska*. Retrieved from https://www.eia.gov/state/state_one_pager/Alaska.pdf
- Energy Information Administration (EIA). (2016). Alaska, State Profile and Energy Estimates. Retrieved from <https://www.eia.gov/state/?sid=AK#tabs-5>

- Energy Information Administration (EIA). (2016, October 20, 2016). Alaska - State Profile and Energy Estimates. Retrieved from <https://www.eia.gov/state/analysis.php?sid=AK>
- Fazzino, D. V., & Loring, P. A. (2009). From Crisis to Cumulative Effects: Food Security Challenges in Alaska. *NAPA Bulletin*, 32, 152-177. doi:10.1111/j.1556-4797.2009.01033.x
- Fiksel, J. (2003). Designing resilient, sustainable systems. *Environmental Science & Technology*, 37(23), 5330-5339. doi:10.1021/es0344819
- Foley, J. A. (2005). Tipping points in the tundra. *Science*, 310(5748), 627-628. doi:10.1126/science.1120104
- Folke, C. (2006). Resilience: the emergence of a perspective for social-ecological systems analysis. *Global Environmental Change*, 16(3), 253-267. doi: <https://doi.org/10.1016/j.gloenvcha.2006.04.002>
- Ford, J. (2008). Emerging Trends in Climate Change Policy: the Role of Adaptation. *International Public Policy Review*, 3(5), 5-16.
- Gerlach, S. C., Loring, P. A., Turner, A., & Atkinson, D. E. (2011). Food Systems, Environmental Change, and Community Needs in Rural Alaska. In A. L. L. Hajo Eicken (Ed.), *North by 2020: Perspectives on a Changing North*. Fairbanks, AK: University of Alaska Press.
- Gibson, R. B. (2006). Beyond the Pillars: Sustainability Assessment as a Framework for Effective Integration of Social, Economic, and Ecological Considerations in Significant Decision-Making. *Journal of Environmental Assessment Policy and Management*, 08(03), 259-280. doi:10.1142/S1464333206002517
- Ginetti, J. (2011). United Nations International Strategy for Disaster Reduction. [Personal Communication].
- Hamilton, L. C., & Mitiguy, A. M. (2009). Visualizing Population Dynamics of Alaska's Arctic Communities. *Arctic*, 62(4), 393-398. doi:10.14430/arctic170
- Hamilton, L. C., Saito, K., Loring, P. A., Lammers, R. B., & Huntington, H. P. (2016). Climigration? Population and climate change in Arctic Alaska. *Population and Environment*, 38(2), 115-133. doi:10.1007/s11111-016-0259-6
- Hojjati, B. (2004). *Householder's Perceptions of Insulation Adequacy and Drafts in the Home in 2001*. Retrieved from Washington, DC: <https://www.eia.gov/consumption/archive/residential/insulation.pdf>
- Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, 4(1), 1-23.

- Hood, E. (2005). Dwelling Disparities: How Poor Housing Leads to Poor Health. *Environmental Health Perspectives*, 113(5), A310-317. doi:10.1289/ehp.113-a310
- Hossain, Y., Loring, P. A., & Marsik, T. (2016). Defining energy security in the rural North—Historical and contemporary perspectives from Alaska. *Energy Research & Social Science*, 16, 89-97. doi:http://dx.doi.org/10.1016/j.erss.2016.03.014
- Huberman, N., and D. Pearlmutter. (2008). A Life-Cycle Energy Analysis of Building Materials in the Negev Desert. *Energy and Buildings* 40: 837-48. doi:https://doi.org/10.1016/j.enbuild.2007.06.002
- International Panel and Climate Change (IPCC). (2014a). *Climate Change 2014—Impacts, Adaptation, and Vulnerability: Regional Aspects*: Cambridge University Press.
- International Panel and Climate Change (IPCC). (2007). *Climate Change 2007, Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: 104pp.
- International Panel and Climate Change (IPCC). (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA.
- International Panel and Climate Change (IPCC). (2014b). *Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Retrieved from Cambridge, UK and New York, NY, USA: http://pure.iiasa.ac.at/11125/1/ipcc_wg3_ar5_summary-for-policymakers.pdf
- International Organization for Standardization (ISO). (2006). "ISO 14044 - Environmental Management - Life Cycle Assessment - Requirements and Guidelines, Management Environnemental - Analyse Du Cycle De Vie - Exigences Et Lignes Directrices." 1-46. Geneva, Switzerland: International Organization for Standardization.
- Kohler, N., & Moffatt, S. (2003). Life-Cycle Analysis of the Built Environment. *UNEP Industry and Environment*(April-September), 17-21.
- Kwok, A. G., & Rajkovich, N. B. (2010). Addressing climate change in comfort standards. *Building and Environment*, 45(1), 18-22. Doi: <https://doi.org/10.1016/j.buildenv.2009.02.005>
- Larsen, P. H., Goldsmith, S., Smith, O., Wilson, M. L., Strzepek, K., Chinowsky, P., & Saylor, B. (2008). Estimating Future Costs for Alaska Public Infrastructure at Risk from Climate Change. *Global Environmental Change*. doi:10.1016/j.gloenvcha.2008.03.005

- Larsen, P. H., Goldsmith, S., Smith, O., Wilson, M. L., Strzepek, K., Chinowsky, P., & Saylor, B. (2008). Estimating future costs for Alaska public infrastructure at risk from climate change. *Global Environmental Change*, *18*(3), 442-457. doi:10.1016/j.gloenvcha.2008.03.005
- Li, D. H. W., Yang, L., & Lam, J. C. (2012). Impact of climate change on energy use in the built environment in different climate zones – A review. *Energy*, *42*(1), 103-112. doi:http://dx.doi.org/10.1016/j.energy.2012.03.044
- Liddell, C., & Morris, C. (2010). Fuel poverty and human health: a review of recent evidence. *Energy Policy*, *38*(6), 2987-2997. doi:10.1016/j.enpol.2010.01.037
- Loring, P. A., & Gerlach, S. C. (2009). Food, Culture, and Human Health in Alaska: an Integrative Health Approach to Food Security. *Environmental Science & Policy*, *12*, 466-478. doi: https://doi.org/10.1016/j.envsci.2008.10.006
- Loring, P. A., Chapin III, F. S., & Gerlach, S. C. (2008). Services Oriented Architecture: Ecosystem Services as a Framework for Diagnosing Change in Social Ecological Systems. *Ecosystems*, *11*(3), 478-489. Doi:10.1007/s10021-008-9136-1
- Loring, P. A., Gerlach, S. C., & Penn, H. J. (2016). "Community Work" in a Climate of Adaptation: Responding to Change in Rural Alaska. *Human Ecology*, *44*(119). doi:10.1007/s10745-015-9800-y
- Martin, S., Killorin, M., & Colt, S. (2008). *Fuel Costs, Migration, and Community Viability*. Denali, Alaska: Institute of Social and Economic Research in collaboration with First Alaskan Institute and Alaska Native Policy Center.
- Meadow, A. (2009). *Evaluating and Designing Urban Food Systems: The Role of Local Initiatives*. Unpublished doctoral dissertation. University of Fairbanks Alaska. Fairbanks, AK.
- Oliver-Smith, A. (2004). Theorizing Vulnerability in a Globalized World: A Political Ecological Perspective. In G. Bankoff, G. Frerks, & D. Hilhorst (Eds.), *Mapping Vulnerability*. Sterling, VA: Earthscan.
- Ostrom, E. (2007). A Diagnostic Approach for Going Beyond Panaceas. *National Academy of Sciences of the United States*, *104*, 15181-15187.
- Parenti, C. (2012). *Tropic of chaos: Climate change and the new geography of violence*: Nation books.
- Penn, H. J. F., Loring, P. A., & Schnabel, W. E. (2017). Diagnosing water security in the rural North with an environmental security framework. *Journal of Environmental Management*, *199*, 91-98. doi:https://doi.org/10.1016/j.jenvman.2017.04.088
- Reed, L. J. (1995). *Diet and Subsistence in Transition: Traditional and Western Practices in an Alaskan Athabaskan Village*. Unpublished doctoral dissertation. University of Oregon.

- Rudge, J., & Gilchrist, R. (2007). Measuring the health impact of temperatures in dwellings: Investigating excess winter morbidity and cold homes in the London Borough of Newham. *Energy and Buildings*, 39(7), 847-858. doi:10.1016/j.enbuild.2007.02.007
- Slaughter, D. (1982). *The Point Barrow House Type: An Analysis of Archeological Examples from Siraagruk and Other Sites in Northern Alaska*. Fairbanks, AK: University of Alaska Fairbanks.
- Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change-Human and Policy Dimensions*, 16(3), 282-292. doi:10.1016/j.gloenvcha.2006.03.008
- Stefansson, V. (1913). *My Life with the Eskimo*. New York, NY: The Macmillan Company.
- Szymoniak, N., Fay, G., & Villalobos-Melendez, A. (2010). *Components of Alaska Fuel Costs: An Analysis of the Market Factors and Characteristics that Influence Rural Fuel Prices*. Retrieved from Anchorage, Alaska:
- U.S. Census Bureau. (2005). "Interim State Population Projections", edited by U.S. Census Bureau. Washington, DC.
- U.S. Consumer Product Safety Commission, (2017). *The Inside Story: A Guide to Indoor Air Quality*. Retrieved from <https://www.cpsc.gov/safety-education/safety-guides/home/the-inside-story-a-guide-to-indoor-air-quality>
- U.S. Department of Energy (2012). *2011 Buildings Energy Data Book*. Retrieved from Silver Spring, MD: <http://buildingsdatabook.eren.doe.gov/DataBooks.aspx>
- van Aalst, M. K. (2006). The impacts of climate change on the risk of natural disasters. *Disasters*, 30(1), 5-18. doi: 10.1111/j.1467-9523.2006.00303.x
- Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, Adaptability and Transformability in Social-ecological Systems. *Ecology and Society*, 9(2), 5-14.
- Wheeler, T., & von Braun, J. (2013). Climate Change Impacts on Global Food Security. *Science*, 341(6145), 508. doi:10.1126/science.1239402
- World Health Organization (WHO). (2007). *Housing, Energy, and Thermal Comfort*. Retrieved from Copenhagen, Denmark: http://www.euro.who.int/__data/assets/pdf_file/0008/97091/E89887.pdf
- Yin, R. K. (1989). *Case Study Research: Design and Methods*. Newbury Park: Sage Publishers.
- Younger, M., Morrow-Almeida, H. R., Vindigni, S. M., & Dannenberg, A. L. (2008). The built environment, climate change, and health: opportunities for co-benefits. *American Journal of Preventive Medicine*, 35(5), 517-526. doi: <https://doi.org/10.1016/j.amepre.2008.08.017>

Chapter 2

Defining Energy Security in the Rural North - Historical and Contemporary Perspectives from Alaska³

2.1 Abstract

In this paper we discuss the historical dimensions of energy in rural Alaska to argue that energy security in rural locations involves different considerations than in urban areas, and as such a definition of energy security needs to be downscaled to a place-based perspective, addressing individual and household needs as opposed to national issues of supply, consumption, and distribution. The definition of energy security for local communities that we propose is adapted from the food security literature: having sufficient access to energy generation or provisioning services to conduct a sustainable life. Also similar to the food security literature, the framework we propose includes four dimensions to energy security: availability, access, quality, and stability. This paper applies the proposed definition and framework to the example of rural Alaska. Alaska has an abundance of energy sources, from oil and gas to a host of renewables, however due to colonial legacies, lack of infrastructure, policies and social structure a number of communities in rural Alaska struggle with energy insecurity.

2.2 Introduction

Energy security is an oft-discussed but rarely elaborated upon component of environmental security and community sustainability [1, 2]. Its importance has been elevated by research on the so-called food-water-energy nexus [1, 3], but questions remain regarding what exactly constitutes energy security at the household, community, or regional level, as compared to global and national levels where energy security primarily involves whether state governments have control over their energy generation and

³ Hossain, Y., Loring, P. A., & Marsik, T. (2016). Defining energy security in the rural North—Historical and contemporary perspectives from Alaska. *Energy Research & Social Science*, 16, 89-97.
doi:<http://dx.doi.org/10.1016/j.erss.2016.03.014>

provisioning resources [2,4, 5, 6, 7]. Like its counterparts in the nexus, energy security has different meanings depending on the level and location of analysis; energy security in rural areas often involves different features than in urban ones, and household and community energy security have little in common with energy security when construed in a militaristic or statist sense. For a rural community, energy security can mean resilience and self-sufficiency through an escape from the global carbon “lock in” [8]; for an individual, it may well mean something as simple as being able to survive a cold winter or having a light at home so that children can study at night [9, 10].

Sovacool and Brown [4] argue that energy security may ultimately prove to be the most important component of human environmental security, in that energy influences so many different aspects of people’s lives, including food production and the distribution and treatment of drinking water. As was the case for making progress on food security research and policy [11], we argue that new place-based perspectives are needed on energy security that scale down focus to the issues facing individuals, their households and livelihoods. As we describe below, this means paying attention to such diverse issues as breaking out of historical legacies of colonialism and development and the political ecology of energy resources [12, 13].

In this paper, we illustrate some of the place-based contours of energy security through a discussion of historical and contemporary energy security in the high latitude North. Alaska and the Arctic are well known to the energy security literature because of the oil and gas reserves in the region, but relatively few academic studies to our knowledge have been published that evaluate the energy security of communities in the North. Studies we are aware of for Alaska are government publications and assessment reports for non-governmental organizations [14, 15, 16, 17, 18]. The North, while unique, is an exemplar of remote rural issues elsewhere in the world: complicated and unreliable supply chains, limited employment and economic development, a history of boom and bust economic development, and rapidly shifting demographics. Alaska is also rich in colonial legacies influencing the local energy discourse directly undermining indigenous practices, which is explored in this paper. In terms of infrastructure, the North shares a number of features with other rural and developing parts of the world, specifically distributed power generation (usually diesel) and the unfeasibility of extending electrical grids [19, 20, 21]. Therefore the discussion in this paper has applicability to a wider context than the case study used for illustrating purposes, for example the challenges to energy security that Alaska faces are not unknown to countries in Africa and in South Asia [20,21, 22].

We propose and justify both a definition and framework for energy security that attends to these complex circumstances at the local level. We draw guidance from the food security literature, which as

noted has undergone a similar “scaling down” in focus in the last few decades from global and state-level issues to those facing individuals, households, and communities. To illustrate the usefulness of this conceptual framework, we discuss the historical timeline of heat efficiency of homes and food production in rural Alaska and the effect this has had on energy security. We believe there is value in exploring the linkage between the role historical behavior plays in present day energy use and attitudes and how this relates to energy security. We also examine contemporary issues of energy, transportation, and food security and how they relate to each other directly affecting the vulnerability and resilience of communities of the region.

While some examples given in this paper refer to specific forms of energy, such as electricity, it should be clarified that the paper as a whole, including the energy security definition, is concerned with household energy use in a broad sense, including electricity, heat, and transportation.

2.3 Conceptual Background

The concept of energy security can be interpreted in a wide variety of ways based on the level and scale of interest, as well as the cultural context, which involves expectations regarding energy availability and also ethics regarding how energy ought best be generated and provisioned. ‘Energy generation’ as used in this paper describes technologies that convert energy resources into a form useful for human activities. At a national level, energy security is often linked to economic policies, foreign relations, financial affordability and even environmental policies [6,7]. From the perspective of Saudi Arabia, for example, energy security can be construed as securing global demand for their oil and gas resources; conversely in the U.S., energy security has come to mean securing the supply of oil at low prices, at a predictable and sustainable rate and, increasingly, from national rather than foreign sources [4]. Similarly, for transnational oil and gas producers, energy security is linked to securing access to new reserves and widening the distribution or consumer network, giving them control of the pipeline infrastructure and access to the consumers. Whereas for consumers it likely involves both access to energy supply without disruption and affordability on a reasonable household budget.

On a local level, people’s concerns about their energy reliability and affordability also feed into concerns about societal and ecological trade-offs related to electrical power generation and other aspects of their environmental security. For example, local air quality can be severely impacted by emissions from power plants [23], and household air quality can be compromised where people rely on

fuel lamps for lighting [10]. Some have proposed biofuels as an alternative to carbon-based energy generation, but biofuel production can usurp land that would otherwise be used to produce food crops. Similarly, some consider hydroelectric energy to be an environmentally friendly form of energy generation, but hydroelectric dams can interfere with fisheries that are important to local food security [24]. Dams can also alter downstream hydrology and affect the flow of tributaries and floodplains [25].

These examples illustrate the many ways that energy security interlinks in a 'nexus' with food security, water security, and environmental health [1, 3, 26]. This nexus approach is relatively new to the research and development literatures, and is arguably useful because it highlights linkages and potential trade-offs or synergies among these domains.

2.4 Energy Security Definition and Framework

Energy security is purported as a concept hard to define especially in a global context [27, 28, 6, 29]. Energy supply and demand varies largely based on the size of a country or community, the available local resources, economic development and geopolitical factors and jurisdiction, to name a few [30, 31]. What energy security may encompass for a developed country in Europe with a northern temperate climate may not apply to a developing country in Africa with a warm desert climate. The heating needs, fuel resources, economic development, population size and geopolitical factors would likely all be different. One other noteworthy challenge in defining energy security is that developed countries' definition of energy security may not work well for rural communities, in that the latter may have a standard of living closer to a developing country, as our case study of rural Alaska exemplifies. As Martchamadol's [30] research states developed countries' understanding of energy security is often "a resilient energy system and securing the amount of energy required for people's lives, economic and social activities, defense and other purposes for acceptable prices." Developing countries, by comparison, have a differing understanding; "enough energy supply (quantity and quality) to meet all requirements at all time of all citizens at an affordable and stable price, and it also leads to sustain economic performance and poverty alleviation, better quality of life without harming the environment." Furthermore, the energy security literature often focuses on indicators of energy security in a nationalistic sense [2, 6, 31, 32, 33] that may not be appropriate for a local community.

We define energy security as a situation in which people have reliable access to socially acceptable energy generation or provisioning services, at a level sufficient to conducting a sustainable life. This

definition is adapted from contemporary definitions for food security [34], with our goal being to "downscale" the energy security discussion to the household and community level in order to capture the varied and often inequitable experiences that local households and communities can have with energy [11].

While not explicitly mentioned in our definition, it is important to clarify that energy efficiency is implied by the definition as a possible means to help achieve energy security. While energy efficiency doesn't directly affect the access to energy generation or provisioning services, it does decrease the amount of energy considered sufficient to conduct a sustainable life. As a result, there are two basic ways to increase energy security: a) increase reliable access to socially-acceptable energy generation or provisioning services; or b) use energy efficiency measures to decrease the amount of energy needed to conduct a sustainable life.

2.4.1 A Framework for Energy Security

Hughes [27] distills three indicators from the Information Energy Agency's definition of energy security; affordability, availability and acceptability. Similarly, Giampetro and colleagues [26] discuss issues of availability, viability, and desirability as being central to energy security. Here, we follow Loring and colleagues, who synthesize literature across the domains of food, water, and energy, and argue for four main components (see Figure 2.1) of energy security:

1. Availability on a local level, which may relate to whether communities are located in grid service areas or if there is sufficient grid infrastructure
2. Access, which involves equitable access to energy by all members of a society; this relates to the economic cost of purchasing energy as well as if individual households have connection to a utility grid
3. Utility, which involves the reliability, efficiency, and social acceptability of energy harvesting, distribution, and utilization
4. Stability, which refers to the sustainability of energy sourcing and generation, policies that regulate extraction, environmental laws and policies, local governance and the direct environmental impacts, such as bad air quality.

There are a number of ways that the four components interact with each other, in some cases creating feedback loops. Limited energy generation in an area can increase the price of energy, thus limiting equitable access to it from all community members. Similarly, drivers that affect the stability of energy sourcing will interact with access, but will also affect the availability of energy sources: while energy resources may be available, such as oil, policies and laws prohibiting its extraction will impact the utilization of the energy source. Or, if there is limited support of the use of renewable energy by existing utility companies, this can affect the access to using this energy source by driving up cost. In turn this may diminish the social acceptability of using renewable energy sources thus erecting social and economic barriers to connecting renewable energy to the utility grid. Additionally, if extracting an energy resource, such as tar sands, has environmental concerns, the utility or social acceptability of using the energy source may be affected. Adding some of the feedbacks together can also produce cumulative effects, in addition to individual interactions, locking communities into fewer options or a trajectory of energy development that they do not support [8].

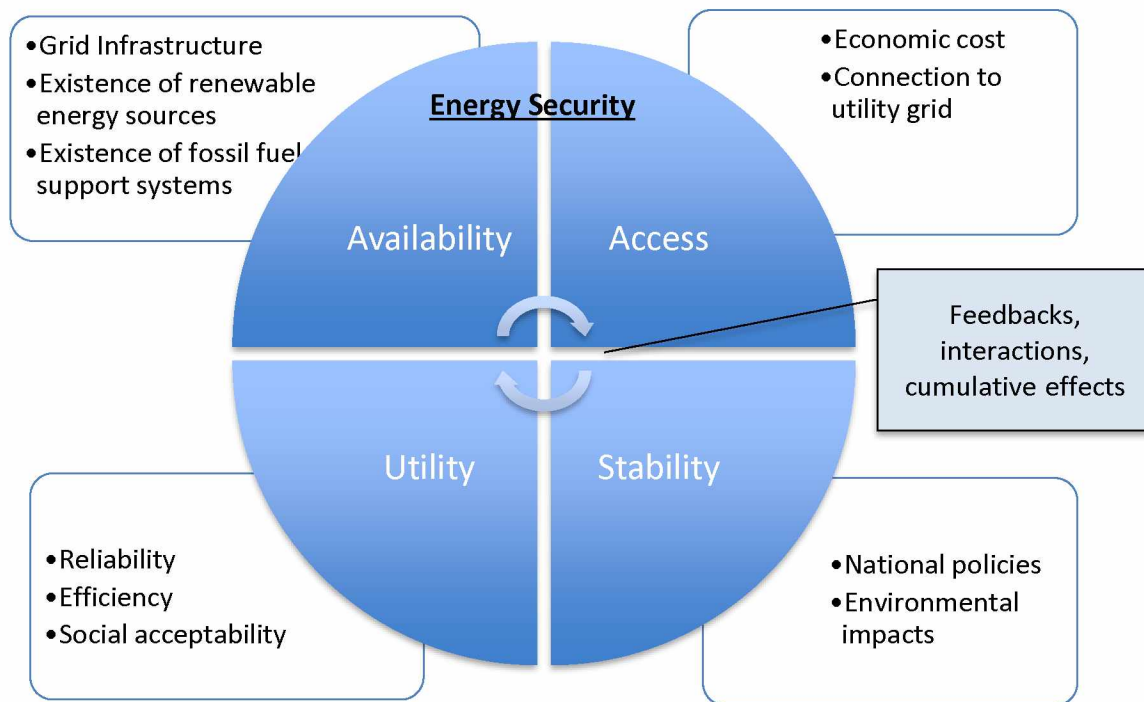


Figure 2.1. Components of Energy Security

Availability, accessibility, utility, and stability are used throughout this paper as shorthand for understanding the facets of energy security in Alaska at a household and community scale. In addition,

we note four categories of energy use for which these four components should be evaluated in order to assess energy security (adapted from Reddy and Subramanian 1979 [19]):

1. Food production and harvest involves the energy needs of agriculture (fuel or animal traction) or of hunting, gathering, herding, etc., including transportation
2. Household activities including cooking, heating, lighting, and personal transportation
3. Municipal activities, where relevant, include energy needs for water treatment and distribution and other public services, and lighting and heating of public spaces
4. Manufacturing and commerce, where relevant, which can have energy needs at a scale different than the previous three.

2.5 Energy Security in the Pre-contact North

Prior to Euroamerican contact, indigenous Alaskans utilized locally sourced energy sources such as seal oil and firewood, had limited energy needs and relied highly on heat-efficient housing to keep fuel requirements low. This changed with the advent of colonization, which is elaborated on below. Of the four categories of energy use proposed above, only two (food production and household activities) are relevant in a pre-contact setting.

Differences in cultural adaptations for energy use are found throughout Alaska, in a distribution that not surprisingly coincides with the different climatic regions of the state (see also Moran 1981 [35]). Energy adaptations in the Arctic, Interior, Southwest, and Aleutian regions of the state are all expanded upon below. A recurring observation is how these energy adaptations are interwoven with climate and biogeography and also patterns of subsistence and mobility.

The climate in Alaska is influenced largely by the high latitude environment [36]. The northern half of the state experiences limited daylight hours in the winter months and almost constant daylight during the summer. Mean temperatures have a relatively large range in the state; from 4C in a southern maritime region to -12C north of the Arctic circle [37].

2.5.1 Homes and Households

The Iñupiat Eskimo tribes inhabiting the Northern region of mainland Alaska typically inhabited insulated sod dwellings in the winter and movable homes in the summer with a tent like structure and

caribou hides [38, 39, 40, 41, 42]. The winter homes were dug into the sides of sand dunes, hills or river embankments to maximize natural insulation features in the landscape. The sod insulation layers were up to one meter thick. Homes were heated primarily with sea mammal oil lamps and body heat from the inhabitants. Up to 15 people would occupy the winter homes, comprised of multiple families, constituting an occupancy rate of 1.1 to 1.7 square meters per person [43, 44]. Summer tents were usually occupied by only one family, allowing for more space per person at 2.6 square meters per person. As a comparison, in 2005 the average occupancy space in the U.S. was 57.5 square meters per person [45].

Energy use in winter was kept at a minimum with design features of the dwellings. For example, the entrance to the main living area was dug into the ground with a long tunnel of 3 to 9 meters in length serving as a cold air trap [38, 39, 40, 41, 42]. Meat and other perishable foods were stored in this tunnel, utilizing the natural refrigeration of the winter air and the permafrost walls. Nooks in the tunnel closest to the tunnel entrance were carved into the permafrost for further storage. These combined techniques kept the indoor room temperature between 10-15 degrees Celsius during the coldest winter temperatures, which often reached -51C, roughly a difference of 60C between the outdoor and indoor temperatures achieved without the use of burning wood or oil. Energy security for the Iñupiat Eskimo was therefore closely linked to successful seal hunts, having large families and the ability to build well-insulated sod homes.

In the interior of Alaska, by comparison, Athabaskan people were historically highly mobile, moving from camp to camp with the hunting and fishing seasons. In summers they built tent dwellings similar to the tents used by the Eskimos in the North of Alaska [46, 47]. Some families chose to live in the tents year-round and added an extra layer of animal hide to the walls of the tent with the fur attached on the inside to act as additional insulation. Some also used semi-permanent winter homes, though this varied slightly across the interior region based on differences in climate and natural resources. Most commonly, such structures were similar to the sod homes described above, built semi-subterranean with wood framing covered with spruce or birch bark and a layer of soil for extra insulation as well as moss. Other versions included wood boards covered with woven grass on the outside. When it snowed, the snow blanket functioned as additional insulation over the dwellings. Wood, as well as animal oil fires were built for cooking and heating. Wood and cooking oil were readily available and the small scale of burning wood did not lead to unmanageable air pollution. Energy conservation, in the form of multifamily dwellings and shared cooking were also practiced. It is noteworthy however that while there is no evidence that outdoor air quality was poor as a result of these fuel uses, indoor air quality

problems from lamp smoke has been identified as a likely cause for emphysema among some pre-contact northern peoples [48].

The Yup'ik of Southwest Alaska also occupied similar sod homes year-round [40, 44, 49]. Milder temperatures than in the Interior allowed for the homes to be built above ground in many cases. Entrance tunnels, while shorter than in Iñupiaq homes, were still used as a cold air trap. Some homes had two entrances: one tunnel below ground as the winter entrance and one above ground as the summer entrance. In some instances, the only heat source in the sod homes was that generated by the bodies of the residents. This was mainly possible in homes where interior square meter-to-inhabitant ratio was relatively small, on average 0.8 square meters per person, and for homes with sufficient insulation [43, 44, 50]. Other heat sources came from lamps and fires.

Aleut and Alutiiq people in the Alaska Peninsula and Aleutian Islands region lived typically in multifamily dwellings that were made out of primarily grass and turf layers coated on the outside with mud, earth, clay or bark. These homes were called *barabaras* by early Russian settlers, a name later adopted as the common term for this type of house [43, 44, 51]. Heating and light was provided with sea mammal oil lamps and cooking was done over a fireplace also fueled by sea mammal oil. Some homes included stone foundations and had stone slab hearths with stone channels capable of funneling heat and steam through the floor to create an efficient form of floor heating [43, 52]. These homes provided 1.9-2.8 square meters of living space per person [43, 44].

2.5.2 Food Systems Linkages

Historically, Alaska Native food systems provided people with a high measure of food security through adaptive strategies tailored around high levels of seasonal variability, mobility, and innovation [61]. These food systems activities have also been particularly energy-efficient, relying primarily on human energy (labor) and innovative methods of food storage. Transportation was key, given the emphasis on hunting, fishing, and gathering of diverse botanical resources; Athabascan people relied heavily on dog teams for hauling wood and other supplies and for transportation to winter hunting grounds; Aleut people similarly traveled the coastal environment extensively with kayaks, and Yup'ik and Iñupiaq whalers navigated the ice-filled waters of the Arctic Ocean with the impressive, hand-made *umiaq* skin boats.

Energy use for food storage was kept relatively low. As mentioned above, during the cold months ice, snow or permafrost was used as natural refrigeration in cellars and nooks. In warmer months, foods were mostly eaten fresh, fermented, dried or smoked, requiring at most small wood fires.

2.5.3 Colonial Changes

Alaska Natives transitioned to living year-round in fixed villages primarily as a result of government policies requiring that their children attend school [53]. The social impacts of the transition have been noteworthy and lasting: food security was impacted because living in fixed villages reduces people's ability to move across the landscape [62] water security and sanitation emerged as problems [54], and as we discuss here, energy security was impacted in myriad ways.

Wood frame houses, for example, arrived with the first Euroamerican settlers in the Arctic region near Barrow over one hundred years ago. These houses were drafty and not well insulated by comparison to traditional structures, and as such they required large amounts of fuel for heating [38, 55]. The advent of the sheet iron stove, using wood as a fuel source, also drastically changed home heating practices in the North [55] because it generated a substantially larger amount of heat compared to the sea mammal oil lamps and was also lightweight and portable. Arguably, the shortening of tunnel length and elimination of the cold trap and the subterranean characteristic of the Eskimo sod houses that has been observed in the historical archaeological record can be attributed to the introduction of colonial housing elements, such as the new wood stove, above ground housing with windows and larger area per occupant [56]. However, since trees in Alaska's Arctic North were not abundant and driftwood was of short supply, lumber to build the new wood frame houses and to fuel sheet iron stoves was scarce. Residents were thus forced to use imported lumber for construction and later imported coal and wood to fuel the sheet iron stoves for heat.

In Southwest Alaska, the Russian settlers brought with them a change in architecture as well. The first features adopted were Western-style doors and windows for the *barabaras* made out of imported wood from Siberia or Europe [43]. Gradually throughout Alaska, homes were built above ground and included more and more timber and less of the locally available turf and sod. Overall the house design the settlers introduced to Alaska was better suited for a European climate and fuel source availability.

The U.S. Government pressured Alaska Natives to leave their traditional homes as early as the 1800s offering financial help [57] though the promises for assistance for these "development" initiatives were often not realized [58, 59]. Aid that did come was used to build homes that were often substandard, not

meeting the requirements of the local climate or the culture of the inhabitants. In the mid-20th century the Bureau of Indian Affairs and the Department of Housing and Urban Development funded a massive housing boom for all Indigenous tribes throughout the U.S. [58]. The homes were all modeled after post-World War II tract housing, in an attempt to help Indigenous people assimilate into the prevailing culture. These types of homes were clearly not suitable for the Alaskan climate, built to federal codes rather than local construction standards. The homes were similar to the new home designs the settlers introduced. In addition to inadequate insulation and imported building materials, heating appliances were generally powered by fuel oil, which also had to be imported. Additionally, many of these homes did not have adequate ventilation, which created mold problems and impacted the respiratory health of residents [58].

The legacy of the homes built by the federal government is still visible in Alaska today. In 2005, a study found that over 21% of households in Alaska were unable to maintain an indoor temperature of 21 degrees Celsius, both due to the high cost of heating fuel as well as inadequate construction or condition of the house [60]. Out of this subsection, 45% had a household income of \$30,000 or less, indicating that affordability of fuel oil is an important driver. For nine percent of homes surveyed, however, the single biggest problem for effective heating was found to be the condition of the house.

2.6 Contemporary Energy Security Concerns in Alaska

In rural Alaska, dependence on fossil fuel permeates all of the categories of energy use noted above: subsistence and food production, household activities, municipal activities, and industry. Today, imported diesel and gasoline are the primary energy sources for rural Alaskan villages [61]. Diesel is used for electricity and heat for household, municipal and industrial activities, and gasoline is used as fuel for snowmobiles and four-wheelers for subsistence activities as well as transport of imported goods, including food and supplies from hub communities. Energy and other municipal infrastructure in rural Alaska is also relatively new, designed when fossil fuel was inexpensive, abundant, and not implicated in climate change. Indeed, Alaskans now are locked in to an overreliance on imported fuel for all aspects of rural life, which makes them vulnerable to any environmental, economic or social change that affects the supply or price of fuel [62].

Rural communities have a unique challenge in that a large number of rural areas are accessible only by plane or barge as they are not on the road system. This increases the general cost of living when

compared to the urban centers [63] because the majority of goods, including fuel, building supplies, and food has to be imported long distances. Likewise, the cost of energy in rural regions can be as high as \$10/gallon of diesel and over \$1/kWh for electricity [64, 65]. Colt et al [66] estimate that the consumption of diesel fuel and gasoline in rural Alaska equals roughly 1,000 gallons per person annually, including fuel consumption for heating, electricity and transportation, but not including the indirect fuel costs associated with imported foods. Electric utilities in rural areas receive high subsidies from the state, such as through the Power Cost Equalization Program, to be able to lessen the cost of energy such that local utilities can be sustainable [67]. Nevertheless, even temporary fluctuations in the cost of fuel can drive local families into an energy insecure state [63].

Fossil fuel use in rural Alaska also has impacts on local ecosystems. For example, storage of diesel is key because fuel can only be barged to many communities in the summer months because of river and sea ice (most rural communities in Alaska are not on the road system). Due to aging and inadequate infrastructure, storing a year's worth of diesel and gasoline can lead to leaking storage tanks, spills and discarded drums that all have adverse impacts on the ecosystem and human health [68]. Chapman [68] estimated the cost of remediating the environmental impacts caused by emissions and spills from diesel engine operation at an additional \$3/gallon.

Finally, the community power plant equipment is likewise often at risk of failing, leaving entire communities without power for weeks. Maintenance and repair is difficult in remote communities that are not accessible by road and often don't have skilled technicians living in the community. Moreover, in the event of a disaster or other shutdown of all transportation modes to Alaska the import of fuel would cease and the overall livability of remote communities would be considerably impacted. This scenario happened in a community in Northwest Alaska in the fall of 2011. The annual fuel delivery by barge to Nome could not occur due to a severe storm in the Bering Sea making the water impossible to navigate [69]. By the time the storm died down Nome was already locked in by sea ice. The residents did not have enough fuel to last through the winter. With no other way to get enough fuel for the entire town a Russian ice breaker had to make the trip to transport the fuel to Nome. Flying the fuel in by plane would have raised the fuel prices from \$5.40 to \$9 per gallon and as such been cost prohibitive for the residents [70]. The emergency fuel did not reach the community until January 2012 [71].

2.6.1 Food-Energy Interactions

Alaska's rural community food systems, including both subsistence and small-scale agricultural

production, are also now much more energy dependent than they were in the past, with transportation as one example. The predominantly subsistence lifestyle requires fuel for hunting and fishing with snowmobiles, all-terrain vehicles, and motorboats. Climate change is also affecting the subsistence lifestyle of many rural Alaskans [62] retreating sea-ice, shorter freeze periods of rivers and lakes and changing vegetation patterns leading to changing game migration patterns are impacting the availability of fish and game and safety of transportation across land, rivers, and the ocean. Due to these factors, as well as the creation of federal and state parks, restricted hunting and fishing on private land and the high cost of fuel, the reliance on subsistence foods in rural Alaska is continuously decreasing [72]. With reduced access to and availability of subsistence foods, community members rely on larger amounts of imported foods. On average food sold in local grocery stores travels a long distance from the lower 48 before reaching Alaska and as such the price of food and fuel in these communities is tightly coupled (Figure 2.2), with the cost of the foods sold in the village stores is as much as 2-5 times that of food sold in the contiguous U.S. [62].

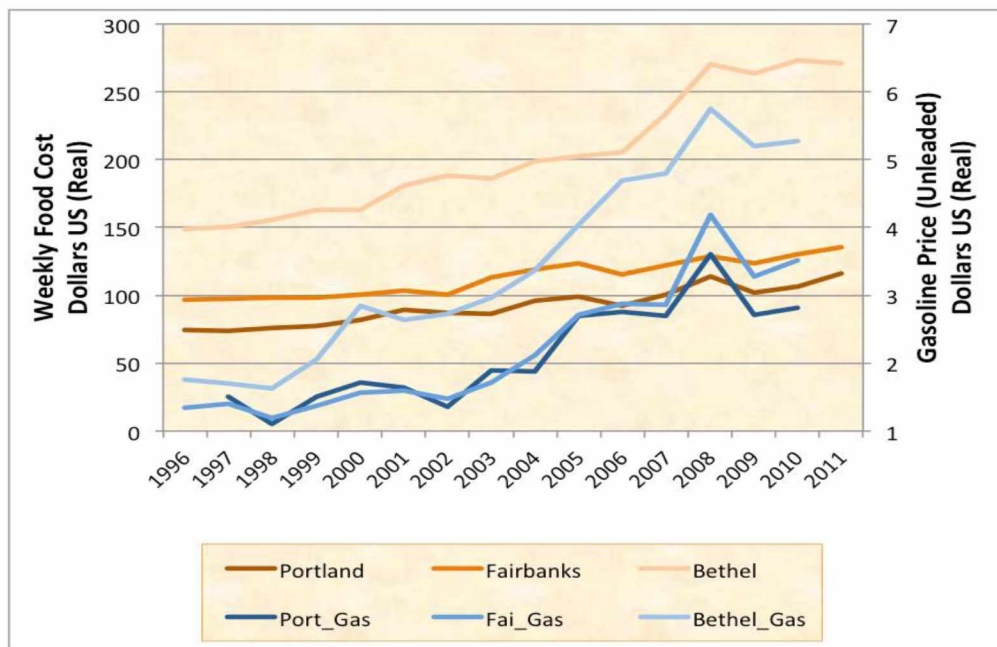


Figure 2.2: Comparisons of food and gasoline prices/gallon (2013 USD) for Portland, OR, Fairbanks, AK, and Bethel, AK. Note the spike in costs during the 2008 fuel crisis.

2.6.2 Household and Municipal Uses

Energy for heat, lighting and running electric appliances is important to both household and municipal buildings. Families often feel energy insecure if they cannot afford the high cost of electricity and heating fuel to be comfortable throughout all of the seasons of the year. With the upkeep of a modern lifestyle that includes using electronics such as TV, computer, mobile devices and game consoles electricity use is furthermore increased. Municipal energy use has similar concerns, such as being able to keep offices heated adequately and have enough budgeted to pay for electricity without needing to cut-back on other areas. Aside from the availability factor of fuel in rural Alaska, increasing fuel prices coupled with the high cost of food are leading some low-income families to decide whether to spend a large portion of their income on either food or fuel to heat their home because they can't afford both [63, 73]. Rural low-income families spent up to 47% of their household income on home energy use in 2008, as compared to urban families who spent up to 18% [74].

2.6.3 Stability

One way to evaluate the question of whether or not the existing energy economy in rural Alaska can be maintained over time is with the concepts of resilience and vulnerability. When energy security is viewed through the lens of resilience it can be interpreted as energy self-reliance and independence. Resilience in this context is the magnitude of a change in supply and demand, delivery or affordability of energy services that the system could withstand without experiencing a fundamental change in the energy security baseline [75, 76]. For example, the resilience of a household is determined by how long they can continue generating and using power if an ice storm prevents shipment of fuel to their region if their sole power source is imported fuel. Increased resilience can take the shape of additional fuel drums that a household has in storage but could also be their ability to adapt, reorganize and innovate. One example is if households join forces and share cooking and other electrical needs they can stretch their combined fuel reserves, thus increasing their resilience to the system shock.

An increased dependence on imported food also increases the reliance on fuel for the transportation of the food to the store and the electricity to power the freezers, fridges and lights in the store. An example of a situation where aging infrastructure in a local community power plant failed and affected food security occurred in the fall of 2014 in the village of Tuluksak, near Bethel in Southwest Alaska. All three generators in the local power plant failed at the same time, leaving the village with no power [77, 78]. The main concern was keeping the villages' food supply in freezers from thawing. Many

families store the bulk of the food they consume throughout the winter in freezers. The school and the village store have private generators and can remain open, however the village clinic did not have any power. None of the generators were salvageable and new generators are very costly. The state of Alaska flew in an emergency generator to turn the power back on in the village, but the residents were without power for over two weeks.

In January 2016 another village in Alaska was left without power for four days [79]. The only generator in Newtok, a rural community in Southwest Alaska, failed leaving the entire community without power. The main concern for residents was keeping warm. The state flew in an emergency generator. In total roughly \$30,000 was spent restoring power to the community. This scenario again addresses the availability component of energy security, but merely replacing the generators does not address the access, utility or stability of the future energy security of the village.

Vulnerability of rural energy security increases if there is a sole reliance on imported energy sources, such as oil and gas. If there are diversified energy sources combined with energy conservation measures the resilience is increased multifold. In parallel with issues surrounding food security, availability of raw materials for generating energy is often not the culprit; it is access and distribution that needs to be improved upon [80]. The natural resources of Alaska provide a host of energy options: aside from oil there is solar, wind, hydro, geothermal, biomass, tidal and natural gas, but access to technology to harness and use these for generation is limited and slow to progress [81]. Potentially due to its nature as an oil and gas supplying region, coupled with the legacy of climate inappropriate home heating and construction models the vast majority of households are largely dependent on oil and gas in the rural areas. Affordability often rules out exploring alternative energy sources on a household level, though a number of organizations and state programs are on the upswing to provide assistance in the adoption of renewable energy and climate appropriate house designs [82, 83].

2.7 Discussion

The contrast of historical and contemporary energy uses and needs in rural Alaska illustrates the importance of adopting a place-based approach to energy security. While the state itself is a major oil producer and urban households are all connected to energy grids, the picture in rural Alaska is one of vulnerability more than resilience, a result of expensive imported fuel with unreliable import schedules, inefficient homes and inefficient use of heating fuel. A significant segment of the population is

therefore energy insecure, specifically within three out of the four energy use categories proposed above. Food systems, household activities, and municipal activities -- such as water supply and heated public buildings -- are all vulnerable.

The categories of access, availability, utility, and stability add clarity to our assessment. There are abundant energy resources available in Alaska including oil, natural gas, geothermal, solar, wind, biomass, hydro and ocean/tidal power [84] but most people do not have widespread access to these options. While some subsidies exist, they are often not sufficiently high to make these options affordable. Since the current predominant fuel type in remote Alaskan communities is diesel, increasing access in the current system would mean purchasing and storing additional drums for fuel or facilitating cheaper fuel transportation to rural communities on a more frequent schedule. This however, can affect stability through the environmental impact, since this increases the risk for leaking fuel drums causing polluted ground and water resources. It would simultaneously impact the affordability of energy as more upfront payment would be needed to purchase the fuel drums. Branching out into renewable energy sources, such as wind, solar and hydropower would afford a larger availability of energy. However, installing renewable energy in rural Alaska can also be cost prohibitive because of the high costs of shipping the equipment. A number of non-profit organizations and state funded grants are providing assistance in installing wind turbines and tapping into geothermal power, as well as utilizing solar energy for community buildings, to heat greenhouses and provide hot water [85]. This is in alignment with Alaska's energy policy to obtain half of the state's electricity from renewable sources by 2025 [86].

As stated earlier, energy costs in rural Alaska are relatively high compared to urban areas in the state. Rural inhabitants therefore are often confronted with trade-offs, in some cases choosing between heating or eating. This raises the important question of how much energy is required to maintain a sustainable standard of living. While that amount can vary from household to household, we believe that most would agree that having to choose between food and heating a home is not consistent with any possible definition of energy security.

The utility dimension of energy security encompasses both the energy efficiency of the technologies at use as well as the social and cultural acceptability and appropriateness of those technologies. Historically, technologies used in rural Alaska for housing, hunting, even clothing embedded aspects of energy security; today, we argue that new energy options would likewise need to be place-based, that is, designed according to locally available energy sources and governed locally. The efficiency of technologies used for the four activities above play an important role as well, whether for buildings,

appliances, transport vehicles or machinery.

Energy efficiency is supported by Alaska's energy policy to decrease energy use per capita by 15 percent by 2020 [86]. If homes are heat efficient, less of the heating fuel will be required, thus lowering the yearly cost, thus increasing affordability, which allows for less trade-offs and arguably can increase the standard of living if tradeoffs between using fuel and purchasing household goods or food does not need to be factored in any longer. Education to increase the energy literacy of homeowners is also an important part of the solution, especially when it comes to simple measures such as replacing light bulbs for more efficient ones [87]. Energy literacy also gives homeowners more control over their energy security.

It is important that an indigenous and decolonized conversation be had about energy security in the North and how it ought to be pursued, with some skepticism at least about whether new technologies developed outside the North make sense for northern people and places. As elaborated above, colonialism of Alaska and the invasion of settlers significantly changed the fuel sources, energy uses and home energy efficiency of the indigenous populations. Households went from using appropriate, locally available, affordable, and very efficient methods of using energy sources with a relatively fuel secure situation to a complete conversion using imported fuel sources. Additionally, the imported fuel was used at a much higher rate due to energy inefficient homes, which impacted affordability of energy directly leading to a questionable if not energy insecure situation for most households. The colonial legacy cannot be underestimated when reviewing the energy situation of a region. As can be seen with organizations building homes with features of pre-contact homes, sometimes the way forward to increase energy security is to take a look backwards.

Finally, and as noted above, rural energy systems are lacking stability, both in terms of the vulnerabilities that communities are exposed to through current systems and also because of the inherent unsustainability of those technologies. The carbon pollution associated with oil and gas extraction, transportation and burning fossil fuels for its end-use is well known, and the climatic changes that are resulting are impacting livelihoods in rural Alaska in myriads of ways. With the effects of climate change already visible, the local environmental consequences of fossil fuel-based energy generation multiply the problems. However, due to limited availability and access to alternatives, residents don't usually have a choice in the matter. Implementing energy efficiency measures is one possible exception. Though there is typically an upfront cost associated with energy efficiency improvements and the payback rate is low, especially when oil prices in rural Alaska are relatively high.

2.8 Conclusion

Whether the place is rural Africa or rural Alaska, the primary drivers, and determinants of energy security at the household level will invariably involve some combination of historical, economic, political, geological, cultural, and ecological dimensions. As has been previously done for food security, we offer here a framework for “downscaling” the energy security discussion to bring clarity to these dimensions and how they interact. In so doing, we have illustrated the highly place-based nature of energy security and how it interacts with other components of the food-water-energy nexus. If energy democracy and/or energy justice are the goals, it is imperative that policies take these localized contours into account.

Alaska is fruitful with oil and gas reserves (which benefit the state’s treasury) but its people are lacking in rural energy security. In this Alaska is similar to many other oil producing nations that lack the infrastructure, policies, or political will to ensure that outcomes are equitable and their people are secure. Many government and non-governmental organizations in Alaska are working with remote communities to lessen their overreliance on imported fuel through renewable energy generation, though the costs remain high and institutional support is only nascent. What we learn from the discussion above is that building energy security in these places is not just a matter of implementing the latest and greatest alternative energy technologies, but also of confronting the structural and built legacies of colonialism. To that end, it is essential that local governance and decisions regarding the cultural appropriateness of technologies must play a central role in shaping a region’s energy future. Planners and policymakers must look at the local discourses surrounding alternative energy when developing these solutions such that local people are literally and figuratively empowered by reforms; the alternative is to repeat past mistakes by implementing technologies that do not meet local needs and that lock people into a posture of dependency.

2.9 References

- [1] Loring, P. A., Gerlach, S. Craig, & Huntington, H. P. (2013). The New Environmental Security: Linking Food, Water and Energy for Integrative and Diagnostic Social-Ecological Research. *Journal of Agriculture, Food Systems and Community Development*, Advance online publication. doi: 10.5304/jafscd.2013.034.005
- [2] Sovacool, Benjamin K., & Mukherjee, Ishani. (2011). Conceptualizing and measuring energy security: A synthesized approach. *Energy*, 36(8), 5343–5355. doi: 10.1016/j.energy.2011.06.043
- [3] Bizikova, Livia, Roy, Dimple, Swanson, Darren, Venema, Henry David, & McCandless, Matthew. (2013). The water-energy-food security nexus: Towards a practical planning and decision-support framework for landscape investment and risk management: International Institute for Sustainable Development.
- [4] Sovacool, Benjamin K., & Brown, Marilyn A. (2010). Competing Dimensions of Energy Security: An International Perspective. *Annual Review of Environment and Resources*, 35, 77-108. doi: 10.1146/annurev-environ-042509-143035
- [5] Bielecki, J. (2002). Energy Security: Is the Wolf at the Door? *The Quarterly Review of Economics and Finance*, 42(2), 235-250. doi: 10.1016/S1062-9769(02)00137-0
- [6] Kruyt, Bert, van Vuuren, D.P., de Vries, H.J.M., & Groenenberg, H. (2009). Indicators for Energy Security. *Energy Policy*, 37(6), 2166-2181. doi: 10.1016/j.enpol.2009.02.006
- [7] Yergin, Daniel. (2006). Ensuring energy security. *Foreign Affairs – New York*, 85(2), 69.
- [8] Unruh, Gregory C. (2000). Understanding carbon lock-in. *Energy Policy*, 28(12), 817-830. doi: 10.1016/S0301-4215(00)00070-7
- [9] Bottomly, J.M. (2001). Energy Assistance Programs: Keeping Older Adults Housed and Warm. *Topics in Geriatric Rehabilitation*, 17, 71-81.
- [10] Mills, E. (2005). The Specter of Fuel-based Lighting. *Science (Washington)*, 308, 1263-1264.
- [11] Maxwell, Simon. (1996). Food security: a post-modern perspective. *Food Policy*, 21(2), 155-170. doi: 10.1016/0306-9192(95)00074-7
- [12] Maxwell, Simon, & Smith, Marisol. (1992). Household food security: a conceptual review. *Household Food Security: concepts, indicators, measurements*. Edited by S. Maxwell and T. Frankenberger. Rome and New York: IFAD and UNICEF.
- [13] Loring, P. A., & Gerlach, S. Craig. (In Press). Searching for Progress on Food Security in the North American North: A Research Synthesis and Meta-analysis of the Peer-review Literature. *Arctic*.

-
- [14] Colt, S., Goldsmith, S., Wiita, A., & Foster, M. (2003). Sustainable Utilities in Rural Alaska: Final report. Prepared for USDA Rural Development and Alaska Science and Technology Foundation.
- [15] Martin, Stephanie, Killorin, Mary, & Colt, Steve. (2008). Fuel Costs, Migration, and Community Viability. Denali, Alaska: Institute of Social and Economic Research in collaboration with First Alaskan Institute and Alaska Native Policy Center.
- [16] Wilson, Meghan, Saylor, Ben, Szymoniak, Nick, Colt, Steve, & Fay, Ginny. (2008). Components of Delivered Fuel Prices in Alaska. Anchorage, AK: University of Alaska Anchorage Institute of Social and Economic Research.
- [17] Fresco, Nancy, & III, F. Stuart Chapin. (2009). Assessing the Potential for Conversion to Biomass Fuels in Interior Alaska. (Res Pap. PNW-RP-579). Portland, OR.
- [18] Nicholls, David. (2009). Wood Energy in Alaska - Case Study Evaluations of Selected Facilities. (Gen. Tech. Rep. PNW-GTR-793). Portland, OR.
- [19] Reddy, Amulya Kumar N, & Subramanian, DK. (1979). The design of rural energy centres. Paper presented at the Sadhana (Academy Proceedings in Engineering Sciences).
- [20] Brew-Hammond, Abeeku, & Kemausuor, Francis. (2009). Energy for all in Africa - to be or not to be?! *Current Opinion in Environmental Sustainability*, 1(1), 83-88. doi: <http://dx.doi.org/10.1016/j.cosust.2009.07.014>
- [21] Hiremath, R. B., Kumar, B., Balachandra, P., Ravindranath, N. H., & Raghunandan, B. N. (2009). Decentralised Renewable Energy: Scope, Relevance and Applications in the Indian Context. *Energy for Sustainable Development*, 13, 4-10.
- [22] Amigun, B., Sigamoney, R., & Blottnitz, H. von. (2008). Commercialisation of Biofuel Industry in Africa: A Review. *Renewable and Sustainable Energy Reviews*, 12, 690-711. doi: [10.1016/j.rser.2006.10.019](http://dx.doi.org/10.1016/j.rser.2006.10.019)
- [23] Gaffney, Jeffrey S, & Marley, Nancy A. (2009). The impacts of combustion emissions on air quality and climate—From coal to biofuels and beyond. *Atmospheric Environment*, 43(1), 23-36. doi: [10.1016/j.atmosenv.2008.09.016](http://dx.doi.org/10.1016/j.atmosenv.2008.09.016)
- [24] Brown, J. Jed, Limburg, Karin E., Waldman, John R., Stephenson, Kurt, Glenn, Edward P., Juanes, Francis, & Jordaan, Adrian. (2013). Fish and hydropower on the U.S. Atlantic coast: failed fisheries policies from half-way technologies. *Conservation Letters*, 6(4), 280-286. doi: [10.1111/conl.12000](http://dx.doi.org/10.1111/conl.12000)

-
- [25] Poff, Leroy N., & Hart, David D. (2002). How Dams Vary and Why It Matters for the Emerging Science of Dam Removal. *BioScience*, 52(8), 659-668. doi: 10.1641/0006-3568
- [26] Giampietro, Mario, Aspinall, Richard J., Ramos-Martin, Jesus, & Bukkens, Sandra G.F. (2014). Addressing the Complexity of Integrated Resource Assessment. In M. Giampietro, R. J. Aspinall, J. Ramos-Martin & S. G. F. Bukkens (Eds.), *Resource Accounting for Sustainability Assessment; The Nexus Between Energy, Food, Water and Land Use* (pp. 1-8): Routledge.
- [27] Hughes, Larry. (2012). A generic framework for the description and analysis of energy security in an energy system. *Energy Policy*, 42, 221-231. doi: <http://dx.doi.org/10.1016/j.enpol.2011.11.079>
- [28] Chen, Zhan-Ming, Chang, Yuan, & Sun, Yi-Ming. (2015). How Does Energy Security Definition Vary Across Nations? A Review of Major Energy Consumers. *Journal of Technology Innovations in Renewable Energy*, 4(2), 73-79. doi: <http://dx.doi.org/10.6000/1929-6002.2015.04.02.4>
- [29] Chester, Lynne. (2010). Conceptualising energy security and making explicit its polysemic nature. *Energy Policy*, 38(2), 887-895. doi: <http://dx.doi.org/10.1016/j.enpol.2009.10.039>
- [30] Martchamadol, Jutamane, & Kumar, S. (2013). An aggregated energy security performance indicator. *Applied Energy*, 103, 653-670. doi: <http://dx.doi.org/10.1016/j.apenergy.2012.10.027>
- [31] Löschel, Andreas, Moslener, Ulf, & Rübhelke, Dirk T. G. (2010). Indicators of energy security in industrialised countries. *Energy Policy*, 38(4), 1665-1671. doi: <http://dx.doi.org/10.1016/j.enpol.2009.03.061>
- [32] Greene, David L. (2010). Measuring energy security: Can the United States achieve oil independence? *Energy Policy*, 38(4), 1614-1621. doi: <http://dx.doi.org/10.1016/j.enpol.2009.01.041>
- [33] Winzer, Christian. (2012). Conceptualizing energy security. *Energy Policy*, 46, 36-48. doi: <http://dx.doi.org/10.1016/j.enpol.2012.02.067>
- [34] Food and Agriculture Organization of the United Nations (FAO). (2013). *The State of Food Insecurity in the World 2013: The Multiple Dimensions of Food Security*. Rome, Italy: Food and Agriculture Organization of the United Nations.
- [35] Moran, Emilio F. (1981). Human Adaptation to Arctic Zones. *Annual Review of Anthropology*, 10, 1-25.

-
- [36] The Alaska Climate Research Center. (2016). Alaska Climatology. Retrieved January 31, 2016, from <http://akclimate.org/Climate>
- [37] Western Regional Climate Center. (2016). Climate of Alaska. Retrieved January 31, 2016, from <http://www.wrcc.dri.edu/narratives/ALASKA.htm>
- [38] Slaughter, Dale. (1982). The Point Barrow House Type: An Analysis of Archeological Examples from Siraagruk and Other Sites in Northern Alaska. In A. D. Shinkwin (Ed.), *Anthropological Papers of the University of Alaska* (pp. 141-158). Fairbanks, AK.
- [39] Giddings, James Louis Jr. (1952). *The Arctic Woodland Culture of the Kobuk River* The University Museum. Philadelphia, PA: University of Pennsylvania.
- [40] Murdoch, John. (1852). *Ethnological Results of the Point Barrow Expedition*. In J. W. Powell (Ed.), *Ninth Annual Report of the Bureau of Ethnology*. Washington, DC: Smithsonian Institution.
- [41] Mauss, Marcel, & Beuchat, Henri. (1979). *Seasonal Variations of the Eskimo - A Study in Social Morphology*. London, UK: Routledge & Kegan Paul Ltd.
- [42] Spencer, Robert F. (1959). *The North Alaskan Eskimo: A Study in Ecology and Society* Bulletin 171. Washington, DC: Bureau of American Ethnology. Smithsonian Institution.
- [43] Rogers, Jason S. (2012). Architecture and Complex Hearth Features at the Amaknak Bridge Site, Eastern Aleutian Islands, Alaska. *Arctic Anthropology*, 48(2), 92-112. doi: 10.1353/arc.2012.0004
- [44] Lee, Molly, & Reinhardt, Gregory A. (2003). *Eskimo Architecture: Dwelling and Structure in the Early History Period*. Fairbanks, AK: University of Alaska Press.
- [45] Blake, Kevin S., Kellerson, Rebecca L., & Simic, Aleksandra. (2007). *Measuring Overcrowding in Housing*. In I. International (Ed.). Fairfax, VA: U.S. Department of Housing and Urban Development - Office of Policy Development and Research.
- [46] Deer, Charlie, George, Marquam, Kaluza, Phil, Loudon, Phil, Moore, Ginny, Musick, Mike, . . . Woodward, John. (2008). *Alaska Residential Building Manual*. In R. Seifert (Ed.), (Vol. 7th Edition). Fairbanks, AK: Cooperative Extension Service, University of Alaska Fairbanks.
- [47] Partnow, Patricia H. (1985). *Alaska Athabascans Indian Education Act Project*. Anchorage, AK.
- [48] Bishop, K. (2011). Thule Palaeopathology: The health concerns of an arctic lifestyle. *Totem: The University of Western Ontario Journal of Anthropology* 19(1):4.

-
- [49] Ray, Dorothy Jean, & Edmonds, H.M.W. (1966). *The Eskimo of St. Michael and Vicinity as Related by HMW Edmonds*. Fairbanks, AK: University of Alaska Press.
- [50] Fienup-Riordan, Ann. (2000). *Where the Echo Began and Other Oral Traditions from Southwestern Alaska Recorded by Hans Himmelheber*. Fairbanks, AK: University of Alaska Press.
- [51] McCartney, Allen P, & Veltre, Douglas W. (1999). Aleutian Island prehistory: Living in insular extremes. *World Archaeology*, 30(3), 503-515. doi: 10.1080/00438243.1999.9980426
- [52] Knecht, Richard, & Davis, Richard. (2004). *Amaknak Bridge Site Data Recovery Project Final Report # Mgs-Stpbr-0310 (S)/52930*. Anchorage, AK: Museum of the Aleutians, Unalaska and Alaska Department of Transportation.
- [53] Barnhardt, Carol. (2001). A History of Schooling for Alaska Native People. *Journal of American Indian Education*, 40(1), 1-30.
- [54] Eichelberger, Laura Palen. (2010). Living in Utility Scarcity: Energy and Water Insecurity in Northwest Alaska. *American Journal of Public Health*, 100(6), 1010-1018. doi: 10.2105/AJPH.2009.160846
- [55] Stefansson, Vilhjalmur. (1913). *My Life with the Eskimo*. New York, NY: The Macmillan Company.
- [56] Whitridge, Peter. (2008). Reimagining the Iglu: Modernity and the Challenge of the Eighteenth Century Labrador Inuit Winter House. *Archaeologies*, 4(2), 288-309. doi: 10.1007/s11759-008-9066-8
- [57] Office of Indian Affairs. (1877). *Annual Report of the Commissioner of Indian Affairs for the Year 1877*. Washington, DC: Office of Indian Affairs.
- [58] Seltenrich, Nate. (2012). Healthier Tribal Housing: Combining the Best of Old and New. *Environmental Health Perspectives*, 120(12), a460. doi: 10.1289/ehp.120-a460
- [59] Government Accountability Office (GAO). (1978). *Substandard Indian Housing Increases Despite Federal Efforts - a Change Is Needed*. In T. C. General (Ed.), *Report to the Congress of the United States*. Washington, DC: U.S. General Accounting Office.
- [60] Rogers, Brian, & Lister, Cady. (2005). *2005 Alaska Housing Assessment*. In A. H. F. Corporation (Ed.). Fairbanks, AK: Information Insights prepared for Cold Climate Housing Research Center.

-
- [61] Isherwood, William, Smith, J. Ray, Aceves, Salvador M., Berry, Gene, Clark, Woodrow, Johnson, Ronald, Seifert, Richard. (2000). Remote power systems with advanced storage technologies for Alaskan villages. *Energy*, 25(10), 1005-1020. doi: 10.1016/s0360-5442(00)00028-1
- [62] Gerlach, S. Craig, Loring, Philip A., Turner, Amy, & Atkinson, David E. (2011). Food Systems, Environmental Change, and Community Needs in Rural Alaska. In A. L. L. Hajo Eicken (Ed.), *North by 2020: Perspectives on a Changing North*. Fairbanks, AK: University of Alaska Press.
- [63] Fazzino, David V., & Loring, Phillip A. (2009). From Crisis to Cumulative Effects: Food Security Challenges in Alaska. *NAPA Bulletin*, 32, 152-177. doi: 10.1111/j.1556-4797.2009.01033.x
- [64] Hamilton, Lawrence C., White, Daniel M., Lammers, Richard B., & Myerchin, Greta. (2011). Population, climate, and electricity use in the Arctic integrated analysis of Alaska community data. *Population & Environment*, 1-15. doi: 10.1007/s11111-011-0145-1
- [65] Authority, Alaska Energy. (2015). *Power Cost Equalization Program, Statistical Data by Community, Amended*. Anchorage, AK.
- [66] Colt, S., Goldsmith, S., Wiita, A., & Foster, M. (2003). *Sustainable Utilities in Rural Alaska: Final report*. Prepared for USDA Rural Development and Alaska Science and Technology Foundation.
- [67] Schwörer, Tobias and Ginny Fay. (2011). "The Cool 100 Book." edited by James Haselip and David Pointing. Roskilde, Denmark: UNEP Risø Centre on Energy, Climate and Sustainable Development.
- [68] Chapman, RN. (1996). Hybrid Power Technology for Remote Military Facilities. *Proceedings for Power Quality Solutions/Alternative Energy*, 415-427.
- [69] DeMarban, Alex. (2011, November 30th). Nome Faces Energy Crisis in Wake of Bering Sea Storm, *Alaska Dispatch News*.
- [70] Murphy, Kim. (2011, December 2nd). Ice Halts Delivery of Winter Fuel to Nome, Alaska, *Los Angeles Times*.
- [71] Lipman, Don. (2012, January 18th). Nome Weather-Related Crisis Averted, for Second Time in History, *The Washington Post*.
- [72] Loring, Philip A., & Gerlach, S. Craig. (2009). Food, Culture, and Human Health in Alaska: an Integrative Health Approach to Food Security. *Environmental Science & Policy*, 12, 466-478.

-
- [73] Simon, Mallory. (2009). In Rural Alaska Villages, Families Struggle to Survive, CNN. Retrieved from <http://www.cnn.com/2009/US/02/09/rural.alaska.villages/index.html?iref=storysearch>
- [74] Saylor, Ben, Haley, Sharman, & Szymonkiak, Nick. (2008). Estimated Household Costs for Home Energy Use, May 2008 (Vol. Note No. 1). Anchorage, AK: Institute of Social and Economic Research.
- [75] Holling, C.S. (1986). Resilience of Ecosystems: Local Surprise and Global Change. In W. C. Clark & R. E. Munn (Eds.), *Sustainable Development and the Biosphere*. Cambridge, UK: Cambridge University Press.
- [76] Chapin III, FS, Peterson, G., Berkes, F., Callaghan, TV, Angelstam, P., Apps, M., Danell, K. (2004). Resilience and vulnerability of northern regions to social and environmental change. *AMBIO: A Journal of the Human Environment*, 33(6), 344-349. doi: 10.1579/0044-7447-33.6.344
- [77] Demer, Lisa. (2014, November 15th). Power Restored to Tuluksak, Alaska Dispatch News.
- [78] Demer, Lisa. (2014, November 11th). Residents of Western Alaska Village without Power since Friday, Alaska Dispatch News.
- [79] The Associated Press. (2016, January 22). Power Restored to Newtok after Days-Long Outage, *Juneau Empire*. Retrieved from <http://juneauempire.com/state/2016-01-21/power-restored-newtok-after-days-long-outage>
- [80] Sen, Amartya. (1999). *Development as Freedom*. New York, NY: Alfred A. Knopf, a division of Random House, Inc.
- [81] Alaska Center for Energy and Power (ACEP). (2012). *Stranded Renewable Energy Resources of Alaska: A Preliminary Overview of Opportunities and Challenges to Development*. The National Renewable Energy Laboratory prepared by The Alaska Center for Energy and Power.
- [82] Cold Climate Housing Research Center. (2010). *Sustainable Northern Shelter Program*. Fairbanks, AK: Cold Climate Housing Research Center.
- [83] DeMarban, Alex. (2012, May 2nd). Wind Power Fuels Alaska's Push for Rural Renewable Energy Sources, Alaska Dispatch News.
- [84] U.S. Energy Information Administration, (EIA). (2015, June 19, 2014). *Alaska State Profile and Energy Estimates*. Retrieved April 1st, 2015, from <http://www.eia.gov/state/analysis.cfm?sid=AK>

-
- [85] Renewable Energy Alaska Project (REAP). Alaska's Renewable Energy Projects. Retrieved April 1st, 2015, from <http://alaskarenewableenergy.org/why-renewable-energy-is-important/alaskas-renewable-energy-projects/>
- [86] The Alaska State Legislature. (2010). State Energy Policy House Bill 306: 26th Legislature.
- [87] Marsik, Tomas. (2016, January 7, 2016). Energy Literacy Yield Extraordinary Financial Returns while Helping the Planet, Commentary, Alaska Dispatch News. Retrieved from <http://www.adn.com/article/20160107/energy-literacy-yields-extraordinary-financial-returns-while-helping-planet>

Chapter 3

The Evolution of Home Energy Efficiency in Alaska⁴

3.1 Abstract

This paper is a review of Alaskan homes, with emphasis placed on energy efficiency features. The review begins with pre-contact homes in the north, interior, and southwest regions of Alaska. The changes brought by early settlers and the influence they had on architecture is explored, as well as how energy efficiency evolved in home design through the 20th and 21st centuries. Special attention is placed on indoor thermal comfort, occupancy rates, and sense of place. Several energy efficiency features in pre-contact homes have been re-introduced in modern homes. Housing legacies reveal that energy efficiency is not enough to provide a vital sense of place to its occupants, the social and cultural aspects of a home need to be considered by designers in addition to energy conservation. I use the term ‘vernacular’ building style in this paper to describe homes throughout the history of Alaska adapting to a range of external stressors. I posit that the vernacular design of historical homes fostered the capacity of households to adapt to changing conditions. Homes tell stories about historic legacies, socioeconomic conditions, ecological conditions, politics, and cultural influences, and the importance placed on feeling a sense of place.

3.2 Introduction

This paper provides an overview of ‘vernacular homes’ in Alaska and considers not only architectural features of homes and how they have evolved over time, but also draws connections to cultural considerations such as occupancy rates and sense of place. Vernacular, in this case, refers to a building style that references so-called ‘organic’ design: choices that are adapted to suit the local region as well as the living patterns of previous generations (Fewins, 2013). As I describe below, in Alaska, people have different approaches to the incorporation of energy efficiency features in their homes and this tells a tale of diverse regional cultures that are rich in tradition and ingenuity in acclimating to both

⁴ Hossain, Y. & Loring, P.A. In Preparation. The Evolution of Home Energy Efficiency in Alaska. *Northern Review*.

a cold climate, as well as concerns over surviving arctic and subarctic temperatures. Human adaptation to environmental circumstances can be observed in the home designs spanning the history of the state; from adapting to the changing seasons, invasion of settlers, changing subsistence economies, fluctuating oil prices, to poverty trends and rural outmigration. Vernacular homes in Alaska tell a tale of a socio-political environment where more than one fifth of households are unable to keep their homes at 70 degrees Fahrenheit (Rogers & Lister, 2005). This may to some degree indicate a discrepancy of government assistance programs and the need for government intervention. The modern local home designs, and future trends, also point to a society that has a rich indigenous culture but the continued use of lumber and other imported building materials also reflects the influences from a settler culture, utilizing natural resources that are not locally available and are very expensive to transport to the building site.

I begin this essay by describing pre-colonial homes in the northern, interior, and southwest regions of Alaska, looking at the influences settlers had on vernacular homes and ends with a survey of homes built in the 20th and 21st century. Throughout this essay, I focus on heating efficiency features of the dwellings as a common thread in the history of vernacular buildings in the state. Since Alaska spans, geographically, an arctic and subarctic climate, indoor heating is a paramount feature of Alaskan homes, and heating costs can be substantial. Today, Alaska's cold climate coupled with high oil prices, sparse transportation modes, socio-economic conditions and changing climate are creating energy insecurity in many areas of the state (Hossain et al., 2016). Energy-efficient home features, especially heating efficiency can arguably be seen as a step towards regaining energy security, especially on the household level. Finally, I posit that vernacular homes serve as an example of planned human adaptation to a changing world.

3.3 Concepts and Methods

Glassie (1976) makes a case for studying architecture of different cultures as a way of comprehending their history. Homes have the potential to encode a household or culture's worldview, from social relations and meaning to cosmological, and ritual connotations (LeMoine, 2003; Tanner, 1991). Architectural structures are commonly analyzed in archaeology, cultural geography, sociology, and anthropology to provide insights into the culture of a region (Abrams, 1989; Tester, 2009, Spencer, 1959; Cutting, 2006). This is because interrelational aspects of a culture such as gender, for example,

can be reflected in the spaces in which household members spend most of their time, and these patterns invariably influence building design features (Dawson, 1995). A residence can therefore be a wellspring of information about its inhabitants, evoking insights into family structure, gender roles, political organization, socio-economic conditions, and social hierarchy (Blunt, 2005). The clues that homes provide the researcher are often as simple as the building materials that were used, construction design, use of space, and how the home was heated.

In this essay, I engage with the following concepts, which I explore in more detail below: vernacular architecture, sense of place, space syntax as it relates to sense of place, and human adaptation to global change. The historical survey that follows spans the northern, interior, and southwest regions of Alaska, and does not include the southeastern region. This is due to the vastly dissimilar and warmer climate of southeast Alaska making it difficult to compare heating and other cold weather requirements with the other regions.

Vernacular Architecture

Vernacular architecture describes designs that are based on traditions in a culture and are built utilizing local materials and resources without an architectural design plan (Zhai & Previtali, 2010; Fewins, 2013). Commonly, this term is used when discussing indigenous buildings, but in this paper, the term is broadened to include contemporary homes as well as to inform thinking about future designs, as it arguably relates to a more expansive description of vernacular architecture as given by Paul Oliver (1997, xxiii):

“Vernacular architecture comprises the dwellings and other buildings of the people. Related to their environmental contexts and available resources, they are customarily owner- or community-built, utilizing traditional technologies. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economies and ways of living of the cultures that produce them.”

There is a case to be made that in Alaska not only pre-colonial dwellings, but also modern homes can be considered built in the vernacular style. I posit that the term vernacular building style in Alaska can be likened to vernacular language. Vernacular language represents regional or cultural patterns of language modification to meet local conditions of expression. Vernacular buildings in Alaska point to regional, cross-cultural patterns of adaptability to extreme cold temperatures, fuel source scarcity and high costs, while accommodating occupant values. Indigenous homes as well as modern homes that place emphasis on energy efficiency are accommodating not only environmental resource availability,

but also considerations of the economic needs of occupants. Some modern energy-efficient homes even repurpose pre-colonial energy efficiency home design features, as I explore in this paper. I recognize that technological innovations are not customarily included in the concept of vernacular style architecture, however, in the context of this paper, technology not only represents the external influences of a changing culture but also a means of planned human adaptation.

Human Adaptation

The concept of adaptation is often applied to changing environmental conditions (IPCC, 2014). Its usefulness can also be applied to changes in the political landscape, as well as economic- and demographic change. Taking into account multiple drivers of change, the definition can get murky, as climate change adaptation is considered anticipatory and geared towards planning and policy, while behavioral and cultural adaptation is observed over time (Thornton & Manasfi, 2010; Loring et al., 2016). The intricacy and usefulness of adaptation theory is beyond the scope of this paper, but see Loring et al., 2016 for further discussion. In this overview paper, I use Thornton and Manasfi's (2010) description of human adaptation as

not a single strategy but rather a set of diverse, intersecting processes that may evolve autonomously or through planning in response to the panoply of climatic and non-climate stressors. (p. 148).

This definition does not limit adaptation to a specific temporal referent as immediate adaptation strategies and long-term planned adaptation are included. In the event of a slow change, such as a changing climate, human adaptation can encompass innovation of new technologies. Or in the event of a sudden shift in conditions, such as loss of employment of the head of the household, coping strategies can be utilized instantly. Human adaptation is dependent on a variety of factors, none of which would suffice on its own for successful adaptation (Boyd et al., 2011; Thornton & Manasfi, 2010). Human cognitive abilities coupled with detailed bodies of knowledge, social arrangements, market exchanges, technological innovations, institutional and community governance, cultural influences, and utilization of tools from the environment are important. However, for one single human to acquire all the necessary skills for successful adaptation strategies in one lifetime is not feasible. The most successful adaptation strategies hinge on knowledge acquired across generations and the unique ability to learn from others (Boyd et al., 2011). For this reason, in this paper I survey not only the physical elements of current homes, but widen the scope to encompass the housing legacy in Alaska passed down since pre-colonial time. While vernacular style homes may be an outcome of adaptability of humans, specific

features that form a pattern not only regionally but also throughout history can be considered a human adaptation.

Sense of Place

Research conducted on residents' sense of place as it relates to their home, community, or their place in society is linked to both the physical structure of a home and a sense of identity that is subjective and unique to each individual (Hay, 1998; Tuan, 1979). Additionally, the social context of the community, cultural connections, and the ancestral connection to a geographic place are important factors that can influence an individual's identity as it relates to a place (for a further detailed literature review of the concept see Hay, 1998). The difference between an ancestral bond to a place and a cultural bond, is that the former exists through generations of family living on land and having spiritual ties, while cultural connections are formed through being raised in a place. Both, however, can contribute to a sense of identity.

Sense of place is not always dependent on the length of time spent living in the place; a superficial or partial sense of place can exist for transitory households as well. While this type may not exhibit as longstanding a connection, the personal quality of the connection may run deep nonetheless. On the flip side, a sense of place can be negatively impacted by feelings of being trapped in a place, due to economic or family circumstances. This is an important factor when considering emotional ties to a place that form place identity (Hay, 1998).

Residential homes can foster a connection to human wellbeing, as they are physical spaces that allow us to control nature, or rather create our own indoor microclimate that is not related to the natural exterior climate (Tuan, 1979). In high latitudes, the sense of place connection to a home can be an especially deep connection as it ties directly into human survival, at least during the long cold winter months. Within a building, the sense of place of inhabitants can also be influenced by space syntax. The study of space syntax of buildings was developed by researchers at University College London as a way of investigating the influence of spatial layout on social interactions between household members (Dawson, 2002). Space syntax can inform gender roles, social hierarchies, and household organization within occupants of a dwelling (Dawson, 1995; LeMoine, 2003).

3.4 Historical Survey of Home Design in Alaska

3.4.1 Pre-Colonial Home Designs

Northern Alaska

In the northern region of Alaska, the arctic, Iñupiat Eskimo tribes typically had a summer dwelling and a winter home. The permanent winter homes were insulated with sod and were sometimes dug into the sides of sand dunes, hills or river embankments utilizing this feature as natural insulation (Slaughter, 1982; Giddings, 1952; Murdoch, 1852; Mauss & Beuchat, 1979). In summer most families inhabited lighter, movable dwellings allowing them to be mobile for subsistence hunting, fishing and gathering purposes. The summer homes consisted of a tent-like structure with caribou hide walls (Spencer, 1959). Some families inhabited the tents year-round, especially if the inhabitants went caribou and moose hunting in the winter months.

The permanent sod homes of the Alaskan Iñupiat were anywhere from 130-210 square feet (Slaughter, 1982; Spencer, 1959; Giddings, 1952; Murdoch, 1852). The height of the living area characteristically only reached about 5 feet. They were entered through an underground tunnel which was anywhere from 10-30 feet in length. In some houses around Barrow the tunnel sloped slightly downwards to create a cold trap directly before the trapdoor like entrance to the main room. The trapdoor was placed around 4 feet above the tunnel floor to minimize the heavy cold air that stayed close to the ground from entering the main living area when the trapdoor was opened and closed. The tunnel entrances in the homes found along the Kobuk River were oriented south facing, presumably to maximize sunlight and avoid wind gusts. The tunnel entrances were closed with animal hide or a wooden cover. In spring when the snow and ice melted the tunnels were often filled with water forcing the residents to move to their summer dwellings. In the fall the water froze and the inhabitants were able to chip the ice away from the tunnel thus enabling them to take up residence again.

Closest to the outdoor entrance of the tunnel storage nooks were carved out, often into the permafrost layer, to store frozen meats and other perishable goods utilizing the natural refrigeration of the cold air at the entrance to the tunnel as well as the exposed permafrost. Closest to the entrance to the main room was a kitchen alcove, where food was prepared over an open fire using blubber and sea mammal oil as fuel. An opening in the roof above the fire acted as a smoke hole. The main living room had a similar ventilation system, where a small area of the roof was left uncovered, or covered with a plank of wood that could be removed to regulate ventilation needs. Additionally, an area in the roof above the entrance to the main room was covered by stretched walrus, grizzly bear or seal intestines and in some cases an ice sheet functioning as a skylight for natural lighting. Additional light and the

primary heat source for the room came from sea mammal oil lamps that kept the indoor room temperature between 50-60 degrees Fahrenheit during the coldest winter temperatures. Anecdotal information indicates that keeping the house cool was more of a challenge than keeping it warm.

The tunnel and the storage chambers were insulated by the surrounding sand dune if built into one or by sod bricks. The layer of sod could be up to three feet thick. If the sod dried out, water was poured over it to moisten the sod and when the water froze it provided a windproof ice insulation layer. The sod bricks were stacked on top of each other in layers, with the grass side turned inwards. Some houses also added a layer of snow or soil to the outside of the sod bricks as additional insulation. The floors were either sand or earth, covered with organic material such as wood chips, shavings and twigs for added insulation.

The household members slept either in the living area or in the tunnel alcoves or the tunnel itself. There was no separation of sleeping areas, which didn't allow for any privacy. The sleeping place of highest honor was in the living room furthest from the trapdoor entrance, which was presumably the warmest spot. Families sometimes built double sod homes comprised of two living areas connected by a central tunnel and a shared kitchen and storage facilities (Spencer, 1959). This was mostly for economical purposes. Similarly, families at times made agreements to cook and eat meals together for higher efficiency and to save on fuel oil.

Temporary winter houses for visitors or for a family on a hunting trip were built completely out of snow (Murdoch, 1852). The homes were typically built into a snow bank when possible or made by piling up blocks of snow. The layout was similar to the sod houses, with an entrance tunnel and a living area higher than the tunnel above the cold trap. The structures were framed with wooden poles and canvas. A fireplace in the living area provided most of the heat. The first fire caused a large initial snow melt but once the melt froze it created a thick ice layer, the fire only melted a minimal amount of snow from then on. Animal intestines served as window coverings of the openings left in the roof. These types of homes were built in a short amount of time and easily biodegraded and assimilated back into the environment when they were no longer in use. These types of snow homes were often also built in villages as workrooms or as additional food storage sheds.

The summer homes were tent-like structures and were easy to erect and transport and were especially convenient as mobile homes during migration or hunting (Spencer, 1959; Giddings, 1952; Murdoch, 1852; Lee & Reinhardt, 2003). Inland Eskimos, such as the Nunamiut, often lived in the tents year-round due to their migratory lifestyle. The main frame was made from willow branches covered by roughly 20-25 caribou hides or other animal skin weighed down at the bottom with sod blocks, stones or

gravel depending on what was available in the area. The hides were positioned so that the fur was turned outward and in winter an additional layer of hides with the fur side placed inward was overlaid. The two fur sides back to back created an air chamber between them that utilized the trapped air as insulation. The footprint of the tents was oval or round, running between 10 to 15 feet in length and 8 to 10 feet at the widest part accommodating roughly 10 inhabitants. A grizzly bear hide, if available, covered the door opening with the fur side turned inward. This hide was typically heavy and thick enough to keep out cold air from the outside. Similar to the permanent homes and snow houses, the tents had a skylight covered with animal intestine. The tents were heated primarily with lamps or fires built by the door area if the tent had an indoor smoke-hole. In summer the cooking fire was outdoors.

Interior Alaska

Athabascan people living in the Interior of Alaska had a lifestyle based on seasonal migrations since their food source came from hunting, fishing, and gathering (Deer et al., 2008; Partnow, 1985). Their migration patterns influenced their home structure greatly as they needed a dwelling that was easily movable. The Athabascans had tents similar to the tents used by the Eskimos in the north of Alaska (Deer et al., 2008; Partnow, 1985). The tents were built with long poles up to 24 feet long and secured with animal intestines and then covered with overlapping animal hides from moose, caribou, and bears. The floor was insulated with grass and brush and then covered with additional hides. A fire in the middle of the tent served for heating and cooking. One of the poles was attached to a flap above the fire and could be moved to open the flap and regulate the ventilation and smoke-hole of the tent. The tents served primarily as housing during the summer at fishcamps, during hunting trips year-round as well as moving to new gathering locations for berries and roots.

In winter, Interior Alaskans inhabited more permanent homes similar to the sod homes, with the exception of extended hunting trips that the entire family would engage in (Partnow, 1985). The types of winter homes varied slightly throughout the Interior based on differences in climate and natural resources. Most commonly the structure was semi-subterranean with wood framing covered with spruce or birch bark and a layer of soil for extra insulation as well as moss. Other versions included wood boards covered with woven grass on the outside, instead of bark and soil. Once it snowed, the snow blanket functioned as additional insulation over the dwellings. Some Athabascans lived year-round in tents, which were also dome-shaped. For additional warmth in winter an additional animal hide was often added to the tent. In some regions, the dwellings were constructed for one family only,

including extended family members, and in others co-housing with several different families was common.

Southwest Alaska

In mainland southwest Alaska, the homes of the Yup'ik were built similarly to the sod homes of the Iñupiat but with minor variations (Murdoch, 1852; Lee & Reinhardt, 2003; Ray, 1966). The shapes were often rectangular or hexagonal with an average 100 square foot indoor space (Lee & Reinhardt, 2003). The milder temperatures in southwest Alaska compared to the northern region would mean less snowfall and hence in spring the entrance tunnels were not flooded by the melting snow. This enabled the residents to inhabit the sod homes year-round. In some of the warmer locations the sod homes were even built completely above ground instead of subterranean or into the sides of hills or dunes. The tunnels were also not as deep as in the Iñupiaq winter homes, or there were two entrances, one subterranean tunnel for winter use and one above ground covered walkway which could be sealed off in winter. In summer the square smoke-hole in the roof also acted as an entryway. In addition to the sod insulation in the walls and ceiling the floor was covered with grass or spruce and overlaid with grass mats for comfort to walk, sit or sleep on.

In some instances, the only heat source in the sod homes was the heat generated by the bodies of the residents. This was mainly possible where the interior square foot-to-inhabitant ratio was relatively small and the home had sufficient insulation (Fienup-Riordan, 2000). Other heat sources came from lamps and interior hearths. Since their homes had less insulation than the Northern Alaskan sod homes and were often built above ground, keeping the home warm in winter was more of a challenge than keeping it cool. Especially when the smoke-hole was opened to ventilate the indoor air it would significantly cool down the indoor temperature.

When summer dwellings were constructed in southwest Alaska they were typically temporary shelters (Lee & Reinhardt, 2003; Clark, 1984). Along the coast, it was common to build a summer house with a tipped over *umiak*, or whaleboat, propped at a 45-degree angle with oars and driftwood and covered with bark and animal skins. Grass huts were another type of summer home constructed, with either a hole dug in the ground or branches leaned against each other and covered with long grasses or animal hides. The types of homes were mainly used as shelter during subsistence activities, such as fishing, hunting or gathering.

Aleut and Alutiiq people inhabited the Aleutian Island chain, Kodiak Island, Prince William Sound, and the Kenai Peninsula in southwest Alaska. They lived in a similar type of subterranean sod

house as the Yupiit and Iñupiat. Early Russian settlers termed these homes *barabaras* (McCartney & Veltre, 1999; Rogers, 2012; Lee & Reinhardt, 2003). The *barabaras* were entered through the roof with ladders. They typically did not have the same entrance tunnel architecture as the traditional Eskimo sod homes had. The layout was round, oval, or rectangular for larger structures. Multiple additional cavities in the roof were used for ventilation and as smoke-holes. The wall material and insulation was primarily grass and turf layers coated on the outside with mud, earth, clay, or bark. The framing was whalebone or driftwood. Alutiiq homes had floors dug two to three feet below the surface and a total living area of 300-400 square feet on average. Aside from the central room the dwellings had relatively large sleeping chambers carved out into nooks adjacent to the living room. Each nook was one family's sleeping area as *barabaras* typically housed several families.

Evidence of permanent homes built with stone foundations and stone walls instead of sod and turf was discovered on one of the Aleutian Islands (Rogers, 2012). The stone walls were around three feet thick lined in the interior with stone slabs. While temperatures in the Aleutian Islands aren't as low as in northern Alaska, these types of homes protected its inhabitants from icy wind and rain coming from the ocean. Furthermore, the subterranean aspect of the homes provided a natural architectural element of adaptation to the hazard of ash clouds caused by volcanic eruptions and earthquakes, both of which occurred frequently in the island chain. To protect themselves from tsunamis, most of the settlements were on the Bering Sea side of the islands versus the side facing the open ocean. The homes ranged in size, the largest housed around 100 family members and was 165 feet long.

Sea mammal oil was used as the primary fuel source for fireplaces used for cooking, heat, and lamps for light. The homes that included stone foundations often had stone slab hearths with stone channels funneling heat and steam through the floor of the house (Knecht & Davis, 2004; Rogers, 2012). Stone as a building material contains a lot of thermal mass and has the property of radiating heat long after the fire is extinguished. The hearth was built below floor level or directly into the stone walls for the purpose of heating up the stone walls and radiating the heat into the dwelling. Additional shafts leading from the hearth upwards through the roof or leading to the outdoor side of the wall were used as chimneys or flues for fresh air intake and as a force to push the hot air through the channels running through the floors into the interior of the house. Some of the homes built with stone walls were clustered together sharing walls. This may have also been a function of maximizing the stored heat in the stones from the fireplace built into the stone wall.

Food storage was essential for the Aleut, with a need to safely store anything from whale meat and other sea mammals to dried fish, roots, and berries (McCartney & Veltre, 1999). The cold storage

pits were dug into the soil outside of the *barabara* and some of the dried items were stored in subfloor pits covered with stone slabs for easy access from inside the house (Rogers, 2012).

The Aleut were not in need of seasonal hunting migration, and as such, their *barabaras* were often occupied year-round and ownership passed down through generations of families (Rogers, 2012).

Table 3.1: Key Design Features of Dwellings in Pre-Colonial Alaska.

Regions in Alaska			
	North	Interior	Southwest
Population mobility	Seasonal migration along the coast, inland permanent dwellings	Seasonal migration	Stationary
Dwelling style	-Permanent sod home built into hills, river banks -Movable tent	-Permanent semi-subterranean permanent sod home -Movable tent	-Permanent above ground sod homes, <i>barabaras</i> , semi-subterranean stone home
Insulation	-Sod home: sod bricks with grass turned inward, sand, earth, hills, ice, snow -Tent: animal hides, air pockets created with fur turned in-or outward	-Sod home: bark, soil, moss, woven grass, snow -Tent: animal hides, grass, brush	-Sod home: Sod, grass, spruce, grass mats -Barabaras: grass, turf, mud, earth, clay, bark -Stone home: stone slabs
Entry way	Sod home: Underground tunnel with cold trap		Sod home: Short tunnel, in summer smoke-hole acted as entry or covered walkway; in winter subterranean tunnel <i>Barabara</i> : Roof entrance
Heating method	-Sod home: oil lamp -Tent: oil lamp, wood fire	-Tent: wood fire	-Sod home & <i>barabaras</i> : body heat, oil lamp, wood fire -Stone home: slab hearth with floor channels
Ventilation	Roof opening	-Tent: smoke-hole regulated with pole attached to flap in roof	Sod home & <i>barabaras</i> : smoke-hole in roof Stone home: chimney, flue
Fuel type	-Sod homes: Blubber and sea mammal oil -Tent: sea mammal oil, wood	Wood	Sea mammal oil, wood

3.4.2 Settlers' Influences on Architecture

Euro-American wood frame houses arrived with the first settlers in the Barrow area in Northern Alaska. The new type of house construction was drafty, not well insulated, required large amounts of fuel for heating and was overall not well suited for the local climate (Stefansson, 1913; Slaughter, 1982).

The changes in the house construction and design were informed by a variety of factors; the most important ones being technological innovations, economic circumstances, and prestige associated with Euro-American designs and materials.

Specifically, the arrival of the sheet iron stove that used wood as a fuel source changed house designs and energy requirements (Stefansson, 1913; Slaughter, 1982). The European sheet iron was portable and lightweight. Compared to the traditionally used sea mammal oil lamps, the stove generated a larger amount of heat as well. The introduction of the sheet iron stove was one of the most influential factors in the elimination of the cold trap in pre-colonial homes, building homes above ground and shortening of the entrance tunnel length. However, due to a scarcity of trees in the arctic north, and an irregular and scarce supply of driftwood, lumber to build the new wood frame homes was scarce. Additionally, there was a lack of locally sourced wood to fuel the sheet iron stoves. The residents were forced to use imported lumber for construction and later imported coal and wood to fuel the sheet iron stoves for heat. Having to import and purchase lumber to stay warm in winter meant relying on economic and political influences. If a lumber delivery was delayed or a household could not afford to purchase wood to fuel their stove, their wellbeing was significantly impacted. Russian settlers arriving in southwest Alaska incorporated Western-style doors and windows into the *barabaras*. The lumber for this was also mostly imported from Siberia (Rogers, 2012).

The settlers had lower occupancy rates in their homes, reducing the added radiant body heat component (Stefansson, 1913; Slaughter, 1982). Additionally, the new type of home construction, which was popularized by government school teachers stationed in the region, had to be kept sealed tightly to keep the indoor temperature above freezing. While indoor air quality was arguably unhealthy in sod homes, especially for women tending the cooking fires and sea mammal oil lamps (see Zimmerman & Aufderheide, 1984), the lack of air ventilation in the settlers' homes provided a continuation of unhealthy indoor air quality in home design. Overall the house design the settlers introduced to Alaska was better suited for a European, rather than Alaskan, climate, natural resource availability and culture.

Economically, the local inhabitants became dependent on imported goods attained during the commercial whaling explosion in Alaska (Slaughter, 1982). However, with the collapse of the whaling industry in the early 20th century income opportunities were shifted from whaling to dealing in arctic fox fur. This translated into less time and manpower to collect sea mammal oil for heating and light since Alaskans spent more time trapping for profit than hunting sea mammals. On the other hand, the pay from trapping provided more income to purchase imported wood to be used for cooking and heating.

In the interior of Alaska, log wood cabins were adopted with the advent of European settlers (Deer et al., 2008). Since trees were more abundant in the interior than in the north or southwest of Alaska, the wood did not need to be imported, it could be felled locally. However, since the native people still depended largely on subsistence hunting and fishing they continued utilizing the traditional tent dwellings in summer to live in camps near fishing sites and in winter for hunting trips.

Settlers influenced insulation material as well (Deer et al., 2008). Whereas before it would be air pockets between hides, dried grass, branches, earth, snow, ice or sod the settlers began using dried sphagnum moss, which was especially useful as chinking between logs in log homes. The saws brought by the Europeans enabled collection of sawdust as a byproduct, which became the other new insulation material, especially for wood frame houses.

3.4.3 Modern Era Homes

In the last two centuries, house construction changed even further in Alaska mainly due to new freight options. World War II necessitated the construction of airfields for military purposes, which also had the lasting effect of introducing airfreight options to Alaska (Deer et al., 2008). Simultaneously, the construction of the Alaska Highway opened an overland connection between Alaska and the Lower 48 via truck freight. These new avenues of transportation allowed for increased ease and lower cost of imported construction materials, such as lumber.

In post-World War II, wood framed houses were the norm in Alaska instead of the exception. However they were still not well suited for most of the climate of Alaska (Seifert, 2011; Deer et al., 2008). The types of homes were not very energy-efficient, due to poor insulation, design and required massive amounts of heating fuel. The importance of a highly-insulated home in relation to heating fuel efficiency was publicized for Western home design in the U.S. in the mid-1960s by a company that sold heat pumps. However, the cost of energy, mostly produced by oil, was still relatively low at the time, and the construction cost of super-insulated homes was high so these types of homes did not become popular until the oil embargo in the 1970s. After the prices for energy rapidly doubled, the concept of an energy-efficient house gained new momentum. In sheer need to adapt to this situation, the U.S. Department of Housing and Urban Development (HUD) in 1974 initiated the Arkansas Project, building 35 homes with 6-inch walls, R-19 fiberglass insulation, which was considered high at the time. The R-value of an insulating material relates to the capacity of it to resist heat flow, thus containing heat within a structure. Two years later a team at the University of Illinois at Urbana-Champaign built a home with

R-30 walls and R-40 ceiling including double-glazed south-facing windows that required one-third the heating fuel as homes built to HUD standards at the time. In Alaska, three pioneers built a similar version of a super-insulated house in Fairbanks in conjunction with the University of Alaska Cooperative Extension that featured 9 inches of wall insulation. This home was used as a prototype and closely monitored for energy efficiency. One of the findings was that round or sphere-shaped homes were more energy-efficient than square or rectangular ones. Later research in Alaska found that, in addition to increased insulation, a small surface-to-volume ratio of the house decreases its heating requirements (Rice, 1975).

In 1976, the double-wall house was patented, which can be described as two separate wall systems, one fitting within the other, leaving a continuous cavity between them for insulation materials (Deer et al., 2008). The house additionally included a heat recovery ventilation system that provided for sufficient ventilation while warming the outside air prior to its entry into the house, thus minimizing heat loss of indoor air and drastically improving the indoor air quality for the residents.

The second oil embargo in the second half of the 1970s further drove up the price of oil and reinforced the need for highly energy-efficient homes as an adaptation strategy. In the early 1990s, Alaska passed the Building Energy Efficiency Standard (BEES), mandating that all residential buildings funded by the government's Alaska Housing Finance Corporation subscribe to the energy-efficiency standard, which continues to be revised and updated periodically.

The continued high price of oil coupled with environmental concerns, such as resource depletion, climate change and the negative health effects of indoor and outdoor air quality from burning oil and wood have continued driving the building industry towards building energy-efficient homes in the 21st Century. Rural low income families spent up to 47% of their household income on home energy use in 2008, compared to urban families who spent as much as 18% (Saylor et al., 2008). The cost of energy in rural regions can be as high as \$10/gallon of diesel and \$0.35/kW for electricity (Hamilton et al., 2011). Increased fuel prices and consumption may even be linked to an increase in outmigration of rural residents to urban centers directly threatening village survival (Martin et al., 2008).

Utilities in rural areas receive high subsidies from the state, such as through the Power Cost Equalization Program, to be able to provide affordable electricity to their customers and to stay in business (Schwörer & Fay, 2011). Government and private agencies have a large interest in investing resources into energy-efficient housing and renewable energy systems in rural Alaska to counteract the high-energy prices. For example, the Alaska Housing Finance Corporation offers a home energy rebate program including lower interest rates for energy-efficient homes (Davies & Dodge, 2012). The

Department of Health and Social Services offers a heating-assistance program, offsetting fuel costs for low-income residents (Alaska Department of Health and Social Services, 2017). In 2010 the state of Alaska introduced an act intending to increase energy efficiency per capita by 15% by 2020 (Davies & Dodge, 2012). During the last decade, several builders in Alaska began replicating and improving upon the super-insulated home model from the 1960s in conjunction with incorporating features of pre-contact homes (CCHRC, 2010; Marsik, 2014; Seifert, 2011). For example, a building designer in Interior Alaska utilizes masonry stoves and floor heating as the primary heating method (Seifert, 2011). Masonry stoves are built with rocks and stone as the thermal mass, and the floors have stone slabs overlaid to provide radiant heat. Some of the homes are octagonal shaped, with each room sharing a wall with the central masonry stove to maximize the radiant heat from the rocks. This design uses principles similar to the pre-colonial homes found in the Aleutian Islands that had a stone hearth and stone channels funneling heat through the floor. The octagonal shape is reminiscent of the round shape of pre-contact homes of the northern and interior inhabitants as well.

3.5 Elements of Adaptation Strategies

3.5.1 Occupancy Rates

What constitutes overcrowding varies between cultures and even regions sharing the same culture. Overcrowding of a building is based on its occupancy rate sometimes in conjunction with square footage calculations. In Canada, the Aboriginal People's Survey classified a house as overcrowded if there was more than one person per bedroom (Tester, 2009). This led to the determination in 2001 that 54% of Inuit homes in Canada were overcrowded when compared to 7% across the rest of Canada. In the U.S., the Department of Housing and Urban Development set the overcrowding standard at anything below 165 square feet per person in a home (Blake et al., 2007). In 2005, the median occupancy space in the U.S. was almost four times that square footage, at 675 square feet per person.

An average pre-colonial sod house in the north of Alaska would provide between 12-18 square feet per inhabitant—10% of the current overcrowding threshold in the U.S. (Rogers, 2012; Lee & Reinhardt, 2003). The summer tents would typically house only one family, whereas the sod homes would be multi-family dwellings. As such, tents would provide more space per person at an average 28 square feet. Houses on the mainland in western Alaska averaged nine square feet per person in a single-family winter house and 30 square feet per person for multi-family houses. Homes in Kodiak in

the southwest of Alaska provided about 30 square feet per person and a home in the Aleutian Islands had roughly 20 square feet per person. Pre-colonial homes, therefore, would all have been considered starkly overcrowded by modern day U.S. standards. The concept of privacy within a dwelling that arises quite literally from having personal space is largely a concept of Western culture and was not inherent in Alaskan Native cultures (Partnow, 1985).

In 2005, a research study conducted for the Alaska Housing Finance Corporation (Rogers & Lister, 2005) found that 12.5% of households in Alaska had 200 square feet or less per occupant. The same research study considered 200 square feet or less per occupant to indicate overcrowding. From 1991 to 2005 there was a statewide average of an increase of 119 square feet of living space per person. The lowest occupant-square-footage in the state was found in northwest and southwest Alaska, in the Nome and Wade Hampton/Bethel borough regions with 251 and 212 square feet per occupant respectively. The highest square footage per person was found in the Anchorage/Matanuska-Susitna boroughs at an average 641 square feet per person.

In Alaska, 6% of homes are less than 500 square feet, 30% are between 500-1,000 square feet and 65% are larger than 1,000 square feet (Rogers & Lister, 2005). In every region of the state Native Alaskan households had more occupants per house than did non-Native households in 2005. The authors of the research study attribute this difference to a higher low-income rate for Native Alaskans, lack of separate housing facilities for Native Elders and the high cost of housing in rural Alaska. They do not, however, draw a connection to the cultural aspect of pre-colonial homes providing on average 25 square feet per person, which may be a cultural explanation of the difference in resident occupancy rates between Native and non-Native households.

Whatever the underlying social or cultural reason may be for high occupancy rates per household, invariably the more residents in a house the higher the indoor thermal heat radiation (Badescu & Sicre, 2003). Adults on average emit 95W during waking hours and children roughly 60W. High occupancy rates coupled with thick insulation and air tightness can drastically increase the indoor thermal comfort of a household without relying heavily on an external heating source.

3.5.2 Indoor Thermal Comfort

Arguably, thermal comfort falls under the discipline of well-being (Fabbri, 2015). While it does relate directly to meeting the physical needs of inhabitants, having the ability to control indoor thermal comfort greatly affects mental and often emotional wellbeing as well. For this reason, it is considered

necessary for social wellbeing. Indoor thermal comfort is an adaptive strategy employed by inhabitants to adjust to weather conditions. In pre-colonial Alaska, the adaptation strategies included modifying clothing, changing behavior, increasing the occupancy rate, or adding additional temporary insulation to the dwelling, i.e. additional animal hides. In the 20th century, with the advancement of architectural designs and the usage of electricity in the home, the indoor temperature could be controlled through heating or air conditioning systems (Fabbri, 2015). The mechanization of indoor temperature changed the adaptation methods in the 20th century. This development may have added to the drop of occupancy rates in Alaskan homes, since additional body heat was no longer a conscious adaptation strategy.

Indoor thermal comfort can also be a function of socio-economic conditions of households. In present day Alaska, the cost of living is higher in rural areas than in the urban centers (Fazzino & Loring, 2009). Several rural areas are accessible only by plane or barge as they are not on the road system. This greatly increases the cost of building supplies, fuel and food that must be imported. The primary heating fuel used in rural Alaska is imported diesel. In 2005, over 21% of households in Alaska were unable to maintain an indoor temperature of 70 degrees Fahrenheit (Rogers & Lister, 2005; Hossain et al., 2016). Out of this 21%, 45% had a household income of \$30,000 or less. Only 9% percent of residents indicated that the indoor temperature below thermal comfort was solely due to the condition of the house. The high fuel prices are forcing some low-income families to make the tough choice whether to purchase food or fuel, because they cannot afford both (Fazzino & Loring, 2009; Simon, 2009).

Psychologically, thermal comfort is a matching up of temperature expectations with indoor conditions (de Dear & Brager, 2002). In pre-colonial homes the expectations of the indoor temperature may have been different than inhabitants have who live in Alaska today, allowing for a wider range of fluctuation. Over the centuries, the trend has been to switch from self-adaptation (such as adding more clothing layers) to adapting the surrounding environment to the human needs instead (Mahdavi & Kumar, 1996). Regardless of this shift in perspective, the change of how homes are heated and the expectations that go along with that, having a consistent and reliable fuel source has remained a constant requirement to achieve indoor thermal comfort through the history of vernacular homes in Alaska.

3.7 Discussion

Drawing on elements in this overview of energy-efficient housing in Alaska, I propose that vernacular architecture demonstrates human adaptation to multifarious drivers of change. The homes of Alaskans have always provided a platform from which occupants respond to changing external conditions as well as changing needs, values, and ways of living from a cultural and behavioral aspect. The term 'vernacular' in this context describes how adaptability of home features can over time create regional patterns that form a household adaptation strategy. In the context of Alaskan homes through history, the need for energy efficiency is a theme, even though it has not been a linear progression over time. Rather the evolution of energy efficiency in homes has been cyclical; beginning with pre-contact homes that were arguably energy-efficient, as they were a response to the stress of cold temperatures, as well as the availability and capacity of household members to acquire fuel. When Russian and Euroamerican settlers arrived, the external stressor of colonialization was predominant, thus changing the home designs to meet newly emerging socio-cultural needs and demands, i.e. for the settlers to feel a sense of place in a new culture. These changes to the homes were not in-line with energy efficiency. But in the 1970s when one of the dominant stressors was high fuel prices, home energy efficiency was re-emphasized. Today, with the advent of some builders incorporating energy-efficiency features from pre-colonial homes, the nature of the vernacular dwelling is shifting again and evolving, not into what it used to be, but rather taking into account all of the changes that have occurred over time, incorporating lessons learned and adjusting to modern occupant desires and needs. By this line of thought, vernacular homes are not an end goal to be reached, as a final adaptation technology. As long as humans are confronted with shifting conditions, homes will continue to reflect the adaptability of humans. Specifically, the energy efficiency features of homes in Alaska are a vernacular building feature in this case. The changing nature of homes, is- in itself- an adaptation strategy. Static home designs decrease the ability of occupants to adapt to external stressors. By this line of thought, vernacular home features are not only a response to external conditions, but also facilitate the ability of households to adapt.

Alaskans have faced not only changes in climate and environment, but also changes in culture and socio-economic conditions. Additionally, the influx of settlers and changes in government policies speak of the political influences on home designs. Economically, with the adoption of European and Russian building styles, Indigenous residents of Alaska became dependent on wood imports not only as a construction materials but also a fuel source. This was true in the tree-sparse regions of the state especially. Today in Alaska, especially rural Alaska, most households are still dependent on imported fuel and these days imported food as well. This adaptation to a global trade economy can lessen the

coping capacity of households to external forces, such as rising cost of fuel. It may also affect the sense of place inhabitants feel towards their home, especially if they are unable to maintain indoor thermal comfort standards due to socio-economic conditions or fuel import disruptions.

Whether planned or not, the changing features of homes from pre-contact to today that allow for co-habitation increases the heat load in the house without the use of a conventional fuel source. The large occupancy rates of pre-contact homes, either living with extended family or co-housing or -cooking with other households helped residents adapt to the extreme cold climate and allowed them to increase heating and cooking fuel efficiency. The co-habitation and cooking arrangements also arguably contributed to social capital, facilitating a broad social network to rely on as a coping mechanism. The significantly lower occupancy rates of homes in Alaska today are arguably not conducive to adapting to changes in fuel supply or cost. Despite small occupancy to square foot ratios being reintroduced in some home designs in Alaska in the 1970s, it remained a small subsection of housing designs. However, the concept has not disappeared. Even today some builders are combining highly energy-efficient home construction techniques with small square footage, which is arguably reminiscent of pre-contact homes (Marsik, 2014). A small building footprint combined with thick insulation and few windows enable a relatively newly built home in Bristol Bay, in southwest Alaska, to be heated mainly by body heat of its inhabitants, and from electrical appliances, similar to pre-contact sod homes in the same region. This is a good example of how a response to high fuel costs can be combined with pre-colonial housing legacies to adapt to modern circumstances. The legacy of homes in Alaska from the time of the settlers onward can be considered a dismal trend of inefficient and climate in-appropriate housing. However, another tale that can be extrapolated from sociohistorical circumstances, such as the oil embargos in the 1970s, and continued high oil prices in the 21st Century, is that modern builders are incorporating some of the resourceful features of pre-contact dwellings with new energy-efficient adaptation innovations to current building designs.

Settlers were not the last group of outsiders to influence Alaskan architecture. Home designers who were trained in temperate climates are often not familiar with the vernacular home style required for Alaskan residents that is climate and resource appropriate (personal communication, Cooke, 2014). Considering the ancestral and cultural housing legacies of successful homes is not often a practice in for-profit businesses. However, especially in rural Alaskan Native villages, this knowledge can be crucial to designing a home that not only provides for all socio-economic needs, but is also able to maintain indoor thermal comfort and provide a sense of place to its inhabitants. An architect who builds homes in Alaska Native villages noted that because he is not Native he is not always in tune with the emotional

connection his clients had to their home, he noted “how can you create a home for someone until you know what they think a home is like” (Cooke, 2014). For this reason, his approach to designing and building homes in rural Native villages in Alaska is a series of community meetings and discussions. During the first meeting with the community he listens to the community’s history, their ancestors’ building techniques, what is currently not working in terms of home design and what the community desires in a home.

The feeling of a sense of place can be derived from familiarity, emotional attachment, identity and social status (Hess et al., 2008). Local resources, both natural and social, of a place can lend themselves to facilitating an emotional connection. The cultural importance of homes is documented in an early anthropological report, Spencer (1959), for example, observed that the Alaskan Inuit nuclear family’s activities centered around their homes, indicating that they had a very strong emotional attachment to them. In some tribes all houses were named, the names chosen either by the characteristics of the house or the inhabitants, thus conveying a strong emotional identification with the concept of a home. Any change in house design, space syntax or heating methods could disrupt the sense of place of its occupants. This leads to question how the sense of space has been affected by the adaptation of homes in Alaska. The wood-framed houses of the settlers may have been necessary for the settlers to feel culturally at home in a foreign place, but they were not well suited to the local resources or climate. Their impact on the Native Alaskans sense of place was detrimental in turn. Dawson (1995) describes how the government funded prefabricated homes for northern Iñupiat, spanning Canada and Alaska, influenced the sense of place the inhabitants felt, as well as the gender roles. The European-style homes that the settlers first introduced had a kitchen space that was integrated with the living area of the home. This was a marked change from the separate kitchen area in sod homes. The kitchen was the domain of the female, exercising authority by controlling who may enter the kitchen area. This change in space syntax may be linked to an undermining of female authority in family structures. The separate bedrooms in these homes was another change from the shared sleeping area of family members. The bedrooms provided an opportunity for family members to isolate themselves socially from each other. This suggests that the space syntax of the newly introduced homes was suited to a European culture but not to an Iñupiaq culture. This disconnect affected the sense of place Iñupiat felt towards their homes. From a practical perspective, the home designs were not suitable for indigenous food preparation either, the way that pre-contact homes were. For example, meat was stored in the bathtub, animals were butchered in the living room (Thomas & Thompson,

1972). As a result, families spent less time in their homes. Culture shapes the home but the home can also shape a culture.

Even in modern homes, the emotional connection to a home is important. Some homes built today may reflect the most up-to-date energy-efficient design and technology but may be lacking the local cultural aspects necessary for the inhabitants to feel a sense of place. Adapting homes to changing conditions can increase the coping capacity of a household, but it is important to consider the sense of place residents feel related to their home. According to Cooke, an architect in Alaska, homes must be loved by their occupants, unloved homes fall into disrepair and fail not just in building science but in providing a sense of place and belonging (Cooke, 2014). If the adaptation strategy negatively affects the sense of place, the overall success of the strategy is questionable. At the same time, having an energy-efficient home that increases indoor thermal comfort and lessens the burden on take-home pay, and this can play a large role in occupants feeling a sense of place and comfort.

A good example of a modern vernacular building style, while emphasizing a sense of place is exemplified in Cold Climate Housing Research Center's (CCHRC) Sustainable Northern Shelters Program. The mission of the program is to build energy-efficient homes in rural Alaska in close consultation with the Native populations, blending modern technology with traditional home construction (CCHRC, 2010). Examples of features of the buildings that have been built in rural Alaska by CCHRC are emulating the shape of sod homes, utilizing natural insulation such as earth-berming, sand dunes or snow banks. Parts of the buildings are subterranean and include cold storage in permafrost-lined ice cellars. A circular home layout and a long entrance tunnel are being incorporated in the buildings as well. Despite the incorporation of these traditional home features the designers keep in mind the desires of the community for modern homes. According to one of their architects, Native Alaskans he worked with on one housing project did not want to regress to the lifestyle of their ancestors, living in a sod igloo that floods every spring (Cooke, 2014). It would mean changing their lifestyle to move to a different summer and winter residence. Instead CCHRC takes the elements of pre-colonial housing and translates them into modern structures to accommodate present lifestyles not those of the past. For example, the pre-colonial entrance tunnel would not be easily accessible for disabled inhabitants. Instead they suggest shorter, larger arctic entryways with a modern design, which are not as energy-efficient as the original ones but are a contemporary compromise. One of the buildings built through the program is located in an area with strong wind. The designers spent a lot of time modeling a building layout that would retain maximum indoor heat during wind and snow storms. They proposed an octagonal layout of the building to the village. The Elders in the village responded to their innovative design with nonchalance,

explaining that their ancestors already knew this layout is the most energy-efficient design, because they used it in their sod homes.

3.8 Conclusion

Vernacular building style in Alaska is an ongoing reflection of societal and ecological histories and changes. Alaskan homes throughout history tell a tale not only of regional climatic conditions, but also of socio-economic conditions, politics, and the sense of place felt by residents. Common building components that are present in homes throughout the history of Alaska are insulation, air ventilation, arctic entryways, and the need for an external heating source. The approach to these elements differed depending on the available resources and socio-political influences of the era, such as settlers' influences, or the price of oil. It is interesting to note that some of the climate-conscious and energy-efficiency features of the pre-colonial homes are being included in modern-day home design in Alaska by some of the pioneers of energy-efficient, sustainable building designs. For example, if intentional or by chance, the stone hearth and sub-floor stone heating system from pre-colonial Aleutian Islands homes are being incorporated in the form of masonry stoves and floor heating overlaid with stone flooring in some of the newer construction homes in Fairbanks, Anchorage, and the Aleutian Islands. Furthermore, the round or oval floor plan of the tents and sod homes are being recognized as an energy-efficiency feature and incorporated in building layouts throughout the state. The insulating properties of sod and turf are also being explored by the Aleutian Housing Authority in their prototype home built with the rammed earth technology rammed earth prototype home (O'Connor, 2015). The arctic entryway, common to Alaskan homes, especially in the interior and northern regions, resembles the entrance tunnel used in the pre-contact winter homes throughout the state. While adaptability can mean incorporation of new designs in homes, in these cases, it can also lead to a resurgence of historically used designs.

The socio-economic needs of the Alaskan population are reflected in the historical struggle to achieve and maintain indoor thermal comfort, not only in the building energy features but also in the available options to acquire heating fuel. Or as is sometimes the case, the lack of having appropriate means to acquire sufficient heating fuel.

This review of the historic context of home designs in Alaska reflects, above all else, a societal culture that is constantly forced to adapt to change on the local, regional and global level. The home

design features reflect not only an adaptation to environmental conditions but also the value and sense of place that its Alaskan inhabitants have felt over the course of history and continue to feel.

3.9 References

- Abrams, Elliot M. (1989). Architecture and Energy: An Evolutionary Perspective. *Archaeological Method and Theory* (1), 47-87.
- Alaska Department of Health and Social Services. (2017) Heating Assistance Program (HAP). Retrieved from <http://dhss.alaska.gov/dpa/Pages/hap/default.aspx>
- Badescu, V., & Sicre, B. (2003). Renewable energy for passive house heating: II. Model. *Energy and Buildings*, 35(11), 1085-1096. doi:<https://doi.org/10.1016/j.enbuild.2003.09.004>
- Blake, K. S., Kellerson, R. L., & Simic, A. (2007). *Measuring Overcrowding in Housing*. Retrieved from Fairfax, VA: U.S. Department of Housing and Urban Development - Office of Policy Development and Research.
- Blunt, A. (2005). Cultural geography: cultural geographies of home. *Progress in Human Geography*, 29(4), 505-515. doi:10.1191/0309132505ph564pr
- Boyd, R., Richerson, P. J., & Henrich, J. (2011). The cultural niche: Why social learning is essential for human adaptation. *Proceedings of the National Academy of Sciences*, 108(Supplement 2), 10918-10925. doi:10.1073/pnas.1100290108
- Cold Climate Housing Research Center (CCHRC). (2010). "Sustainable Northern Shelter Program." Fairbanks, AK: Cold Climate Housing Research Center.
- Clark, D. W. (1984). Pacific Eskimo: Historical Ethnography. In D. Damas (Ed.), *Handbook of North American Indians*. Washington, DC: Smithsonian Institution Press.
- Cooke, A. (2014, March 21). Personal Communication. [Viability of Highly Energy Homes in Alaska].
- Cutting, M. (2006). More than one way to study a building: approaches to prehistoric household and settlement space. *Oxford Journal of Archaeology*, 25(3), 225-246. doi:10.1111/j.1468-0092.2006.00259.x
- Davies, J. N., & Dodge, K. E. (2012). *Energy Efficiency Policy Recommendations for Alaska*. Technical Report 2012-03. Retrieved from Alaska Energy Authority.
- Dawson, P. C. (1995). "Unsympathetic Users": An Ethnoarchaeological Examination of Inuit Responses to the Changing Nature of the Built Environment. *Arctic*, 48(1), 71-80. doi:10.14430/arctic1226

- Dawson, P. C. (2002). Space syntax analysis of Central Inuit snow houses. *Journal of Anthropological Archaeology*, 21(4), 464-480. doi:[https://doi.org/10.1016/S0278-4165\(02\)00009-0](https://doi.org/10.1016/S0278-4165(02)00009-0)
- de Dear, R. J., & Brager, G. S. (2002). Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and Buildings*, 34(6), 549-561. doi:[http://doi.org/10.1016/S0378-7788\(02\)00005-1](http://doi.org/10.1016/S0378-7788(02)00005-1)
- Deer, C., George, M., Kaluza, P., Loudon, P., Moore, G., Musick, M., . . . Woodward, J. (2008). *Alaska Residential Building Manual, 7th ed.* Retrieved from Anchorage, AK: Cooperative Extension Service - University of Alaska Fairbanks.
- Fabbri, K. (2015). A brief history of thermal comfort: from effective temperature to adaptive thermal comfort *Indoor Thermal Comfort Perception* (pp. 7-23): Springer.
- Fazzino, D. V., & Loring, P. A. (2009). From Crisis to Cumulative Effects: Food Security Challenges in Alaska. *NAPA Bulletin*, 32, 152-177. doi:10.1111/j.1556-4797.2009.01033.x
- Fewins, C. (2013). Vernacular Style. *Homebuilding & Renovating*. Retrieved from <https://www.homebuilding.co.uk/vernacular-style/>
- Fienup-Riordan, A. (2000). *Where the Echo Began and Other Oral Traditions from Southwestern Alaska Recorded by Hans Himmelheber*. Fairbanks, AK: University of Alaska Press.
- Giddings, J. L. J. (1952). *The Arctic Woodland Culture of the Kobuk River*. Retrieved from Philadelphia, PA: The University Museum, University of Pennsylvania.
- Glassie, H. (1976). *Folk housing in middle Virginia: a structural analysis of historic artifacts*: University of Tennessee Press.
- Hamilton, L. C., White, D. M., Lammers, R. B., & Myerchin, G. (2011). Population, climate, and electricity use in the Arctic integrated analysis of Alaska community data. *Population & Environment*, 1-15. doi:10.1007/s11111-011-0145-1
- Hay, R. (1998). Sense of Place in Developmental Context. *Journal of Environmental Psychology*, 18(1), 5-29. doi:<http://dx.doi.org/10.1006/jevp.1997.0060>
- Hess, J. J., Malilay, J. N., & Parkinson, A. J. (2008). Climate change: the importance of place. *American journal of preventive medicine*, 35(5), 468-478. doi:<https://doi.org/10.1016/j.amepre.2008.08.024>
- Hossain, Y., Loring, P. A., & Marsik, T. (2016). Defining energy security in the rural North—Historical and contemporary perspectives from Alaska. *Energy Research & Social Science*, 16, 89-97. doi:<http://dx.doi.org/10.1016/j.erss.2016.03.014>

- International Panel on Climate Change (IPCC). (2014). *Climate Change 2014—Impacts, Adaptation and Vulnerability: Regional Aspects*. Cambridge, United Kingdom, New York, NY, USA: Cambridge University Press.
- Knecht, R., & Davis, R. (2004). *Amaknak Bridge Site Data Recovery Project Final Report # Mgs-Stpbr-0310 (S)/52930*. Retrieved from Anchorage, AK: Museum of the Aleutians, Unalaska and Alaska Department of Transportation.
- Lee, M., & Reinhardt, G. A. (2003). *Eskimo Architecture: Dwelling and Structure in the Early History Period*. Fairbanks, AK: University of Alaska Press.
- LeMoine, G. (2003). Woman of the house: Gender, architecture, and ideology in Dorset prehistory. *Arctic Anthropology*, 40(1), 121-138. doi:10.1353/arc.2011.0028
- Loring, P. A., Gerlach, S. C., & Penn, H. J. (2016). "Community Work" in a Climate of Adaptation: Responding to Change in Rural Alaska. *Human Ecology*, 44(1), 119-128. doi:10.1007/s10745-015-9800-y
- Mahdavi, A., & Kumar, S. (1996). Implications of indoor climate control for comfort, energy and environment. *Energy and Buildings*, 24(3), 167-177. doi:https://doi.org/10.1016/S0378-7788(96)00975-9
- Marsik, Tom. (2014). "Net Zero Energy Ready Home in Dillingham Alaska." *Alaska Building Science News* 17(4), 6-8.
- Martin, S., Killorin, M., & Colt, S. (2008). *Fuel Costs, Migration, and Community Viability*. Denali, Alaska: Institute of Social and Economic Research in collaboration with First Alaskan Institute and Alaska Native Policy Center.
- Mauss, M., & Beuchat, H. (1979). *Seasonal Variations of the Eskimo - A Study in Social Morphology*. London, UK: Routledge & Kegan Paul Ltd.
- McCartney, A. P., & Veltre, D. W. (1999). Aleutian Island prehistory: Living in insular extremes. *World Archaeology*, 30(3), 503-515. doi:10.1080/00438243.1999.9980426
- Murdoch, J. (1852). *Ethnological Results of the Point Barrow Expedition*. In *Ninth Annual Report of the Bureau of Ethnology*, edited by J.W. Powell. Retrieved from Washington, DC: Smithsonian Institution.
- O'Connor, B. (2015, September 26). Experimental Building Project Combines Old, New Techniques. *Frontiersman*.
- Oliver, P. (1997). Introduction *Encyclopedia of Vernacular Architecture of the World*. Cambridge, UK: Cambridge University Press.

- Partnow, P. H. (1985). *Alaska Athabascans*. Retrieved from Anchorage, AK: Indian Education Act Project.
- Ray, D. J., & Edmonds, H. M. W. (1966). *The Eskimo of St. Michael and Vicinity as Related by HMW Edmonds*. Fairbanks, AK: University of Alaska Press.
- Rice, Elbert Floyd. (1975). *Building in the North*. Retrieved from Fairbanks, AK: Geophysical Institute of the University of Alaska Fairbanks.
- Rogers, B., & Lister, C. (2005). *2005 Alaska Housing Assessment*. Edited by Alaska Housing Finance Corporation. Retrieved from Fairbanks, AK: Cold Climate Housing Research Center.
- Rogers, J. S. (2012). Architecture and Complex Hearth Features at the Amaknak Bridge Site, Eastern Aleutian Islands, Alaska. *Arctic Anthropology*, 48(2), 92-112. doi:10.1353/arc.2012.0004
- Saylor, B., Haley, S., & Szymonkiak, N. (2008). *Estimated Household Costs for Home Energy Use, May 2008*. Retrieved from Anchorage, AK: Institute of Social and Economic Research.
- Schwörer, Tobias and Ginny Fay. (2011) "The Cool 100 Book." edited by James Haselip and David Pointing. Roskilde, Denmark: UNEP Risø Centre on Energy, Climate and Sustainable Development.
- Seifert, R. (2011, Summer). Great Home Ideas for our Times. *Alaska Building Science News*, 16.
- Simon, M. (2009). In Rural Alaska Villages, Families Struggle to Survive. *CNN*. Retrieved from <http://www.cnn.com/2009/US/02/09/rural.alaska.villages/index.html?iref=storysearch>
- Slaughter, D. (1982). *The Point Barrow House Type: An Analysis of Archeological Examples from Siraagruk and Other Sites in Northern Alaska*. In *Anthropological Papers of the University of Alaska*, edited by Anne D. Shinkwin. 141-58.
- Spencer, R. F. (1959). *The North Alaskan Eskimo: A Study in Ecology and Society*. Retrieved from Washington, DC: Bureau of American Ethnology, Smithsonian Institution.
- Stefansson, V. (1913). *My Life with the Eskimo*. New York, NY: The Macmillan Company.
- Tanner, A. (1991). *Spatial Organization in Social Formation and Symbolic Action: Fijian and Canadian Examples*. Paper presented at the In Social Space: Human Spatial Behaviour in Dwellings and Settlements, Proceedings of an Interdisciplinary Conference.
- Tester, F. (2009). Iglutaasaavut (Our new homes): Neither "new" nor "ours": Housing challenges of the Nunavut Territorial Government. *Journal of Canadian Studies*, 43(2), 137-158. doi:https://doi.org/10.3138/jcs.43.2.137
- Thomas, D. K., & Thompson, C. T. (1972). *Eskimo housing as planned culture change* (Vol. 4): Ottawa, Northern Science Research Group, Department of Indian Affairs and Northern Development.

- Thornton, T. F., & Manasfi, N. (2010). Adaptation—genuine and spurious: demystifying adaptation processes in relation to climate change. *Environment and Society: Advances in Research*, 1, 132-155. doi:10.3167/ares.2010.010107
- Tuan, Y.-F. (1979). Space and Place: Humanistic Perspective. In S. Gale & G. Olsson (Eds.), *Philosophy in Geography* (pp. 387-427). Dordrecht: Springer Netherlands.
- Zhai, Z. J., & Previtali, J. M. (2010). Ancient vernacular architecture: characteristics categorization and energy performance evaluation. *Energy and Buildings*, 42(3), 357-365. doi:10.1016/j.enbuild.2009.10.002
- Zimmerman, M. R., & Aufderheide, A. C. (1984). The Frozen Family of Utqiagvik: The Autopsy Findings. *Arctic Anthropology*, 21(1), 53-64. <http://www.jstor.org/stable/40316055>

Chapter 4

To Build or not to Build: Highly Energy-Efficient Homes in Alaska⁵

4.1 Abstract

Highly energy-efficient homes can be considered a climate-change-mitigation technology in Alaska. Their adoption has the potential for reducing carbon emissions as well as enhancing the adaptive capacity of households. Using the theory of diffusion of innovations, we explore what barriers currently exist to the continued uptake of this innovation. We conducted semi-structured interviews with seventeen individuals who fall into one or multiple interview categories; homeowners, designers, builders, real estate professionals, finance and lending industry professionals. We conclude that highly energy-efficient homes in Alaska are currently in between the innovators and early adopters' stages of innovation diffusion: the upfront costs are high and there are insufficient resources to value the energy efficiency features at true cost. Fluctuating oil prices and a hesitation of consumers to change their purchasing behavior are also additional barriers that these early adopters face. We conclude by tracing a connection between homeowners of highly energy-efficient homes and their increased adaptive capacity to cope with global change.

4.2 Introduction

Reduced energy-consumption in Alaska has the potential to stabilize energy costs and strengthen the overall economy (1). During periods of high energy-costs affordable living in Alaska is affected. During the 2008 oil price increase, businesses closed and inhabitants left the state (2). For Alaskan households, investing in energy-efficiency not only reduces current energy demand but decreases their future demand (1). Currently, because many regions in the state do not have minimum energy standards a lot of the newly constructed homes are not very energy-efficient. The first weatherization programs in Alaska were introduced in 1976 appealing to a population battling high fuel-costs for heating homes that were designed inappropriately for the arctic and sub-arctic climate (3). By the

⁵ Hossain, Y.; Loring, P.A. In Preparation. To Build or not to Build: Highly Energy-Efficient Homes in Alaska. *Energy Research & Social Science*

1980s, as a result of the high 1970s oil-prices and the publication of the Club of Rome book *Limits to Growth* addressing an impending energy crisis, a ‘super insulated house movement’ was born (4). This building-design innovation evolved over the years, providing homeowners an opportunity to drastically reduce their home energy consumption.

This paper is an ethnographic study of adopters of highly energy-efficient homes in Alaska. We use Rogers’ (5) diffusion of innovations model to gain an understanding of this climate-change-mitigating technology; more specifically, what barriers exist and how can the spread and implementation be furthered? Highly energy-efficient homes are on the extreme end of the energy-efficiency spectrum, incorporating the super-insulated house design with other features, such as efficient-heating and ventilation technologies, thermal mass, passive solar orientation, arctic or remote walls, energy-efficient windows and doors, along with other technological innovations. As a direct result of energy-efficiency, households not only save on energy costs, but the savings also translate into carbon emissions abatement, with the potential to mitigate the exacerbation of climate change. This technological innovation also addresses the adaptive capacity of households in Alaska who are forced to adapt to the impacts of climate change and fluctuating oil prices.

4.3 Background and Framework

Carbon levels in the atmosphere have reached unprecedented levels, exacerbating climate change and the risks it poses to ecosystems, human health, and wellbeing (6). This escalation is attributed primarily to anthropogenic factors--increased fossil fuel emissions and emissions from changes in net land use (7). In response to climate change, two approaches have been identified, mitigation and adaptation (8). Mitigation reduces harmful fossil fuel emissions, leading to a decrease in the exacerbation of climate change. Adaptation adjusts society’s response to climate change to reduce vulnerability to its effects and facilitate coping with it.

The building sector accounts for 41% of energy consumption in the U.S. (9). Energy-efficiency of buildings is recognized by the Intergovernmental Panel on Climate Change (6) as a key climate-change-mitigation technology that is not only among the most environmentally effective but is also among the most cost-effective mitigation strategies.

Climate-change-mitigation technology and climate adaptation are in some instances be closely intertwined (10). The same technology that facilitates adaptation to current or future impacts and

reduces likely harmful outcomes (11, 8) can also lessen energy demand, thus mitigating climate change. Highly energy-efficient homes present the opportunity for both climate-change-mitigation and adaptation strategies. On one hand, the homes cut back on household fuel consumption, thus reducing carbon emissions and on the other hand, they may facilitate an increased adaptive capacity of households to navigate climate-change-stressors, such as increased natural hazards, fuel import disruption, or erratic weather patterns (5). While exposure to climate change is unavoidable, the vulnerability to its effects can be modulated by increasing the capacity to adapt (12, 11). The components that make up adaptive capacity are forms of capital, either individually possessed or collectively; social, cultural, natural, political, and economic capital, in combination with technology and infrastructure (13, 14, 15). The higher the diversity of these forms of capital, the higher the adaptive capacity. In this paper, we explore ways highly energy-efficient homes can contribute to the adaptive capacity of households in Alaska. The success of this technology as an adaptation strategy will depend on the rate and success of diffusion of this innovation.

Rogers' (5) theory of diffusion of innovations proposes a hypothetical adoption-curve that all new technologies ostensibly take. All consumers do not adopt new technological innovations at the same time. Rather, a series of consumer groups adopt new technology in a time sequence. The groups of consumers are classified into five categories, based on their willingness and ability to adopt new products. The first category are innovators, a small group of people at the forefront of change, the second group are the early adopters, those who follow the innovators once the benefits of the new technology have become apparent. The largest two groups of adopters to follow are the early majority and the late majority. These two groups are averse to taking risks and are cost sensitive. For the early and late majority to adopt a new innovation, the cost must already be substantially lower and the innovation must have been tried and tested by others. The last group to follow is the laggards, a smaller segment of the population. This theory acknowledges that differences in adoption behavior depend on socio-economic factors, communication behavior and personality characteristics in addition to market barriers (5, 16).

The rate of adoption is furthermore motivated by social and technological influences (5, 17). Communication methods, social systems, the timeframe of adoption and the quality of the innovation itself are all influences. Furthermore, the rate of adoption and cultural change is affected by societal sub-cultures, agents of change (such as non-profits or innovative builders and homeowners), institutions and economic structures that are in place supporting the adoption of the new technology (5, 18, 19). The economic consideration in this case would fall to the financial lending agencies, as well as the

construction material suppliers, as some of the building materials for highly energy-efficient homes is specialized, more expensive and sometimes difficult to acquire locally in Alaska.

4.4 Methods

Due to the limited number of highly energy-efficient homes in the state, we had a small interview pool. The goal of the interview method in this case is not to gather data from a large sample size to generalize findings, but rather to explore the unique characteristics of the initial pioneers. We contacted known experts in the field and used snowball sampling to widen our interviewee selection. Open-ended interviews were conducted during a three-year timespan, from 2014-2017⁶. Themes addressed in the interview questions ranged and varied slightly based on the interviewee category, which were homeowner, designer/builder, finance/real estate industry professional. All interviewees were asked what their description of a highly energy-efficient house is and how they relate to energy security in Alaska. Homeowners were asked to describe their motivations for owning a highly energy-efficient home and any barriers they faced in acquiring or building it. All interviewees were asked if they experienced a direct increase in their personal or industry knowledge through their involvement with highly energy-efficient homes and/or if they needed to acquire special skills or training in relation to the energy-efficient features of the building. Everyone was also asked if they had any suggestions for process, design, or policy improvements.

The themes for this research paper were chosen because either multiple interviewees talked about it or their importance was stressed in the interviews. Interviewees talked a lot about the benefits achieved from highly energy-efficient homes and also the barriers they faced, or the industry is currently facing. Among the homeowners, interesting similarities emerged from their motivations, their knowledge base, and common difficulties they faced. These similarities allow us to make a conjecture of what stage of innovation diffusion these homeowners fall into.

⁶ See Appendix B for interview questions.

4.5 Results

We interviewed a total of eighteen key informants. The results of the interviews are laid out in this section. Six interviewees are in the finance and real estate industry, including independent appraisers. Ten are homeowners who also were either involved in the design or construction aspect of their home or both. Twelve builders and designers total were interviewed. As mentioned ten are also homeowners, and three are trained architects. One person is a homeowner, builder, and architect. See figure 4.1 for an illustration of the overlapping categories.

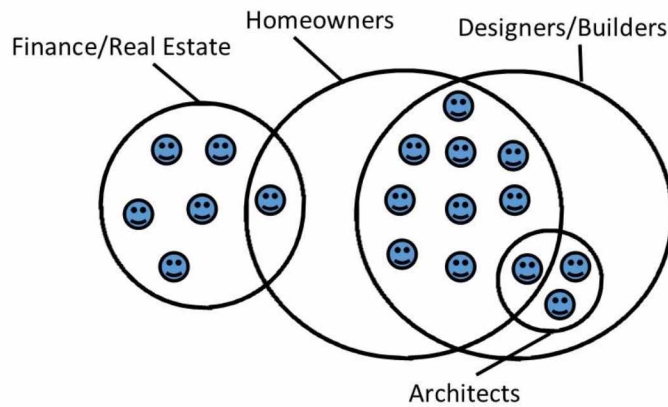


Figure 4.1: Overlapping linkages between interviewee categories.

4.5.1 Adopter Group

Our determination is that highly energy-efficient homes in Alaska are between the innovators and early adopters stage. Innovators and early adopters make up only 16% of all adopters (see figure 4.2). In Alaska, the number of highly energy-efficient homes is still relatively low, keeping the number of homeowners small. In fact, all homeowners reported being acquainted with one or more of the other homeowners.

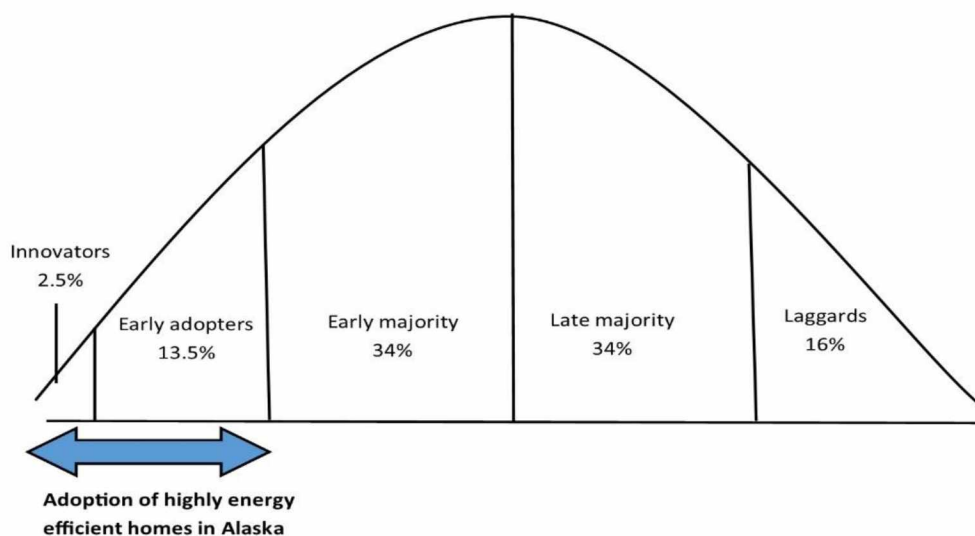


Figure 4. 2: Diffusion of innovation adopter groups. Modified from Rogers (5). Not drawn to scale.

Innovators are described by Rogers (5) as willing to step outside of their comfort zone. They are prepared to experience a financial loss on the innovation and are comfortable with a high level of uncertainty (5, 17). Due to their pioneering status, they typically already have, or are willing to acquire complex technical knowledge about the innovation. Three of the homeowners interviewed are concerned about the resale value of their house and know they will likely sell at a loss, because the energy-efficiency features of the house are currently not a value-added feature in appraisals. All of the homeowners were directly involved in either the design of their home or both design and construction. The homeowners reported that there were very limited options to hire knowledgeable designers or contractors, and often their desire to be involved in the design and construction process stemmed from a necessity to expand their personal knowledge base, to save money and because there weren't many professionals who were familiar with this building style.

The early adopters typically fill leadership roles in their communities, other people ask them for information or advice about the innovation (5, 17). Through social networks, and interpersonal and public information sharing, this group of adopters shares their subjective evaluation of the technology, which decreases uncertainty and acts as an incentive for more people to adopt it. All homeowners we interviewed reported that their primary motivations for building a highly energy-efficient home are

concerns over the high cost of fuel, future price-increases, and/or a personal commitment to sustainability. No one mentioned making a financial profit as a motivation. A contractor who built himself a highly energy-efficient residence, said he was frustrated with the existing building styles in Alaska because they were not climate-appropriate. This motivated him to find ways to build more efficiently, sustainably, and better suited for the climate and human health. His motivation in building his own residence was to use it as a showcase example, to illustrate that high levels of efficiency can be reached even in extreme climates. Five other homeowners cited this reason as one of their motivators as well and are using their home, or future home, as an educational tool for university students, non-profits, and other interested parties.

Rogers (5) makes a case that earlier adopter groups of a technology have attained higher education degrees and have higher income than later groups. We did not collect socio-economic information from the interviewees. However, in a recent study conducted by the Cold Climate Housing Research Center over 40% of respondents who indicated that they were knowledgeable of, or were living in, an energy-efficient home had completed a graduate degree (20). The survey showed a correlation between educational degree attained and homeowners willing to invest in energy-efficiency features for their residence. Some other factors that contributed were household income, availability of local builders knowledgeable in energy-efficient design, or awareness of state or federal programs that assist in financing energy-efficiency improvements.

4.5.2 Social Networks and Knowledge Sharing

In the early adopter stage, it is also common for people to utilize social networks as means of information transmission. In our interviews, a common theme is the central reliance on information gleaned from colleagues, other homeowners and in-person communication with experts.

When asked about knowledge acquisition, from the total of thirteen interviewees who are homeowners, builders, or designers; six cited learning vital information on highly energy-efficient homes from other people, by either gaining hands-on experience helping others build their house, picking the brain of an expert, consulting others who have built similar houses or reaching out to colleagues. Outside the personal transmission of information, six could name an organization from which they took a workshop or course. The three trained architects cited they did not specifically have highly energy-efficient homes addressed during their academic studies, and needed to glean this information elsewhere. Everyone in this interviewee group mentioned learning on the job, improving upon mistakes

made as they were made. Five mentioned learning information through books, magazines, and internet research. All of the interviewees in this group reported gaining their knowledge base from two or more sources, including their own construction experience.

Seven homeowners who were interviewed reported receiving phone calls and visits from neighbors and interested parties wanting information on their highly energy-efficient home. Four homeowners are actively using their home as prototype case studies, opening their home for tours, giving presentations and publishing articles and making information on their homes publicly available. One homeowner who is still in the construction phase of her house, is making Do-It-Yourself videos of the construction process, to educate others who would like to build homes in this style. A different homeowner used the retrofit of his building as an opportunity to offer a public class on retrofitting for energy-efficiency through a non-profit.

It is noteworthy to mention that people from all three interviewee categories (homeowners, builders/designers, finance/real estate industry) mentioned one specific contractor in Fairbanks, from whom they all either received information directly from, or were inspired by, or were knowledgeable of. The contractor, Thorsten Chlupp, designs highly energy-efficient buildings encompassing a range of energy-efficiency and sustainability elements (21). His homes, on the most extreme end of the spectrum, include a Passive House design, utilizing heat storage, remote wall systems, renewable energy installations, with an emphasis on air tightness. Originally from Germany, now a resident of Alaska, Chlupp adapted his knowledge of European buildings with energy-efficiency design to the Alaskan climate. He not only built homes for customers but also built a highly energy-efficient home for himself. Living in it was the best proof for him that this type of building design improves quality of life and well-being for the inhabitants as well as for the environment. His philosophy is that no one should have to “reinvent the wheel.” He spreads his knowledge and lessons learned widely in the building industry, in academia and in other public forums throughout Alaska, as well as nationally and internationally. He is part of a tight-knit community of builders and designers in the U.S. and Canada who share a passion for building highly energy-efficient homes and share knowledge with each other freely, problem-solving together on a project when the need arises. Chlupp’s willingness to share his personal knowledge base with laypeople and experts along with reaching a wide audience with his presentations, articles and lectures played a significant role in the diffusion of highly energy-efficient homes to the early adopters in Alaska. Referring back to the theory of diffusion of innovation, Chlupp fits the role of an agent of change seamlessly.

4.5.3 Barriers

Jaffe & Stavins (22) and Jaffe et al. (23) compiled a list of most common market barriers that adopters of new innovations technology face, especially in the early stages of the adoption curve. The barriers are lack of information available and distributed effectively, no financial compensation for homeowners for distributing information, and spending time and energy spent to acquire the necessary information of suppliers, installation, and correct usage of products. Furthermore, the difficulty in recovering the investment financially or by reaping the benefits of reduced energy consumption is a barrier, and inadequate access to financing, or a financial market failure.

All of these barriers were mentioned by interviewees. The interview results are organized by these market barriers below.

a) Lack of information available and distributed effectively.

Five homeowners stated difficulty in hiring skilled professionals who were familiar with the specialty features of highly energy-efficient homes, such as remote walls, Larsen trusses, thermal storage systems, specialty plumbing to heat domestic hot water in masonry stoves, or radiant floor heating. Three interviewees thought there is a lack of information on the benefits of highly energy-efficient homes. Two homeowners said highly energy-efficient homes can be intimidating because of the advanced technology, and some potential buyers may shy away because they don't understand it and don't think they can effectively operate the energy-efficiency features. When one homeowner moved into her home, she had to hire a Heat Recovery Ventilation (HRV) technician to visit her home to demonstrate and explain how to use it properly. She was experiencing indoor moisture condensation because she was using the HRV sporadically. The technician explained that she needs to leave it on 24-hours a day to maximize its functionality. One contractor also mentioned a need to educate architects and building code officials, as he often gets push-back from them because they don't always understand his highly energy-efficient building design concepts.

An architect talked about the discrepancy that occurs when professionals attend design schools in temperate climates where they are not likely to learn about the specific challenges that Alaska faces, and about the building styles that are appropriate for a northern climate, including the high shipping costs of materials to Alaska. Furthermore, even designers who are from urban areas in Alaska, such as Anchorage or Fairbanks, often find their knowledge is not appropriate for building in rural Alaska. In his opinion, the reason there are many failed buildings, especially in rural Alaska is because the design team has preconceived ideas before visiting the rural community, without having knowledge of the local

culture, space syntax or personal preferences of community members. Homes are an emotional purchase and provide homeowners with a sense of place. According to the architect we interviewed, in order to build highly energy-efficient and sustainable housing the designer needs to understand the place and local people first, which can be a large time commitment. For example, he visits a community and takes time to hear their history and legacy of building homes, listen to the difficulties they face and then works with the community on designing culturally and environmentally appropriate homes.

b) The act of adopting new technology can be a source of information to others, however the adopter is not compensated financially for it, including time and energy spent acquiring the necessary information of suppliers, installation, and correct usage.

Some frustration was expressed by two homeowners who were involved in the construction of their house at having to train the skilled professionals they hired in the specialized building techniques. The homeowners themselves did not get direct monetary compensation for this training, instead the opposite was true, they compensated the professionals for the extra time it took to learn. One homeowner had a situation where the general contractor she hired pushed back when she asked him to build features of her house that strayed from the conventional approach. She also ran into resistance when she contacted a local builders' supply store for a custom order of Larsen trusses for her house. According to her, they declined the order because they were unfamiliar with the design concept.

To avoid duplicating specialized training, a Fairbanks contractor hires the same crew of skilled laborers for each highly energy-efficient house project. He emphasized that the crew should not only know how to build the energy-efficient-elements of the house but also understand the science behind it and how the features they are working on fit in with the rest of the house design. For example, in his crew, the person in charge of blowing-in insulation understands the role air-tightness plays in a highly energy-efficient building.

Another homeowner who used the remote wall system for his house, specifically hired a friend as the contractor. He wanted to provide his friend the opportunity to gain hands-on experience with this building technique so that he could use it for future projects. However, his friend told him it was so complex he wouldn't want to build remote wall systems again unless specifically requested to do so.

A homeowner, who is also the builder and designer of his home, felt that the non-standard construction techniques of highly energy-efficient homes pose a barrier to building code guidelines. Finding a way to abide by them adds another layer of time, energy, and financial investment for the designer.

Eight homeowners, builders, and designers declared a big barrier to be a combination of factors, first finding building materials that fit within the construction budget, then factoring in high shipping costs to Alaska, and making sure the materials fulfill the highly energy-efficient standard. Frequently building materials are imported from out of state. As a consequence, the homeowner experienced construction delays. Mistakes made in ordering and filling the order meant returning the building materials and waiting for the correct ones to be shipped. Along the same lines, a builder told us, he often deals with impatient homeowners, since sourcing and ordering specialized building-materials requires extra time. Additionally, in his experience, not only are the material costs higher than in conventional buildings, but also the labor cost is also higher, because it takes extra design work and specialized labor skills for construction. An architect and designer who primarily works in rural Alaska calculated that as much as 40-50% of the construction budget in rural locations is allocated to the shipping of building materials. In his experience, skilled labor is expensive as well, as workers' lodging and per diem expenses need to be covered as part of the construction budget. He is often faced with a trade-off between the most sustainable building materials, affordability of labor, and shipping cost. For example, instead of using wood studs, which are appropriate for cold climate construction, they sometimes use steel studs because they are lighter and don't take up as much space on the cargo plane.

c) The adopter must recover the investment in the technology directly or by reaping the benefits of reduced energy consumption in the future. Homebuilders need to recoup their investment from the homebuyer or else the increased investment is considered a market failure.

This barrier was identified by all but one of the interviewees. The one exception was a homeowner who had built his highly energy-efficient cabin in the 1980s, with a minimal investment in materials, completing most of the labor himself. His property value has increased in the last thirty years. He is confident he will recoup his investment and make a profit if he sells the property in this real estate market.

Ten homeowners and builders who were interviewed agreed that a significant barrier is the higher upfront-capital-investment highly energy-efficient homes require. One of the homeowners recognized that if he retrofits his house to be more energy-efficient, he will not live long enough to reap the financial payback due to cheap natural gas prices in his area. Two interviewees mentioned acquiring appropriate financing for highly energy-efficient homes as a problem, but did not reference the appraisal system specifically.

Eight homeowners, five professionals in the finance and real estate industry, and one homeowner who is in both in the finance and real estate industry and one other homeowner stated that the resale value of highly energy-efficient homes in Alaska is below its true value. These interviewees all talked about the difficulty of having an appraisal system that doesn't value energy-efficiency features appropriately. The need for an overhaul of the appraisal method used for highly energy-efficient homes in Alaska was particularized by fourteen of the interviewees from all categories. A real estate agent interviewee told an anecdote of touring a highly energy-efficient home in Fairbanks. She conferred with an appraiser and made a rough estimate that she could sell the house for \$330,000, based on the neighborhood it was in and the value of the other homes nearby. When she asked the homeowner, he said he built it for \$550,000 accounting for the cost of a number of highly energy-efficiency features. Three interviewees from the finance and real estate industry, four homeowners, and one person who is both a homeowner and in the finance and real estate industry specifically said not having comparable highly energy-efficient homes on the housing market is a barrier to appraising homes at their true value. One of the homeowners built his house in rural Alaska. He knew that without comparable homes in the area his house will not be assessed at its true value. Prior to building his home, he talked to an appraiser, who responded with incredulity that he would choose to build a house to these high standards knowing the risk of a low resale value. Without more of these types of homes on the market, the resale value will remain low.

d) Inadequate access to financing for significant capital costs, or financial market failure.

Four homeowners applied for a mortgage loan. The rest paid out of pocket. Some completed a large amount of the labor themselves, or saved money and built in stages spanning multiple years. According to the interviewees from the finance and real estate industry, mortgage banks typically do not increase the loan amount to build a highly energy-efficient home versus a conventional home, because most highly energy-efficient features are not included in the appraised value. Homeowners are not able to receive loans for the full investment of building or buying a highly energy-efficient house and need to make up the discrepancy in funds from other sources, or simply cannot afford to own this type of home. An interviewee, who is a builder, has experience with homeowners who are pre-qualified for a home loan. They design their home based on how many square feet they can afford with the pre-qualified loan amount, not considering the extra expenditure of energy-efficiency features. Rather than compromise for a smaller home but with more energy-efficient features, since they cannot increase their home loan amount, they often chose larger homes that are less energy-efficient.

An interviewee in the finance/real estate industry referred to rising interest rates as one of the barriers. In her experience, the government lender in Alaska provides reduced interest rates for energy-efficient buildings as an incentive. However, despite this, the national lenders, Freddie Mac and Fannie Mae, are able to offer even lower interest rates for conventional homes. This low interest rate acts as a disincentive for homeowners to take advantage of the energy-efficiency rate the government lender in Alaska offers.

Five interviewees in the finance/real estate industry, described the primary issue that exists with appraising highly energy-efficient homes at their true value is the lack of comparison homes that exist on the market. The reason for this is because only a few of them exist in Alaska, and most of them were never on the secondary market--the original owner still owns it. An interviewee from the finance/real estate industry knows that her clients who are interested in building highly energy-efficient homes consider them their forever-home. They are not building it to sell it, rather as the last house they will live in. A real estate agent's experience is similar; there are not a lot of highly energy-efficient homes on the secondary market, as often buyers must pay well above the asking price for a highly energy-efficient house, because the builders spent more money than the appraised value. Having to make this additional upfront-investment is prohibitive to putting it back on the market. Two appraisers who were interviewed said that, in the event of not being able to find an appropriate comparison home, they would try to determine what the market reaction would be for a house with highly energy-efficiency features. The market is based on the typical consumer. People who go the extra step for energy-efficiency features, are outliers. In one of the appraiser's mind, the extra features of a highly energy-efficient house are not valued highly if the majority of consumers would not demand it and therefore he typically only makes minor adjustments to the appraised value of a house for these features. He also considers how long a house is on the market. The appraiser told an anecdote of a highly energy-efficient house in Fairbanks that was on the market. He was keeping an interested eye on it to see how fast it would sell. Unfortunately, it didn't sell within 2 years, and when it did the builder lost money on it. In his opinion it was priced too high for the neighborhood it was in, which consisted of 40 to 50 year-old houses that were much smaller in square size and not energy-efficient. This told him that the typical consumer does not place value in purchasing this type of highly energy-efficient house. A barrier identified by two appraisers who were interviewed, is that homeowners don't always know what energy-efficiency features their house has. Unless the homeowners know the features, or they are written on the real estate listing, the appraisers cannot assign value to it. He said an appraiser cannot see the insulation in the walls, for example, to determine what the R-value might be. He also thought

real estate agents are reluctant to put the energy-efficiency rating in the listing because of liability issues, as a homeowner could upgrade their rating with retrofits invalidating the originally recorded rating.

An interviewee from the finance and real estate industry described what in his opinion is a barrier to appraising highly energy-efficient homes at a higher value. Most appraisers in Alaska have been in the profession for a long time and are used to doing appraisals using the same methods. The American Appraisal Institute has three allowable methods that can be used when valuing property, but often only the traditional method of finding comparison homes that have been previously sold on the market is used. For appraisers to value highly energy-efficient homes they need to be technically-qualified through attending specialized training classes. Builders, homeowners, and lending companies can request specially qualified appraisers for energy-efficient home appraisals. However, in Alaska they often chose the most convenient appraiser who is available. For appraisers to use new methods that consider the value of energy-efficient features of a house, they need to invest in expanding their knowledge base. Furthermore, collaboration between realtors and appraisers is required; the more realtors know about energy-efficiency features and can quantify the benefits when listing and selling a property, the more information appraisers will have about valuing energy-efficiency features.

f) Using an inappropriate discount rate, based on the uncertainty of oil prices in the future, the net savings of the new energy-efficient technology and future market prices.

One homeowner acknowledged that making an upfront investment in a highly energy-efficient home with the hope of a 50-year payback is not ideal, because he doesn't know what the fuel cost will be by then. That makes it hard to calculate the payback rate and factor in inflation.

4.6 Discussion

The slow diffusion of energy-efficient technologies was first observed in the 1970s (23). It was termed the energy-efficiency paradox in the 1980s. The emerging theme from our research is that in Alaska there has been a decline in market demand for highly energy-efficient homes in the last decade. This decline can be traced to several factors.

Oil price fluctuations directly influence the discount rate and net savings of investing in energy-efficiency technology. As an example, the price of oil in Dillingham, a rural Alaskan community where

one of the homeowners we interviewed built a highly energy-efficient home, fluctuated from \$4.41/gallon in 2010 (24) to \$5.97/gallon in 2014 (25), and within two years it sunk to \$2.54/gallon by 2016 (26). Furthermore, the upfront cost of purchasing or building a highly energy-efficient house is significantly higher than for a conventional house. Research conducted in the 1990s showed that the adoption of energy-efficiency technologies was more sensitive to up-front cost than to the benefits of long-term operational savings (23). These two factors cloak the financial payback-point in uncertainty and when it comes to economic analysis, uncertainty is a deterrent.

The high upfront-cost of highly energy-efficient homes, and the limited financing options contribute to the slow uptake of this technology. The problem of needing highly energy-efficient homes on the housing market in order for them to be valued at their true cost can be traced back to the affordability of the homes. The higher the cost and the worse the financing options, the more likely it is homeowners who do make the investment are considering it long-term. They do not plan to sell the homes because they know the market value will be below-cost. The dearth of these homes on the market provides appraisers with a lack of comparison homes; thus, further driving down the appraised market price. It is a self-perpetuating cycle.

The theory of diffusion of innovation can be applied on a microscale to the process of appraising highly energy-efficient homes as well. The innovation of developing a tool that places appropriate value on energy-efficiency features of a house is likely in the innovators' stage in Alaska. Further diffusion is facing barriers. The Alaska Housing Finance Corporation, a government mortgage lender, has developed an energy-efficiency appraiser tool and conducted numerous workshops and trainings to spread its use. The calculator can be used to determine the net-present-value of adding energy-efficiency features to a home in the amount of monthly utility-cost-savings. This tool is not, however, used consistently by appraisers in the state. The feedback from the interviewees who are appraisers is that the tool doesn't consider the market value of the house. It is based on the discounted-cash-flow calculation of how much money owners would save over time compared to owning another similar non-energy-efficient home. Since the tool is not market-derived, it is static and the appraisers we spoke to do not use it. When we spoke with an expert in the financing field who was involved in the creation of the tool, he suspected appraisers are reluctant to adopt a new tool, which would change the way they conduct appraisals. The willingness mindset is crucial in the early stages of the diffusion of any new technology, for it to move from the innovators to the early adopters group. Unfortunately, the stagnation of innovation in the appraisal process is slowing down the diffusion of highly energy-efficient homes in Alaska. Along with the high upfront-cost, the low resale-value is another significant deterrent.

In the case of highly energy-efficient homes, builders also struggle to increase their profit margin. Their profit shrinks because the homes they build for sale are not valued at the true cost of labor and specialized building materials and are often sold for a lot less. Instead of building more of these types of homes, to increase their prevalence in the housing market, thus driving up the market value, they are building fewer of them.

On the other side of this phenomenon are the homeowners. Due to the limited number of highly energy-efficient homes on the market in Alaska, they are compelled to also have a hand in the design and construction of their home. The lack of skilled workforce, in Alaska, knowledgeable of highly energy-efficiency features, is a clear indication that the innovation has not yet reached the early majority group of adopters. Rather, the fact that all of the homeowners we interviewed were also designers and builders of their home, is exemplary of the early adopters' stage. The innovators have broken ground on a new way to build homes, by having an open mindset and a willingness to step outside of their comfort zone as well as enough financial assets to afford it. Through word of mouth and publicly distributed information about this innovation in Alaska, early adopters are now engaged in building or retrofitting their own homes using this technology. Furthermore, since the homeowners we spoke with did not mind sharing information about their home without compensation, they exemplified the role of a leader. Early adopters are characterized by assuming a leadership role, paving the path for the early majority. This ties into the primary motivations of the homeowners we interviewed which are not wholly profit-motivated, rather they are philosophical in nature with a desire to benefit the larger society.

A barrier to adoption that we encountered, but that is not included in the Jaffe & Stavins (22) and Jaffe et al. (23) list of common market barriers, is the mindset of adopters. Five interviewees made it explicit that the willingness of potential adopters to step outside of their comfort zone is essential with this innovation. In human nature, one of the biggest challenges we face is an unwillingness to step outside of our comfort zone and try something new, in this case learning a new way of building or living in a house, or appraising the value of a home. Wilk and Wilhite (27) explored the disconnect between consumer behavior and rational-economic-response to high energy prices in 1985, during the same decade that the energy-efficiency paradox was recognized by researchers (23). The researchers surveyed homeowners who considered weatherizing their home for energy conservation. The weatherization options had a short payback period making the investment economically attractive. The research showed that homeowners are less likely to invest in energy conservation if the benefits are purely economic. It is more attractive if the application has one or more benefits, such as improvements

in the aesthetic of the home, energy independence, comfort of home, or a significant contribution to ameliorating global energy demand. While this research was completed almost three decades ago, it appears, the homeowners' motivations have not changed too much. Marketing highly energy-efficient homes to encompass multiple benefits, in addition to economic savings, will be influential in their continued adoption.

Tracing the development of the social networks among our interviewee group shows that not only are the homeowners acquainted with each other, but the builders/designers and financial/real estate professionals tap into the same network. For example, the appraisers know the builders who in turn worked with a homeowner, and now an informal knowledge sharing network is beginning to be established. The small size of the innovators and early adopters' groups, no doubt helps facilitate this formation of a social network. Communication plays a vital role in the diffusion of new technologies, from utilizing mass media for marketing to personal and business referrals (28). Information gleaned from personal contacts typically lends itself to higher adoption rates than the other communication modes (28), which likely assisted the innovation to move from the innovators to the early adopters group.

The emerging social networks that are forming among the innovators and early adopters directly enhances the adaptive capacity of households. Adaptive capacity comprises social, economic, ecological, and political capital. The more diverse and abundant these forms of capital are, the more vulnerability to external stressors is reduced. In this research, the stressors not only encompass climate change impacts, but also oil price fluctuations. Adaptive capacity can be described as the ability to cope with or respond to variability and change in the external environment (6). Viewing vulnerability in the context of building energy demand, mitigation is achieved through reducing the overall energy-usage (11). The reduced reliance on energy has additional benefits that enhance adaptive capacity as well. Due to the early stages of the diffusion of highly energy-efficient homes in Alaska, the social network of homeowners and other stakeholders is strong. They can gain practical information from each other and assist in spreading details of this technology through workshops, presentations, classes, thus widening the social network even further, strengthening the social capital. One of the non-profits that works in rural Alaska, the Cold Climate Housing Research Center, uses the opportunity of building a highly energy-efficient house to teach a class on sustainable, energy-efficient home construction when their crew builds a new home. This develops a skilled, local labor force in rural Alaska. Their goal is to not patent or copyright any of their building products or techniques, but rather spread the knowledge widely to the public. This non-profit can be viewed as another agent of change in the diffusion of this

technology and another node in strengthening the social capital of Alaskans trying to adapt. Economic capital is addressed in the lowered operational cost of living in a highly energy-efficient home. While the oil price may fluctuate, the total expenditure on heating fuel will always be lower in a highly energy-efficient house than in a conventional house. Low-income families in remote communities in Alaska spent up to 47% of their household income on home energy use in 2008, and on the road system communities spent as much as 18% (29). Freeing up the expenditure on heating fuel in a household budget has the potential to substantially widen the economic capital base for a household. A co-benefit of the highly energy-efficient home design, the tight building-envelope coupled with high amounts of insulation and thermal mass, keeps heat contained in the house for significantly longer periods compared to conventional homes. In the event of a power supply disruption, such as impassable transportation routes, or a power outage if the electrical grid fails, households will have an increased capacity to cope with these stressors, especially in extreme cold temperatures.

While these factors can be considered a broadening of a household's adaptive capacity, it only addresses the needs of the homeowners who are the innovators and early adopters. Arguably the climate-change-mitigation effect of energy-efficiency benefits all segments of society. But what about the remaining Alaskan households who do not currently live in a highly energy-efficient home? What limits are placed on their adaptive capacity? First, financial capital. As elucidated in this paper, at current market prices, highly energy-efficient homes are expensive with limited financial assistance and an uncertain payback rate. Second, the knowledge-capital doesn't yet exist widely, skilled professionals both for designing and building this innovative technology are sparse in the state, at present. Not every community has access to this knowledge base, and, if the homeowner does not have the time or technical disposition to educate themselves about building techniques, there appears to be limited alternative options at the moment. The building materials, which often are specialized to meet the requirements of highly energy-efficient construction techniques, are expensive and hard to acquire, especially in rural Alaska. Ecological capital, in this scenario owning land to build on, is also a financial capital investment and depending on the location of the land can pose logistical or transportation hindrances to building a home in this building style. It appears, a household requires a certain amount of adaptive capacity in order to build or procure a highly energy-efficient home, which would then enhance their larger-scale adaptive capacity. In these instances, it is often through policy that a cycle of this kind can be broken. Environmental policies directly addressing climate change by limiting carbon emissions or setting a new standard for energy-efficiency are vital in determining the success of the diffusion of energy-efficiency technologies (23).

4.6.1 Recommendations

We received numerous recommendations from interviewees on how to effectively spread the diffusion of this innovation. The most common recommendations are listed below.

- Banks should not only restructure their mortgage system to offer loans for the full-amount of capital investment in highly energy-efficient homes but should also offer low-income loans. Often paying the monthly utility bills is a struggle for low-income households in Alaska. Reducing the heating cost could provide a relatively large financial break.
- Having a larger variety of highly energy-efficient homes, from size, style, number of rooms, and so on, on the market could help diversify potential homeowners. A realtor noted how in her experience, builders are building highly energy-efficient homes with large square footage, to increase their profit margin. However, first time homebuyers interested in energy-efficiency cannot afford large homes. If builders were to build small, highly energy-efficient homes the market the demand will be driven up.
- More locally manufactured building materials could help keep cost low and the materials would more likely be built climate-appropriate for Alaska.
- Educating other stakeholders in the building industry, such as realtors, appraisers, building code officials on energy-efficiency features of a house was a common recommendation. If these stakeholders are knowledgeable of the benefits, both environmental and health benefits, and the financial savings of these features, then the demand for these homes would increase.
- Broadening the reach of education through detailed documentation of the energy-efficiency features, benefits, costs, and carbon savings is important. Homeowners need to have easy access to this information. For example, living in a well ventilated highly energy-efficient home has the potential to decrease sick days of household members, especially for upper respiratory illnesses, directly leading to less absences at work.
- Extensive training for new homeowners by the building company on how to effectively use the energy-efficiency features of the home would increase consumer satisfaction. Potentially, even having a follow-up visit a year after purchase of the home to answer any new questions that may have arisen.

To build off these recommendations from the stakeholders we interviewed, we furthermore recommend that tax credits or technology subsidies would facilitate a higher diffusion-rate. For

example, if federal or state policy subsidized mass quantities of insulation – which would be required to build a highly energy-efficient house and would help lower the upfront cost of building it. Taxing carbon emissions from boilers and furnaces could provide another incentive to invest in a highly energy-efficient house, making the upfront cost a worthwhile investment, since the carbon emissions from burning heating fuel will always be the same, regardless of oil price fluctuations.

A research study conducted by McMichael & Shipworth (28) shows that focusing on the diffusion of information through social networks is the most effective marketing tool. This could be highlighted by policymakers to increase adoption rates, even marketing highly energy-efficient homes as contributing to national energy security, since they facilitate less dependency on oil. Communication strategies and knowledge-sharing seems to be essential for the diffusion of this innovation as well. Appraisers need to be involved in the design of a tool that aids them in assessing the value of energy-efficiency features of a home. The tool needs to be compatible with their needs, if it is not a match they will likely not use it, as is the case with the existing tool that was developed in Alaska. Appraiser and real estate agents can assist each other, in raising the value of highly energy-efficient homes. If real estate agents acquire knowledge of energy-efficiency features of a home they can add the features to the house listing. This will help homebuyers in their education as well as appraisers who can use this information to value the property higher, thus increasing the asking price and facilitating a higher profit margin for the realtors in turn.

Artificially raising the demand for highly energy-efficient homes, through government policies, such as government housing following highly energy-efficient building guidelines, the number of homes on the market would increase. With increased demand, contractors and builders will be motivated to receive training in the specific building features. Construction would become less specialized allowing contractors to lower their fees, materials may become more accessible locally due to the higher demand and at lower cost thus getting the ball rolling for wider and faster adoption rates throughout the state.

4.7 Conclusion

Highly energy-efficient homes in Alaska have a large potential to strengthen the adaptive capacity of households in Alaska. Alaskans are vulnerable not only to the impacts of climate change but due to the high-energy demand for heating also to oil price fluctuations. A significant portion of the household budget is spent yearly on energy needs. Currently, this climate-change-mitigation and

adaptation technology is in the beginning stages of diffusion in Alaska. From our research and the key informant interviews, it appears that in Alaska, the innovators and early adopters have taken hold of the technology so far. However, the barriers they are facing, coupled with the declining cost of oil and problems with the low appraised-value of the homes, is slowing the adoption rate. If the barriers are not addressed through policy intervention they may prove to be a hindrance for the early majority and late majority to adopt this technology. To expedite the adoption rate a few key components are necessary; education of potential homeowners and other industry stakeholders such as realtors, appraisers, and code officials on the benefits of highly energy-efficiency features, specialized skill training for designers, builders and other skilled laborers, a policy intervention to appraise highly energy-efficient homes at their true value, allowing for a higher resale value as well as higher mortgage loans. Implementing policies artificially driving market demand for highly energy-efficient homes would furthermore aid in breaking through the mental barrier some prospective homeowners may be facing, not wanting to explore options outside of conventional homes. Once highly energy-efficient homes become more mainstream, they will be the new normal and hopefully within homeowners' comfort zones.

4.8 Reference

- 1 Davies, J. N., & Dodge, K. E. (2012). *Energy Efficiency Policy Recommendations for Alaska*. Technical Report 2012-03, prepared for Alaska Energy Authority, May 2012.
- 2 Davies, J. N., Mohatt, N. V., & Lister, C. (2011). *Alaska Energy Efficiency Policy and Programs Recommendations: Review & Update*. Interim Report to Alaska Housing Authority. June 2011.
- 3 Hossain, Y., Loring, P. A., & Marsik, T. (2016). Defining energy security in the rural North—Historical and contemporary perspectives from Alaska. *Energy Research & Social Science*, 16, 89-97. doi:<http://dx.doi.org/10.1016/j.erss.2016.03.014>.
- 4 Holladay, M. (2010). *The History of Superinsulated Houses in North America*. Paper presented at the British Columbia Building Envelope Council, Vancouver, BC.
- 5 Rogers, E. (2003). *Diffusion of Innovations* (5th Ed.). New York, NY, Free Press.

-
- 6 International Panel on Climate Change (IPCC). (2014). *Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Retrieved from Cambridge, UK and New York, NY, USA: http://pure.iiasa.ac.at/11125/1/ipcc_wg3_ar5_summary-for-policymakers.pdf
- 7 International Panel on Climate Change (IPCC). (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA.
- 8 Royal Institute of British Architects (RIBA). (2009). *Climate change toolkit – climate change briefing*. Retrieved from London, UK:
https://www.architecture.com/Files/RIBAHoldings/PolicyAndInternationalRelations/Policy/Environment/2Climate_Change_Briefing.pdf
- 9 U.S. Department of Energy (2012). *2011 Buildings Energy Data Book*. Retrieved from Silver Spring, MD: <http://buildingsdatabook.eren.doe.gov/DataBooks.aspx>
- 10 Saavedra, C., & Budd, W. W. (2009). Climate change and environmental planning: Working to build community resilience and adaptive capacity in Washington State, USA. *Habitat International*, 33(3), 246-252. doi:<http://doi.org/10.1016/j.habitatint.2008.10.004>
- 11 Ren, Z., Chen, Z., & Wang, X. (2011). Climate change adaptation pathways for Australian residential buildings. *Building and Environment*, 46(11), 2398-2412.
doi:<http://doi.org/10.1016/j.buildenv.2011.05.022>
- 12 Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, 16(3), 268-281.
doi:[10.1016/j.gloenvcha.2006.02.006](http://doi.org/10.1016/j.gloenvcha.2006.02.006)
- 13 Folke, C. (2006). Resilience: the emergence of a perspective for social-ecological systems analysis. *Global Environmental Change*, 16(3), 253-267. doi:[10.1016/j.gloenvcha.2006.04.002](http://doi.org/10.1016/j.gloenvcha.2006.04.002)
- 14 Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, 4(1), 1-23. doi:[10.1146/annurev.es.04.110173.000245](http://doi.org/10.1146/annurev.es.04.110173.000245)
- 15 Chapin III, F. S., Gary P. Kofinas, Carl Folke. (2009). *Principles of Ecosystem Stewardship, Resilience-Based Natural Resource Management in a Changing World*: Springer Science+Business Media, LLC.
- 16 Laukkanen, T., & Pasanen, M. (2008). Mobile banking innovators and early adopters: How they differ from other online users? *Journal of Financial Services Marketing*, 13(2), 86-94.
doi:[10.1057/palgrave.fsm.4760077](http://doi.org/10.1057/palgrave.fsm.4760077)

-
- 17 Sahin, I. (2006). Detailed review of Rogers' diffusion of innovations theory and educational technology-related studies based on Rogers' theory. *TOJET: The Turkish Online Journal of Educational Technology*, 5(2).
- 18 Mlecnik, E., Visscher, H., & Van Hal, A. (2010). Barriers and opportunities for labels for highly energy-efficient houses. *Energy Policy*, 38(8), 4592-4603. doi:10.1016/j.enpol.2010.04.015.
- 19 Nelson, R. R., & Nelson, K. (2002). Technology, institutions, and innovation systems. *Research policy*, 31(2), 265-272. doi:10.1016/S0048-7333(01)00140-8
- 20 Dodge, Kathryn, and Yasmeen Hossain. (2013). "A Report on the Effectiveness of Alaska Craftsman Home Program Consumer Education Classes and Recommendations for Improvements." Fairbanks, AK: Cold Climate Housing Research Center.
- 21 Chlupp, T. (2014, January 29) Personal Communication.
- 22 Jaffe, A. B., & Stavins, R. N. (1994). The energy-efficiency gap - What does it mean? *Energy Policy*, 22(10), 804-810. doi:10.1016/0301-4215(94)90138-4
- 23 Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2002). Environmental policy and technological change. *Environmental and resource economics*, 22(1-2), 41-70. doi:10.1023/A:1015519401088
- 24 Department of Commerce, Community, and Economic Development (DCCED). (2010). Current Community Conditions: Fuel Prices Across Alaska, Department of Commerce, Community, and Economic Development; Division of Community and Regional Affairs.
- 25 Department of Commerce, Community, and Economic Development (DCCED). (2014). Alaska Fuel Price Report: Current Community Conditions, Department of Commerce, Community, and Economic Development; Division of Community and Regional Affairs.
- 26 Department of Commerce, Community, and Economic Development (DCCED). (2016). Alaska Fuel Price Report: Current Community Conditions, State of Alaska, Department of Commerce, Community, and Economic Development; Division of Community and Regional Affairs.
- 27 Wilk, R. R., & Wilhite, H. L. (1985). Why don't people weatherize their homes? An ethnographic solution. *Energy*, 10(5), 621-629. doi:http://dx.doi.org/10.1016/0360-5442(85)90093-3
- 28 McMichael, M., & Shipworth, D. (2013). The value of social networks in the diffusion of energy-efficiency innovations in UK households. *Energy Policy*, 53, 159-168. doi:10.1016/j.enpol.2012.10.039
- 29 Saylor, B., Haley, S., & Szymonkiak, N. (2008). *Estimated Household Costs for Home Energy Use, May 2008*. Retrieved from Anchorage, AK: Institute of Social and Economic Research.

**Conducting Life Cycle Assessment (LCA) to Determine Carbon Payback:
A Case Study of a Highly Energy-Efficient House in Rural Alaska⁷**

5.1 Abstract

Buildings are responsible for a large portion of global greenhouse gas emissions. While energy efficiency features can significantly reduce the greenhouse gas emissions during a building's operational stage, extra materials and processes associated with these features typically involve higher greenhouse gas emissions during the construction phase. In order to study this relationship, a case study of a highly energy-efficient house in rural Alaska was performed. For the purposes of this case study, a theoretical counterpart home was designed that has the same interior space, but insulation values close to the code minimum requirements. Using computer simulations, life cycle assessment (LCA) was performed for the case study home as well as its conventional counterpart. The extra greenhouse gas emissions associated with the construction of the case study home were compared to the annual savings in greenhouse gas emissions achieved thanks to the energy efficiency features, and carbon payback was calculated. The carbon payback was calculated to be just over three years, which is only a small fraction of the life of the building. The results of this study show that despite higher greenhouse gas emissions during the construction phase, highly energy-efficient homes can play an important role in addressing climate change.

5.2 Introduction

About 40% of energy-related greenhouse gas emissions in the U.S. can be attributed to the built environment (U.S. Department of Energy, 2012). The U.S. Census Bureau estimates that by 2030, 14.5 million new homes will need to be built to accommodate the expanding population in the U.S. (U.S. Census Bureau, 2005). The increase in emissions from the building sector worldwide is estimated to rise from 8.6 Gt CO₂ in 2004 to 14.3 Gt CO₂ reached by 2030 (Levine et al, 2007). While highly energy-

⁷ Hossain, Y.; Marsik, T. In Preparation. Conducting Life-Cycle Assessment to Determine Carbon Payback: A Case Study of a Highly Energy Efficient House in Rural Alaska. *Energy and Buildings*.

efficient buildings during their operational stage can have significantly lower greenhouse gas emissions compared to their conventional counterparts, their construction typically involves higher greenhouse gas emissions due to the extra materials and processes needed to build the highly energy-efficient buildings. The main purpose of the research described in this paper was to evaluate how the initial greenhouse gas emissions associated with highly energy-efficient features compare to the greenhouse gas emissions saved in the operational stage of the building thanks to these highly energy-efficient features. The term highly energy-efficient house in the context of this paper denotes buildings that are close to having zero fossil fuel requirements for heating achieved through massive insulation, passive solar design, tight building envelope, and other energy-efficiency measures. Carbon payback was used as the main metric to quantify this relationship.

A case study approach was utilized in our research and a highly energy-efficient home in rural Alaska was selected for the analysis. Alaska is uniquely positioned for this research. Alaska not only sees pronounced impacts of climate change (Hinzman et al., 2005), but it also belongs to leaders in energy-efficient construction due to the cold climate and associated heating requirements (World Record Academy, 2013). Alaska, rural Alaska in particular, also faces challenges with respect to energy security due to high costs of energy, low income, reliance on imported fuels, and other factors (Hossain et al., 2016) which led to several pilot projects involving highly energy-efficient residential construction in this region. One of these homes was selected for the case study in our research.

This research not only adds to the dialogue on the role highly energy-efficient homes could play in reducing greenhouse gas emissions, but it also helps address the topic of reliance on imported fossil fuels in rural Alaska.

5.2.1 Case Study Overview

The case study house used for this analysis is located in Southwest Alaska, in Dillingham, the hub community for Bristol Bay. Dillingham is a rural off-the-road community accessible only by air or sea. In 2015, the population estimate for the city was 2,404 (U.S. Census Bureau, 2015). The average temperature is 1 degree C (U.S. Climate Data, 2015). The homeowners built the case study home themselves. The home was built as a prototype to explore the possibilities of a highly energy-efficient home in rural Alaska with little to no need for an external heating source. The home was built to last at a minimum 100 years into the future. The case study home opens up a discussion for how many square feet per occupant is needed to achieve the balance between comfort and high energy efficiency. The

net living area of the house is about 54.8 square meters built for a family of two adults and one child, with two bedrooms, one full bathroom, and one and half stories tall. The second floor is an open loft to allow for the open concept feeling. The outside dimensions are 7.3 m by 7.3 m with 71 cm thick walls.

The house falls into the category of a net-zero energy ready building, consuming roughly 3,000 kWh annually for all energy needs. This amount is sufficiently small, due to the energy-efficient nature of the construction, the appliances and the homeowner's lifestyle, that the energy demand could easily be produced through renewable energy. If the annual 3,000 kWh energy demand is sourced from renewable sources the house would be considered net zero energy.

5.3 Materials and Methods

5.3.1 Case Study Home

The case study home was built based largely on the Passive House standard, which relates to homes where the internal heat gain supplies sufficient heat so that there is no need for a conventional heating system (Passive House Institute, 2016). The case study house meets the air tightness requirement of the standard, but exceeds the heat load because the standard penalizes small houses with small footprints. Air tightness was measured at 0.05 air changes per hour (ACH) at 50 pascals and went on record with the World Record Academy as the world's tightest house (World Record Academy, 2013).

The case study home was built utilizing a "box-in-a-box" technique with a continuous polyethylene vapor barrier surrounding the interior "box". This construction method allowed for a continuous vapor barrier with minimal thermal bridging (see Figure 5.1). The vapor barrier is on the outside of the interior framing so that the wiring for the interior of the house does not puncture the vapor barrier. The 60 cm cavity between the interior and exterior wall was filled with blow-in cellulose insulation. There is fiberglass insulation within the interior framing. The walls have an RSI value of about 16 K·m²/W. The ceiling of the house has an RSI of about 25 K m²/W.

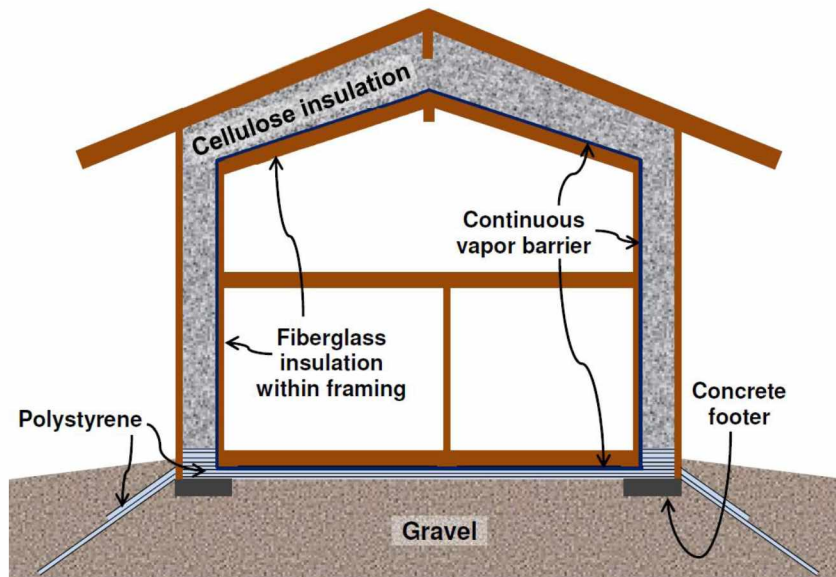


Figure 5.1: Case Study Home, Dillingham, Alaska

Other energy efficiency features of the house are triple-pane high-performance windows, a heat recovery ventilator (HRV), low-flow plumbing fixtures, ENERGY STAR appliances and an indoor heat pump water heater. The house is currently heated with an air source heat pump that uses about 600 kWh electrical energy and supplies about 1,114 kWh heating energy in a typical year, as determined by simulations (Marsik et al., 2016). The simulation results are in reasonable agreement with the actual performance.

It should be noted that the heat pump in this house is used for research purposes and it is not a proven technology for heating in this climate. Instead, an oil-fired heating system is used in most homes in Dillingham. Therefore, an oil-fired heating system will also be assumed for the analysis in this paper.

5.3.2 Life Cycle Assessment for Buildings

For this analysis, we chose to use a Life Cycle Assessment (LCA) approach, since this quantitative assessment tool can provide valuable information on environmental impact trade-offs that assists in decision-making (Blom et al, 2011; Dahlström et al, 2012; Bayer et al., 2010; Ortiz et al., 2009; Kohler & Moffat, 2003; Monahan & Powell, 2011). This method provides users with a summary of environmental impacts from the input and operation of the entire lifespan of a building, starting at resource extraction, manufacturing, construction, operational phase to decommissioning and possibly even quantifying the

impacts of material reuse and recycling (Bayer et al., 2010; Huberman & Pearlmutter, 2008; ISO, 2006, Assefa et al., 2007; Bribián et al., 2009). For highly energy-efficient buildings, conducting this analysis can aid in determining the carbon payback and the overall impact over the lifetime of the building. It is only in the last decade that the application of LCA has included buildings and construction materials (Bayer et al., 2010). As such the application to the built environment is not seasoned yet, and we came across several gaps in the analysis method, which are further elaborated on in section 5.6. There are a variety of impact categories and units that can be equated when conducting an LCA.

It is difficult to compare LCA building case studies to each other as buildings are site-specific and region-dependent. Local conditions such as microclimate, ecosystem resilience, local infrastructure, and ecological carrying capacity will vary greatly and all play a role in estimating the environmental impacts (Kohler & Moffatt, 2003), as does occupant behavior. For this reason, comparison of case studies often uses theoretical models of the same building in different conditions or the same conditions with different buildings rather than using existing buildings.

The defining characteristics of the case study home, with respect to its energy efficiency, are the super-insulated walls and ceiling. We modeled a conventional house counterpart to the case study home, built to the same specifications, in the same location, but with the walls and ceiling R-values close to the code minimum (International Code Council, 2012).

It is impossible to create a less efficient model house as a counterpart to the case study house that would have exactly the same interior due to the energy-efficiency features. For example, the case study home has large window boxes to encompass the 71 cm thick walls (the windows are flush with the exterior side of the wall). The less efficient model house cannot have such window boxes due to its relatively thin walls. Therefore, the goal was to create a less efficient house that has an interior very similar to the case study house and has about the same amount of useful space. The conventional counterpart home model has the same interior dimensions of 5.9 m by 5.9 m. The wall structure is a frame with 38 mm x 140 mm studs (referred to as 2x6 frame in the U.S.) with RSI of 3.7 K·m²/W fiberglass insulation and 25 mm polystyrene foam board on the inside, giving the walls an RSI 4 K·m²/W value. The ceiling is a frame with 38 mm x 286 mm ceiling joists (referred to as 2x12 frame in the U.S.) with RSI 6.7 K·m²/W fiberglass insulation and 25 mm foam on the inside giving it an RSI 7.2 K·m²/W value. The air tightness of the house was modeled at 1.0 ACH at 50 Pascals. The conventional model has a 45.7 cm crawl space to create room for the plumbing structures. The case study home has no crawlspace because none is needed; the plumbing is located in the inside framing of the exterior wall without a risk of freezing due to the 60.1 cm thick insulation on the outside of the plumbing.

Analyzing data from both houses allowed the exploration of how CO₂ emissions compare between a highly energy-efficient house and its conventional counterpart house specific to rural Alaska.

5.4 Calculation

The software used for the LCA was SimaPro 8. For this case study, we calculated the climate-change impacts using the Intergovernmental Panel on Climate Change (IPCC) global warming potential 100-year time horizon impact assessment method. The global warming potential is measured as kg equivalents of CO₂ (also referred to as CO₂ emissions in this paper), meaning the relative impact potential of greenhouse gases compared to CO₂. Sequestration of CO₂ and the release of biogenic carbon is not included in this method. Because this study looked at one impact category, the climate-change impacts, it is classified as a single attribute LCA. The libraries used are the European ecoinvent 3 and the Industry data 2.0.

5.4.1 Details of LCA

For the LCA only those components of the case study house and its theoretical counterpart house that are different were included in the SimaPro model. Walls and ceiling materials are different and thus were included in the analysis. Since the theoretical house does not have a double wall system, the overall footprint is smaller and thus the roof and foundation areas differ from the case study house. Therefore, roof and foundation materials were also included in the analysis. However, items that were assumed to be identical in both houses, such as the windows, heat recovery ventilator, heating system, non-envelope framing and so forth were not included in this analysis. Furthermore, when calculating the operational greenhouse gas emissions, only the heating energy was considered, as the heating energy use is the only difference when comparing the case study house to its conventional counterpart. Electricity required for appliances and lighting would be the same in both houses and was thus not included. Heating requirements for the theoretical counterpart house were determined using the same simulation as for the case study home (see section 4.3.1.), except the parameters were changed to the ones of the theoretical counterpart house.

5.4.2 Parameters and System Boundaries

The LCA includes the impact of the building materials, from cradle to warehouse, and the disposal of the materials at the end of the life cycle of the houses. It does not include transportation of the building materials from the warehouse to the building site in Dillingham, nor from the building site to the town landfill or incinerator. We chose to exclude transportation of both the construction materials as well as the heating oil, with the assumption that in calculating the carbon payback their impacts approximately cancel out. The analysis additionally does not include maintenance of the house or the heating system. Differences in on-site energy use during the construction of homes were also not included.

5.4.3 Materials

We used secondary data from the life cycle inventory libraries for all of the processes in the analysis. It means, as an example, that instead of a sheet of plywood from a given manufacturer used in the house, a sheet of plywood from a different manufacturer available in the library was used for the analysis. In the material list for both houses, items of very small quantities such as sill sealer were not included, assuming the difference in the amount of sill sealer between the houses to be negligible.

5.4.4 Disposal Scenario

The waste scenario used for this analysis was based on present day disposal options, rather than making a prediction as to what waste disposal might look like 100 years into the future. In 2014, the city of Dillingham had a permit to incinerate all lumber and buried all other construction materials in the landfill (City of Dillingham, 2014). There was no official system in place for recycling or reusing construction materials.

5.5 Results and Discussion

5.5.1 LCA Results

The building materials, not counting the disposal of them, in the highly energy-efficient home are responsible for 14,728 kg CO₂ eq. The conventional house is responsible for just over 60% of that with 8,844 kg CO₂ eq.

This finding relates to a research study Sartori and Hestnes (2007) conducted to compare the

embodied and operational energy requirements for 60 houses from low-energy green buildings to conventional buildings. The study did not include recycling or decommissioning of the buildings and focused on energy consumption. The authors divided up the cases by low-energy houses - defined as requiring less than 70kWh/m² annually for heating - and conventional houses. The findings show a trend of low-energy houses having higher embodied energy than conventional ones in each case, and lower operational energy needs. The houses built according to the Passive House Standard also required only 1/3 the total energy needs of a conventional house with only slightly more embodied energy. In our case study the highly energy-efficient home would use the equivalent of 132.5 liters of heating fuel per year, while the conventional counterpart home would use 609.5 liters per year, so just under 5 times more heating fuel usage in the conventional home. The building materials for the energy-efficient home are responsible for just over 1.6 times more kg CO₂ eq than the conventional home. Our research findings are roughly in line with the Sartori and Hestnes research study findings.

After calculating the life cycle assessment results of all of the building materials together, we separated out the carbon emissions that each home sub-assembly is responsible for. In the highly energy-efficient house, the majority of kg CO₂ eq is attributed to the insulation at 46%, followed by exterior walls at 25%, the roof at 20%, and the interior walls and the foundation both at 3%. In contrast, in the conventional counterpart home, the largest carbon emissions share is a close tie between the exterior walls at 40% and the roof at 39%. The insulation is responsible for 15% and foundation 5%. Since the highly energy-efficient building incorporates a double frame system, this distribution of kg CO₂ eq is in line with the large amounts of extra insulation that this house encompasses.

5.5.2 Carbon Payback

Carbon payback calculations can be used to assess how much a building's envelope influences the heating or cooling of a building (Wilson, 2010; Hacker et al, 2008). We apply this method to evaluate how many years it will take to save the extra CO₂ eq emissions associated with the building materials- from cradle to warehouse- of a more efficient home when matched against the CO₂ eq savings from burning less heating oil. When calculating the carbon payback point we had two thoughts about including the disposal phase. As shown later in the results, carbon parity is reached during the lifetime of the house and not after it has been decommissioned. For this reason, we chose to calculate the carbon payback without including the disposal of the materials.

5.5.3 Calculation and Results

We utilized a simple payback calculation for the CO₂ payback point. The same method, IPCC GWP 2013 (100a), as for the building materials was applied to the heating fuel usage per year for both the case study house and the theoretical house. The difference between CO₂ eq of the materials and the heating oil usage of the highly energy-efficient house and the theoretical house was obtained. To arrive at the carbon payback point, the CO₂ eq. emissions associated with the extra material for the more efficient house were divided by the annual savings in CO₂ eq. emissions thanks to decreased use of heating fuel. The results are detailed in Table 5.1. See Appendix C for the lifecycle inventory data used for the LCA.

Table 5.1: Carbon payback for the additional building materials used in the highly energy-efficient house

	Heating Fuel Use/Year	Building Materials, excluding disposal (cradle- to-warehouse)
Highly Energy-Efficient House	502 kg CO ₂ eq	14,728 kg CO ₂ eq
Conventional House	2,308 kg CO ₂ eq	8,844kg CO ₂ eq
Difference	-1,806 kg CO₂ eq	5,885 kg CO₂ eq
Carbon Payback point = 3.3 years		

The difference in materials used between the highly energy-efficient house and the conventional counterpart is responsible for 5,885 kg CO₂ eq. The heating fuel that is saved by adding these extra materials to the house is responsible for 1,806 kg CO₂ eq per year. The carbon payback for the additional building materials required to build a highly energy-efficient house is reached in only 3.3 years after the house is operational.

The carbon payback for the highly energy-efficient house of 3.3 years is a very short time, roughly 1/30th of the lifespan of the building of a minimum of 100 years.

Ramesh et al. (2010) conducted an analysis of LCA case studies of conventional and energy-efficient homes. The survey results indicated that the operating energy use of a building typically falls into 80-90% of total life cycle energy use and the energy related to materials accounts for 10-20%. Thus,

the life cycle energy of a building can be significantly reduced by cutting back on operating energy needs through passive and active energy efficiency features, despite increases in building materials that these features may hold. In our case study example, the building materials and the disposal of them are responsible for 18,687 kg CO₂ eq. The heating fuel usage over the house's projected lifespan of 100 years is responsible for 50,200 kg CO₂ eq. The materials and their disposal then make up only 37% of the total CO₂ eq of both the materials and the heating fuel over the lifetime of the house, and the heating fuel alone makes up 63%. Comparatively, the breakdown in the conventional counterpart house is as follows. The materials and their disposal make up 9,083 kg CO₂ eq and the fuel over the theoretical lifespan of 100 years is responsible for 230,800kg CO₂ eq, therefore the materials make up only 4% of the total CO₂ eq, and the fuel usage over the lifespan of the house is responsible for 96% of the total CO₂ eq. This is a purely theoretical comparison, as it does not consider climate change scenarios, or any maintenance to the house. However, based on this calculation, the conventional home occupies a significantly larger percentage of CO₂ eq emissions on heating fuel than the highly energy-efficient house, and as such improving upon energy efficiency of the house is well worth it in the carbon balance equation.

5.5.4 Disposal of Building Materials

The disposal scenario for the building materials is a theoretical construct, since we are calculating the lifetime of the house to be a minimum of 100 years, and it is hard to gauge what type of disposal, reuse or recycling system will be applied in Dillingham that far into the future. As noted above, at present all lumber is incinerated and all other waste is buried in a landfill. However, in the future the landfill might be converted to a co-generation plant, which would alter the life cycle assessment of this case study significantly. We chose to model the disposal scenario based on the current waste system that the city utilizes. In our disposal scenario if the cellulose insulation is diverted into the landfill, the disposal of the highly energy-efficient house's materials is responsible for 3,959 kg CO₂ eq, almost 17 times what the materials for the conventional house are responsible for, 239 kg CO₂ eq. One of the main differences between the highly energy-efficient house and the conventional counterpart is the addition of 6,364kg of cellulose insulation. In the disposal scenario, the cellulose alone is responsible for 3,645 kg CO₂ eq. Landfills in the U.S. are the third largest anthropocentric producer of CH₄, a large part of it is a byproduct of the anaerobic breakdown of organic materials, such as paper (EPA, 2016).

Methane gas, or CH₄, has 28 times the Global Warming Potential (GWP) when compared to CO₂ (IPCC, 2013).

5.6 Reflection on Analysis

Common concerns with the interpretation of LCA results is the inherent uncertainty and variability (Huijbregts, 1998). The uncertainty stems from the difficulty in converting real life situations to LCA data and parameters. Especially for buildings, which are typically made up of over 2000 products and over 60 basic materials (Kohler & Moffatt, 2003), it is difficult to maintain a high level of accuracy in analyzing each single component, utilizing available data. In most instances, we assumed global heterogeneity using generic available data for the materials that present limitations to the local application of the study to rural Alaska.

This analysis only considered the face value of carbon savings. When considering the viability of a highly energy-efficient house there are a number of other factors to be taken into account, such as economics, occupancy rate, design and layout, indoor thermal comfort of residents, the ease of obtaining the building materials – which in rural Alaska is not straightforward, and other factors that are hard or impossible to quantify in an LCA.

Another challenge we considered was how to treat the potential for carbon sequestration that the cellulose insulation coming from recycled newspaper could be responsible for. A case could be made for a carbon credit, as it locks in carbon for 100 plus years – the lifespan of the house, instead of disposing of the waste newspaper, potentially in a landfill creating a large contribution to GWP gases. Due to the limitations of this analysis we chose to shelve the idea of including carbon sequestration for a future research study.

5.7 Conclusion

The building industry, as well as the associated stakeholders, is increasingly paying attention to the negative environmental consequences of buildings (Bayer et al., 2010). The immense impact a building can have on the environment, from regionally to globally, is an important consideration during all building stages. In the arctic and sub-arctic, concerns over winter heating, air quality and overreliance on oil brings into focus the role energy efficiency in homes can play in reducing these perils and in some instances threats to survival.

This analysis expresses the building materials required and responsible for the energy efficiency of a residence in carbon savings, instead of monetary cost, to highlight the possibilities of reducing the overall carbon contribution of buildings in sub-arctic climates.

In our analysis of the case study house, the carbon required for the additional building materials of the highly energy-efficient house is paid back in just over three years, after which the home owners essentially reduce their operational carbon footprint by 1,806 kg CO₂ eq per year when compared to living in a conventional house. While there is an additional upfront cost when viewed through the lens of carbon savings, the decision to build a highly energy-efficient house versus a conventional house seems to be a direct route to improved energy and climate resilience. Determining the carbon payback point as well as comparing the carbon emissions in all building phases of the house to a conventional counterpart house provides researchers, homeowners and building professionals alike information on building homes to meet modern sub-arctic and arctic conditions and concerns. While highly energy-efficient homes are on the extreme end of the spectrum, this case study sets an example of what is possible in Alaska, even in a rural setting.

5.8 References

Assefa, G., Glaumann, M., Malmqvist, T., Kindembe, B., Hult, M., Myhr, U., & Eriksson, O. (2007).

Environmental assessment of building properties—Where natural and social sciences meet: The case of EcoEffect. *Building and Environment*, 42(3), 1458-1464.

doi:<https://doi.org/10.1016/j.buildenv.2005.12.011>

Bayer, C., Gamble, M., Gentry, R., & Joshi, S. (2010). *AIA Guide to Building Life Cycle Assessment in Practice*. Retrieved from Washington, D.C.: The American Institute of Architects.

Blom, I., Itard, L., & Meijer, A. (2011). Environmental impact of building-related and user-related energy consumption in dwellings. *Building and Environment*, 46(8), 1657-1669.

doi:<http://dx.doi.org/10.1016/j.buildenv.2011.02.002>

Bribián, I. Z., Usón, A. A., & Scarpellini, S. (2009). Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment*, 44(12), 2510-2520. doi:<https://doi.org/10.1016/j.buildenv.2009.05.001>

City of Dillingham. (2014). Garbage & Recycling Disposal Information. Dillingham, Alaska: City of Dillingham.

- Dahlstrøm, O., Sørnes, K., Eriksen, S. T., & Hertwich, E. G. (2012). Life cycle assessment of a single-family residence built to either conventional- or passive house standard. *Energy and Buildings*, *54*, 470-479. doi:http://dx.doi.org/10.1016/j.enbuild.2012.07.029
- Environmental Protection Agency (EPA). (2016). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014. Retrieved from Washington, DC: U.S. Environmental Protection Agency.
- Hinzman, L. D., Bettez, N. D., Bolton, W. R., Chapin, F. S., Dyrgerov, M. B., Fastie, C. L., . . . Huntington, H. P. (2005). Evidence and implications of recent climate change in northern Alaska and other arctic regions. *Climatic Change*, *72*(3), 251-298. doi:10.1007/s10584-005-5352-2
- Hossain, Y., Loring, P. A., & Marsik, T. (2016). Defining energy security in the rural North—Historical and contemporary perspectives from Alaska. *Energy Research & Social Science*, *16*, 89-97. doi:http://dx.doi.org/10.1016/j.erss.2016.03.014
- Huberman, N., & Pearlmutter, D. (2008). A life-cycle energy analysis of building materials in the Negev desert. *Energy and Buildings*, *40*(5), 837-848. doi:https://doi.org/10.1016/j.enbuild.2007.06.002
- Huijbregts, M. A. J. (1998). Application of Uncertainty and Variability in LCA. *International Journal of Life Cycle Assessment* *3*(5), 273-80.
- International Code Council (2012). *International Residential Code*. Retrieved from Country Club Hills, IL: International Code Council.
- International Panel on Climate Change (IPCC). (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge, United Kingdom and New York, NY, USA:
- International Organization of Standardization (ISO). (2006). "ISO 14044 - Environmental Management - Life Cycle Assessment - Requirements and Guidelines Management Environnemental - Analyse Du Cycle De Vie - Exigences Et Lignes Directrices." 1-46. Geneva, Switzerland: International Organization for Standardization.
- Kohler, N., & Moffatt, S. (2003). Life-Cycle Analysis of the Built Environment. *UNEP Industry and Environment*(April-September), 17-21.
- Levine, M., Urge-Vorsatz, D., Blok, K., Geng, L., et al. (2007). Residential and commercial buildings, Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change O. R. D. B. Metz, P.R. Bosch, R. Dave, L.A. Meyer. Cambridge, U.K. and New York, NY.
- Marsik, T., Hossain, Y., & Donaldson, K. (2016, May 8-11). *World's Tightest Known House*. Paper presented at the 11th International Green Energy Conference, Anchorage, Alaska.

- Monahan, J., & Powell, J. C. (2011). An Embodied Carbon and Energy Analysis of Modern Methods of Construction in Housin: A Case Study Using a Lifecycle Assessment Framework. *Energy and Buildings*, 43, 179-188. doi:10.1016/j.enbuild.2010.09.005
- Ortiz, O., Castells, F., & Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials*, 23(1), 28-39. doi:https://doi.org/10.1016/j.conbuildmat.2007.11.012
- Passive House Institute (2016). *Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard*. Retrieved from Darmstadt, Germany: Passive House Institute.
- Ramesh, T., Prakash, R., & Shukla, K. (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings*, 42(10), 1592-1600. doi:https://doi.org/10.1016/j.enbuild.2010.05.007
- Sartori, I., & Hestnes, A. G. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings*, 39(3), 249-257. doi:https://doi.org/10.1016/j.enbuild.2006.07.001
- U.S. Census Bureau. (2005) Interim State Population Projections. Retrieved from Washington, DC: US Census Bureau.
- U.S. Census Bureau, Population Division (2015). *Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2015* Retrieved from <https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk>
- U.S. Climate Data. (2015). Climate Dillingham - Alaska. <http://www.usclimatedata.com/climate/dillingham/alaska/united-states/usak0068>
- U.S. Department of Energy (2012). *2011 Buildings Energy Data Book*. Retrieved from Silver Spring, MD: U.S. Department of Energy. <http://buildingsdatabook.eren.doe.gov/DataBooks.aspx>
- Wilson, A. (2010). Avoiding the Global Warming Impact of Insulation. *Environmental Building News*, BuildingGreen, LLC. 19 (6).
- World Record Academy (2013). "Tightest Residential Building: Dillingham House Sets World Record." Retrieved August 19, 2015, from http://www.worldrecordacademy.com/technology/tightest_residential_building_Dillingham_house_sets_world_record_213292.html

Chapter 6
Conclusion

“We have a choice: between an energy-efficient low carbon path and an energy-intensive high carbon path, which at an unknown point of time ends catastrophically. This doesn’t seem like a very hard choice.”

Michael Spence, NYU Stern School of Business, Italy
World Economic Forum Annual Meeting
Davos-Klosters, Switzerland, 21-24 January 2015

Climate change is likely one of the biggest challenges facing humanity in the 21st century. The sticking point is that it is not something that is happening to us, we cannot blame an external force and raise our fists to heaven. We, as a species, are directly responsible for the magnitude of the change we are not only anticipating in the future but are already experiencing in our present. The anthropogenic causality of climate change is undeniable from a scientific viewpoint (IPCC, 2014). While it is important to analyze those behaviors of ours that has brought us to this point – and to discontinue such behavior – it is equally important for us to research our options in the present to ameliorate the present impacts and prepare for the future. The way forward seems clear; cutting back on greenhouse gas emissions is paramount.

Technological innovations have come far in mitigating harmful effects of our dependence on fossil fuels. One of the first Western explorers to publish research on Alaska, in 1913, identified that energy technologies are a possible source of resilience to cultures in the North (Stefansson, 1913). The technological innovation this research focuses on, highly energy-efficient homes, not only mitigates the extent of future climate-change impacts, but aids in adapting to the changing conditions. It feels strange, calling energy-efficient features of a home, a ‘new’ innovation. The review of pre-colonial homes in Alaska in this dissertation makes a case that energy efficiency is not a new concept by any means. However, the re-introduction of the features adapted for modern architecture and modern lifestyles can be considered a new re-emergence of old concepts. As the research in this dissertation shows, the existence of the innovation itself is not enough for widespread dissemination and use. Humans are complex creatures, and any innovation needs to exhibit multiple benefits. In the example of this research, highly energy-efficient homes need to be economically sound, aesthetically pleasing,

provide a sense of place, and have a small payback point (financial or carbon). Moreover, the user needs to have an open mindset and be willing to change ingrained behavior.

My research goal was to investigate the components that determine viability of a technology that has the dual benefits of mitigation and adaptation. Viewed purely from a standpoint of what can be gained, it begs to question why the entire North is not populated with highly energy-efficient homes at present. Clearly there are more factors at play: What are the reasons for- or against adoption and diffusion? Why might a homeowner not be capable of adoption even if the willingness is present? My intent in presenting this research to the world is to not only deepen our understanding of what barriers exist but to use this knowledge to effect change. While it may never be possible for every single household on the globe to inhabit a highly energy-efficient home, there does appear to be a sound argument to enable the diffusion of this innovation to the greatest extent possible.

Alaska faces a unique set of challenges, including not only the impacts of climate change, but its remote nature and the reduced accessibility of rural communities within the state (Gerlach et al., 2011). Furthermore, the extreme winter climate necessarily makes residents dependent on one form of fuel or another for survival. The price of oil fluctuates, but on average fuel prices in Alaska are significantly higher than in most of the contiguous U.S. states. The socio-historic legacy of colonization and the foray of settlers and gold seekers adds to the complexity. The combination and interaction of these issues that foster energy insecurity in the state can be likened to the interrelated influences of warfare in complex emergencies. The term complex emergency is typically applied to regions of conflict caused by environmental, economic, demographic, and political instability (Keen, 2008). Regions in Alaska with heightened energy insecurity are arguably affected by instability in all of those areas. The co-occurring instabilities in Alaska are enforced through feedback loops: economic instability affects food security, poverty rates and underdevelopment, and these in turn influence health risks and environmental degradation.

While the causes for instability are co-rooted, energy-efficient buildings can have co-benefits. The 5th Assessment report of the Intergovernmental Panel on Climate Change (IPCC) addressed the co-benefits of mitigation and adaptation that carbon reduction in buildings offer:

“Most mitigation options for buildings have considerable and diverse co-benefits in addition to energy cost savings (...). These include improvements in energy security, health (such as from cleaner wood-burning cookstoves), environmental outcomes, workplace productivity, fuel poverty reductions and net employment gains. Studies

which have monetized co-benefits often find that these exceed energy cost savings and possibly climate benefits (...)". (IPCC, 2014, p.23)

Energy-efficient building technology is related not only to carbon mitigation and adaptation in Alaska but contributes to energy security by reducing reliance on imported fuel. The threats to fuel supply and grid interruption due to natural hazards or technological reasons are occurrences that Alaskans are familiar with. If an event happens in winter, survival is at stake. Highly energy-efficient homes not only conserve fuel resources but also have the capacity to sustain indoor thermal comfort in this event. Healthier indoor air quality through utilization of effective ventilation technology significantly reduces the occurrence of illness, from the common cold to chronic respiratory diseases. This translates into fewer sick days, increasing economic opportunities, or if earnings are based on an hourly-wage - a direct increase in take-home pay. External air quality is improved, and, if the designer considers the emotional connection homeowners have to their home, a sense of place can be significantly fostered. I cannot imagine having a particularly positive emotional connection to a home that is drafty, cold in winter, or that takes most of my household income to heat, leaving me with reduced flexibility in my spending.

These benefits strengthen the adaptive capacity of individual households. Kwok and Rajkovich (2010) frame adaptive capacity in the context of buildings as a reaction to current stresses, requiring the ability not only to learn from past experiences but also to apply lessons learned to future situations. Utilizing highly energy-efficient home designs will be vital to furthering the adaptive capacity of Alaskan residents. Especially the designs that allow for inhabitants to reduce their carbon footprint and also be affordable, and in line with providing a sense of place to a household in an ever-changing world. Building highly energy-efficient homes, or rather laying the groundwork for them to not only be built but also be accessible to a wider segment of the population, is laying the groundwork for an effective climate-change mitigation and adaptation technology.

6.1 Key Findings

The picture drawn in this dissertation is of flailing energy security in Alaska and numerous obstacles and barriers to reducing dependence on energy consumption. Yet the research results point towards much hope and potential for energy efficiency and specifically highly energy-efficient buildings to alleviate some of the pressure, and provide an investment that will pay off for generations to come.

Energy Security

- When defining energy security, it is important to take into consideration at what geographic scale energy security is applied. For example, the definition varies between national and community energy security. On the household and community level, energy security can be defined as *a situation in which people have reliable access to socially acceptable energy generation or provisioning services, at a level sufficient to conducting a sustainable life* (see Chapter 2, p. 10).
- Energy security has four components- availability, access, stability, and utility. These components can be used to evaluate the vulnerability of energy use in these categories- food production and harvest, household activities, municipal activities, and manufacturing/commerce. A significant segment of the Alaskan population is energy insecure, specifically within three of the four categories- food systems, household activities, and municipal activities.

Energy Efficiency

- Due to the rich indigenous history of the state and the colonial legacy, it is important to apply a healthy dose of skepticism to energy efficiency technologies developed outside of Alaska. Not only is there the possibility that the technology is not climate-appropriate but it may also clash with the local culture, needs, and life-style desires.
- It is vital to the success of a home for architects and designers working in rural Alaska to familiarize themselves with the land, culture, and ancestral history prior to laying out the blueprints of a home. Cultural and social acceptability of a home is arguably as important as the economic and ecological features.
- Pre-contact homes of Indigenous Alaskans featured a consideration of both energy conservation and energy efficiency. To summarize home elements from the north, interior and southwest regions of Alaska, the home features in this category were:
 - an entrance tunnel
 - a cold trap leading from the tunnel to the living area
 - using natural landscape features as insulation
 - subterranean building style
 - a circular layout

- the ability to modify wall insulation based on the season
- passive solar orientation
- ventilation mechanism
- skylights as light source
- food storage nooks carved into permafrost
- co-habitation and large occupancy rates
- using stone as thermal mass to store heat
- shared stone walls between houses

Some of these features are reintroduced to modern energy-efficient building designs in Alaska, for example:

- small square foot to occupant ratio
 - passive solar design
 - arctic entrance
 - round or octagonal building layout
 - using earth berming, sand dunes, and snow banks as natural insulation
 - permafrost lined cellars
 - subterranean building style
 - thermal mass
 - shared stone walls between rooms
- Education on energy literacy for households not only provides members more control of their energy security but also facilitates adoption of more energy efficiency measures.

Highly Energy-efficient Homes

- When Rogers (2003) theory of diffusion of innovation is applied to highly energy-efficient homes in Alaska, the adopters' groups that have embraced this technology so far are the innovators and early adopters, making up only approximately 16% of the population. This is based on Rogers estimation of group size, not a statistical survey conducted of homes in Alaska.
- Barriers to the adoption of highly energy-efficient homes in Alaska are economic, psychological, market drivers, and lack of information and/or education. Specific barriers identified in this research are:
 - lack of skilled contractors and laborers familiar with specialized building techniques

- insufficient information on energy-efficient features of homes, both operation and maintenance, as well as the related benefits
- compliance with building codes
- insufficient emphasis placed on cultural and social features of highly energy-efficient buildings and their connection to providing a sense of place for the occupants
- difficulty sourcing specialty building materials, and/or inability to have them custom-made locally
- high cost of the specialty building materials and shipping costs
- high labor costs, due to unique design and building techniques
- an appraisal process that does not value highly energy-efficient features at true cost
- low resale value on the housing market, usually below capital investment
- small or negligible profit margin for builders
- homes not qualifying for mortgage loans that cover the entire upfront cost of the home due to low appraisal value
- long financial payback time due to either fluctuating oil prices or cheap natural gas when juxtaposed with the high upfront capital cost
- competition of low mortgage interest rates from national lenders with energy efficiency mortgage interest rates from state lender
- fluctuating oil prices leading to an inaccurate calculation of discount rate of the investment and the financial payback point
- The mindset of homeowners, builders, and other stakeholders is an important determinant of the uptake of highly energy-efficient homes. This building style is out-of-the-ordinary and is associated with a learning curve. The involved parties generally must be open to moving beyond their comfort zone.
- There is a large potential for highly energy-efficient homes in Alaska to strengthen the adaptive capacity of households to cope with-climate change impacts, import reliance, and oil-price fluctuations. At the same time, there appears to be a need for an already expanded adaptive capacity of a household to be able to achieve living in a highly energy-efficient home, for example, the knowledge base required of the homeowner and builders, significant capital investment, and an expanded social network for skill sharing and acquisition of specialty building materials.

- Life-cycle assessment can be used as a method to determine the carbon payback point of a highly energy-efficient home. A case study example of a home in Dillingham, Alaska showed that, when compared to a conventional counterpart house, the carbon payback is achieved in 3.3 years. At that time, the amount of carbon emissions from heating fuel saved when compared to the counterpart home heating fuel requirements is equal to the carbon emissions equivalent of the building materials of the house.
- In the case study home that was used for the life-cycle assessment in this dissertation, the primary insulating material used is cellulose. The cellulose comes from recycled newspaper. Despite this, the carbon emissions equivalent the cellulose is responsible for is relatively large in context of the entire life-cycle of the house. When organic materials are disposed of in a landfill, a byproduct of the anaerobic breakdown is methane, a greenhouse gas that has 28 times the global warming potential compared to carbon (IPCC, 2013). It is thus especially pertinent to consider disposal when calculating the carbon impact of a material.

6.2 Recommendations

The question remains: Are highly energy-efficient homes viable in Alaska? Given the present research, the answer is a conditional yes – if certain conditions are met and barriers are overcome. I learned from researching this topic that any topic involving sustainability is invariably intricate. There is not one “right” answer, but there are many “wrong” answers. Sustainability is by design based on complexity as it spans three main areas – economic, ecological, and social realms. Within these realms are many minute sub-compartments. It only makes sense that the interplay, feedback, and interdependency of these linkages are involved. I believe mitigating climate change and adapting to its effects are two of the sub-components of sustainability. Highly energy-efficient buildings exemplify sustainable development by addressing not only ecological issues but also the social wellbeing of its occupants (Fiksel, 2003). While designing ideal environmental conditions or societies is not within our reach, adapting and modifying the controllable characteristics of our engineered systems can significantly improve our socio-economic and ecological circumstances. The results in this dissertation make the case that the energy demand and supply scenario in Alaska does not foster sustainability or for that matter human-, ecosystem-, or animal wellbeing, not as a whole. What can be done to foster the growth of energy efficiency and highly energy-efficient homes in Alaska?

The first category for improvement is in the field of education. This research indicates a lack of knowledge is one of the culprits of several problems. As stated throughout this research, energy efficiency is not only a mitigation technology but also an adaptation strategy. However, its mere existence is not enough. Current, and future homeowners need to be aware of and understand the benefits energy efficiency offers. Providing a public class, for example to high school students before they enter the world as potential new homeowners, would aid in building a solid knowledge base in the state. The class would cover not only the impacts energy efficiency technology has on climate change but also on health, wellbeing, and economic savings. Touting only one of the benefits of energy-efficient homes is a marketing flaw; multiple benefits are a higher selling point. For example, in addition to saving money, household members experience improved indoor thermal comfort, reduced upper respiratory illness, reduced sick days at work, potential for increased emotional attachment to home, and energy independence. This marketing approach should be more widely disseminated than to high school students. Real estate agents, professionals in the lending and finance industry, appraisers, building code officials, builders, skilled laborers, government officials, educators themselves, all of these groups (and others) could help further the adoption of energy-efficient buildings if they have the appropriate knowledge base. People in public service positions can use the knowledge for policies to not only increase the adoption rate but to decrease national reliance on imported oil, thus making a case for national security. The spread of education could take many forms, including the aforementioned high school course, mandatory homeowner education classes, a subset of licensing requirements for professionals in the field, continuing education credits for professionals, or post-consumer education for people who have already bought an energy-efficient home. As chapters 2 and 3 detail, Alaska has a rich history of Indigenous homes successfully utilizing energy efficiency features and energy conservation lifestyles. Why reinvent the wheel if we do not have to? Adding information about pre-colonial building styles to the education courses could be very inspiring. It is equally important for designers to educate themselves on the cultural and social preferences of the home's occupants. Some occupants may have a very specific idea of what layout their home should have, and it may not be in line with the round layouts used in pre-contact homes. Energy efficiency is an application that may meet technical requirements. However, if the design contradicts the aesthetic value, social or cultural meaning of the home the benefits may be negated. A balance must be struck.

The appraisal system and lending industry need to be overhauled to be more inclusive of this specialized construction style. Though appraisers are independent, their licensing agency, the American Appraisal Institute has some clout as to what requirements need to be met. For example, as stated

above, mandating a course on energy efficiency would certainly be beneficial for Alaskan appraisers. Furthermore, if appraisers developed a tool for themselves to aid in putting a monetary value on energy efficiency features of a house, without using the conventional method of looking for comparison homes, it may prove to be more useful than if external agencies create the tool for them. A collaboration between the appraisal, real estate, and lending industries seems imperative to raise the value of highly energy-efficient homes in Alaska – thus increasing the profit margin not only for homes on the market but for related industries as well.

The final recommendation is to not underestimate the psychological aspect of adopting new technology. The mindset of adaptation can be very powerful and is linked with the knowledge base or exposure to education about the benefits of energy efficiency. Social acceptability of a home often relates to how it compares to neighboring homes. Does it measure up, or is it a step above or below the others? Humans have an aversion to change, to exploring a concept or a lifestyle we are not accustomed to (Sheth & Stellner, 1979). Especially the early stages of adoption of highly energy-efficient homes fall into this category. Of course, if we are all educated about the urgency of climate change mitigation and adaptation, the choice would not be a difficult one to make. Government policies could significantly help break through the mindset barrier by mandating energy efficiency standards in all new construction and retrofitted homes, or to lead by example and convert all government buildings and government housing to highly energy-efficient standards. This strategy would in turn lower the cost of these homes and increase their market demand, thus breaking through some of the financial barriers currently faced in the market.

6.3 References

- Fiksel, J. (2003). Designing resilient, sustainable systems. *Environmental Science & Technology*, 37(23), 5330-5339. doi:10.1021/es0344819
- Gerlach, S. C., Loring, P. A., Turner, A., & Atkinson, D. E. (2011). Food Systems, Environmental Change, and Community Needs in Rural Alaska. In A. L. L. Hajo Eicken (Ed.), *North by 2020: Perspectives on a Changing North*. Fairbanks, AK: University of Alaska Press.
- International Panel on Climate Change (IPCC). (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge, United Kingdom and New York, NY, USA.

- International Panel on Climate Change (IPCC). (2014). *Summary for Policymakers*. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Retrieved from Cambridge, UK and New York, NY, USA: http://pure.iiasa.ac.at/11125/1/ipcc_wg3_ar5_summary-for-policymakers.pdf
- Keen, D. J. (2008). *Complex Emergencies*. Cambridge, UK: Polity Press.
- Kwok, A. G., & Rajkovich, N. B. (2010). Addressing climate change in comfort standards. *Building and Environment*, 45(1), 18-22. doi:<https://doi.org/10.1016/j.buildenv.2009.02.005>
- Rogers, E. (2003). *Diffusion of Innovations (5th Ed.)*. New York, NY: Free Press.
- Sheth, J. N., & Stellner, W. H. (1979). *Psychology of innovation resistance: The less developed concept (LDC) in diffusion research*: College of Commerce and Business Administration, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL.
- Stefansson, V. (1913). *My Life with the Eskimo*. New York, NY: The Macmillan Company.

Appendices

Appendix A: IRB Approval



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Institutional Review Board

909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

November 6, 2013

To: Philip Loring, PhD
Principal Investigator
From: University of Alaska Fairbanks IRB
Re: [519678-1] Highly Energy Efficient Homes - Social/Cultural Interviews

Thank you for submitting the New Project referenced below. The submission was handled by Exempt Review. The Office of Research Integrity has determined that the proposed research qualifies for exemption from the requirements of 45 CFR 46. This exemption does not waive the researchers' responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

Title:	Highly Energy Efficient Homes - Social/Cultural Interviews
Received:	November 5, 2013
Exemption Category:	2
Effective Date:	November 6, 2013

This action is included on the November 6, 2013 IRB Agenda.

Prior to making substantive changes to the scope of research, research tools, or personnel involved on the project, please contact the Office of Research Integrity to determine whether or not additional review is required. Additional review is not required for small editorial changes to improve the clarity or readability of the research tools or other documents.

Appendix B: Interview Questions

Designer/Builder

1. What do you consider a “highly” energy-efficient house? How would you define it?
2. Tell me about the highly energy-efficient house(s) you built.
 - a. What are the energy-efficient features?
 - b. When was it built?
 - c. Who designed it?
 - d. What was the overall cost?
3. How did the timeframe, cost and skill level compare to other homes you have built?
4. Were you already knowledgeable of highly energy-efficient homes prior to building this one?
5. Did you need any external training, or expertise for the energy efficiency features?
6. Was there a knowledge base or industry knowledge increase directly related to your involvement with this house, that you otherwise would not have gleaned?
7. What was the primary motivation to build this type of house for you?
8. Were there any roadblocks or hurdles in the process? How did you solve them?
9. What role do you see these homes playing in relation to energy security in Alaska?
10. What would you do differently if you were to redo the entire process, if anything?
11. Do you have any recommendations of other people I should speak with?

Homeowner

1. Tell me about your highly energy-efficient house(s).
 - a. What are the energy-efficient features?
 - b. When was it built?
 - c. Who designed it?
 - d. What was the overall cost?
 - e. How does it compare to other homes in the neighborhood/homes you have lived in previously?
 - f. Who was the construction company?
2. Had you seen/read of or heard about other highly energy-efficient homes before you started building/bought/moved into yours? If so, where were they and how did you find out about them?

3. Prior to owning your house, what was your definition of a “highly” energy-efficient house? Did this change after you bought/lived in this house? If yes, what is it now?
4. What role do you see these homes playing in relation to energy security in Alaska?
5. What were your primary motivations to build a highly energy-efficient house?
6. How did you finance your house, did you take up a mortgage or other loan?
 - a. If yes, did you experience any problems with this?
 - b. Is there something about the process/policies you would want improved upon or changed?
7. Was there a knowledge base or industry knowledge increase directly related to your involvement with this house, that you otherwise would not have gleaned?
8. Did you need any external training, or expertise for the energy-efficient features?
9. Were there any roadblocks or hurdles in the process? How did you solve them?
10. Were there any unanticipated
 - a. benefits from building and living in a highly energy-efficient house (aside from a lower heating bill, please include intangible benefits)?
 - b. drawbacks?
11. What would you do differently if you were to redo the entire process, if anything?
12. Do you have any recommendations of other people I should speak with?

Financing/Real Estate Expert

1. What do you consider a “highly” energy-efficient house? How would you define it?
2. Tell me about your experience with highly energy-efficient homes.
3. From the financing/appraising/real estate perspective what is your experience with these types of homes?
 - a. Do you think there are any roadblocks to financing them?
 - b. How does this compare to conventional homes?
 - c. If you could make improvements to the system of financing highly energy-efficient homes, what would they be?
4. Have you heard of and/or used AHFC’s Energy Efficiency for Appraisers tool? Or any other tools to help appraise the value of energy efficiency in homes?
5. What role do you see these homes playing in relation to energy security in Alaska?

6. Has your knowledge of this type of house in Alaska changed or influenced your view on your own home, or a home you'd like to live in, in the future?

7. Do you have any recommendations for other people I should speak with?

Appraisers only

8. How do you calculate the value of energy efficiency features in homes?

Appendix C: Life Cycle Inventory Data

Table C-1: Life Cycle Inventory Data for Highly Energy Efficient House

LCA Case Study: Highly Energy Efficient House					
Process	Amount	Unit	LTS modeling	Notes	Library
Exterior Walls	21.95	kg	Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U		Ecoinvent 3
Exterior Walls	443.36	kg	PVC (suspension polymerisation) E		Industry data 2.0
Exterior Walls	14.55	kg	HDPE resin E		Industry data 2.0
Exterior Walls	756.64	kg	Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Exterior Walls	850.9	kg	Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Exterior Walls	317.79	kg	plywood, vacuum pressure treated, inorganic salt, outdoor use - ecoinvent3 alloc rec u	Custom modeling: 1kg - Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass, 0.0074257kg - Wood preservation, vaccum pressure method, inorganic salt, containing Cr, outdoor use, ground contact {RoW} wood preservation, vacuum pressure	Ecoinvent 3

Table C-1 continued

				method, inorganic salt, containing Cr, outdoor use, ground contact Alloc Rec, U	
Exterior Walls	2683.12	kg	Sawnwood, softwood, kiln dried, planed {RoW}, vacuum pressure treated, inorganic salt, outdoor use - ecoinvent3 alloc rec u	Custom modeling: 1kg - Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass, 0.0074257kg - Wood preservation, vacuum pressure method, organic salts, Cr-free, outdoor use, ground contact {RER} wood preservation, vacuum pressure method, organic salt, Cr-free, outdoor use, ground contact Alloc Rec, U	Ecoinvent 3
Exterior Walls	0.78	kg	oriented polypropylene film E, with acrylic binder, without water {RoW} - ecoinvent3 alloc rec	Custom modeling: 0.75kg - Oriented polypropylene film E, 0.25kg - Acrylic binder, without water, in 34% solution state {GLO} market for Alloc Rec, U	Ecoinvent 3
Exterior Walls	147.87	kg	Steel, low-alloyed, hot rolled, enamelling Alloc, Rec, U	Custom modeling: 1kg - Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U, 0.26169859m2 - Enamelling {RoW} processing Alloc Rec, U	Ecoinvent 3
Foundation	16200	kg	Gravel, round {GLO} market for Alloc Rec, U - waste type cement	Custom modeling: waste type 'cement'	Ecoinvent 3
Foundation	5.35	kg	Concrete, sole plate and foundation {GLO} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Foundation	119.82	kg	Reinforcing steel {GLO} market for Alloc Rec, U		Ecoinvent 3

Table C-1 continued

Foundation	75.45	kg	Bitumen adhesive compound, cold {GLO} market for Alloc Rec, U - waste type PP	Custom modeling: waste type 'PP'	Ecoinvent 3
Insulation	198.18	kg	Glass wool mat {GLO} market for Alloc Rec, U		Ecoinvent 3
Insulation	6363.64	kg	Cellulose fibre, inclusive blowing in {GLO} market for Alloc Rec, U - waste type insulation	Custom modeling: waste type 'insulation'	Ecoinvent 3
Insulation	161.45	kg	Expandable polystyrene (EPS)		Industry data 2.0
Interior Ceiling	131.82	kg	Glued laminated timber, for indoor use {GLO} market for Alloc Rec, U - mass unit	Custom modeling: converted unit to mass	Ecoinvent 3
Interior Ceiling	168.41	kg	Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Interior Ceiling	320	kg	Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Interior Walls	776.51	kg	Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Interior Walls	531.14	kg	Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3

Table C-1 continued

Nails and Sinkers	68.19	kg	Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U		Ecoinvent 3
Roof	316.36	kg	Glued laminated timber, for indoor use {GLO} market for Alloc Rec, U - mass unit	Custom modeling: converted unit to mass	Ecoinvent 3
Roof	1274.01	kg	Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Roof	884.36	kg	Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Roof	75.45	kg	Bitumen adhesive compound, cold {GLO} market for Alloc Rec, U - waste type PP	Custom modeling: waste type 'PP'	Ecoinvent 3
Roof	11.9	kg	Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U		Ecoinvent 3
Roof	559.83	kg	Steel, low-alloyed, enamelling {GLO} - ecoinvent3 alloc rec U	Custom modeling: 1kg - Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U, 0.22558936m2 - Enamelling {GLO} market for Alloc Rec, U	Ecoinvent 3
Roof	72.73	kg	Glass fibre, bitumen seal, polymer EP4 flame retardant, production {RoW} - ecoinvent3 alloc rec U	Custom modeling: 0.55kg - Bitumen seal, polymer EP4 flame retardant {GLO} market for Alloc Rec, U, 0.45kg - Glass fibre {GLO} market for Alloc Rec, U	Ecoinvent 3
Window and Door Boxes	359.27	kg	Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3

Table C-2: Life Cycle Inventory Data for Theoretical Counterpart House

LCA Case Study: Theoretical Counterpart House					
Sub-assembly	Amount	Unit	Process Modeling	Notes	Library
Exterior Walls	2265.4	kg	Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Exterior Walls	645.9	kg	Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Exterior Walls	272.4	kg	plywood, vacuum pressure treated, inorganic salt, outdoor use - ecoinvent3 alloc rec u	Custom modeling: 1kg - Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass, 0.0074257kg - Wood preservation, vacuum pressure method, inorganic salt, containing Cr, outdoor use, ground contact {RoW} wood preservation, vacuum pressure method, inorganic salt, containing Cr, outdoor use, ground contact Alloc Rec, U	Ecoinvent 3
Exterior Walls	492.7	kg	Sawnwood, softwood, kiln dried, planed {RoW}, vacuum pressure treated, inorganic salt, outdoor use - ecoinvent3 alloc rec u	Custom modeling: 1kg - Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass, 0.0074257kg - Wood preservation, vacuum pressure method, organic salts, Cr-free, outdoor use, ground contact	Ecoinvent 3

Table C-2 continued

				{RER} wood preservation, vacuum pressure method, organic salt, Cr-free, outdoor use, ground contact Alloc Rec, U	
Exterior Walls	12.4	kg	HDPE resin E		Industry data 2.0
Exterior Walls	0.6	kg	oriented polypropylene film E, with acrylic binder, without water {RoW} - ecoinvent3 alloc rec	Custom modeling: 0.75kg - Oriented polypropylene film E, 0.25kg - Acrylic binder, without water, in 34% solution state {GLO} market for Alloc Rec, U	Ecoinvent 3
Exterior Walls	17.6	kg	Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U		Ecoinvent 3
Exterior Walls	369.5	kg	PVC (suspension polymerisation) E		Industry data 2.0
Exterior Walls	123.2	kg	Steel, low-alloyed, enamelling {GLO} - eocinvent3 alloc rec U	Custom modeling: 1kg - Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U, 0.22558936m2 - Enamelling {GLO} market for Alloc Rec, U	Ecoinvent 3
Foundation	12150	kg	Gravel, round {GLO} market for Alloc Rec, U - waste type cement	Custom modeling: waste type 'cement'	Ecoinvent 3
Foundation	2.4	kg	Concrete, sole plate and foundation {GLO} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3

Table C-2 continued

Foundation	76.2	kg	Reinforcing steel {GLO} market for Alloc Rec, U		Ecoinvent 3
Foundation	66	kg	Bitumen adhesive compound, cold {GLO} market for Alloc Rec, U - waste type PP	Custom modeling: waste type 'PP'	Ecoinvent 3
Insulation	312.3	kg	Glass wool mat {GLO} market for Alloc Rec, U		Ecoinvent 3
Insulation	131.8	kg	Expandable polystyrene (EPS) E		Industry data 2.0
Nails	34.1	kg	Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U		Ecoinvent 3
Roof	225.0340909	kg	Glued laminated timber, for indoor use {GLO} market for Alloc Rec, U - mass unit	Custom modeling: converted unit to mass	Ecoinvent 3
Roof	1119.9	kg	Sawnwood, softwood, kiln dried, planed {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Roof	690.9	kg	Plywood, for outdoor use {RoW} market for Alloc Rec, U - in mass	Custom modeling: converted unit to mass	Ecoinvent 3
Roof	290.9	kg	Glass fibre, bitumen seal, polymer EP4 flame retardant, production {RoW} - ecoinvent3 alloc rec U	Custom modeling: 0.55kg - Bitumen seal, polymer EP4 flame retardant {GLO} market for Alloc Rec, U, 0.45kg - Glass fibre {GLO} market for Alloc Rec, U	Ecoinvent 3

Table C-2 continued

Roof	226.4	kg	Bitumen adhesive compound, cold {GLO} market for Alloc Rec, U - waste type PP	Custom modeling: waste type 'PP'	Ecoinvent 3
Roof	9.7	kg	Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U		Ecoinvent 3
Roof	447.1	kg	Steel, low-alloyed, enamelling {GLO} - ecoinvent3 alloc rec U	Custom modeling: 1kg - Steel, low-alloyed, hot rolled {GLO} market for Alloc Rec, U, 0.22558936kg - Enamelling {GLO} market for Alloc Rec, U	Ecoinvent 3

Appendix D: Case Study: Affordability of A Highly Energy-Efficient House in Rural Alaska

There are multiple factors that come into play when considering financial affordability of highly energy-efficient homes. In the traditional housing market, the affordability of a home is based on the qualifying mortgage (Smith & Jones, 2003), which is in turn determined in large part by the appraised value of the home. Operating costs are typically not included, such as maintenance, repair, or utility costs. These costs should, however, be included to give a more complete picture of the life-cycle cost of homeownership (Rettig & Maddan, 2016). In this section, we focus on the home energy requirement for heating in Alaska as the primary home operating costs.

Accounting for the cost of heating fuel when purchasing a home is difficult to calculate, due to oil price fluctuations. For example, in 2008 the price of oil was \$140 per barrel. Because of this high price, many residents in Alaska took advantage of a state program to weatherize their home, which increased the home's energy efficiency (Rettig & Maddan, 2016). However, by 2016 the price sunk to \$50 per barrel and enrollment in the program dropped significantly. However, when considering the viability of highly energy-efficient homes, stability and security cannot be underestimated (Hossain et al., 2016; Rettig & Maddan, 2016). Having a home that has minimal heating fuel requirements, means the utility costs for the homeowner will be relatively stable even if oil prices increase drastically at a future point in time. Stability in energy use and supply is a major factor in energy security considerations.

As an illustrative example of affordability and calculating long-term payback points, I use a case study home in Dillingham Alaska. Dillingham is a hub community in rural Western Alaska, accessible by water and air only. The National Climatic Data Center averaged Dillingham to have 11,210 heating degree days over a 30-year timespan from 1981 to 2010 (Alaska Climate Research Center, 2017). The case study home was designed and built by the homeowners themselves in 2010. One of their motivations to build their home was to showcase a prototype of a highly energy-efficient, affordable home in rural Alaska. It is a 2-bedroom home, 590sqf, with 28" thick walls in a double wall system filled with blown-in cellulose. The house is largely based on the Passive House standard and is considered net zero energy ready. In 2010 when the homeowners completed construction and took up residence heating fuel in Dillingham cost \$4.41/gallon (DCCED, 2010). The cost rose to \$5.97/gallon in 2014 (DCCED, 2014), and within two years it sunk to \$2.54/gallon by 2016 (DCCED, 2016). Illustrating the reality of fluctuating oil prices. The homeowners built their home with the goal in mind for it to last at a minimum 100 years.

The home requires minimal heating in the winter, as the thermal insulation and air tightness retains heat from electrical appliances and body heat to such a degree that it makes up 62% of the annual heating demand. Fourteen percent of the heating demand is attributed to solar gain and 24% comes from an electric air-source heat pump. Annual electricity demand of the case study house is 3,200 kWh, for an average house in Dillingham it would be 5,930 kWh. Average heating fuel usage for a house in Dillingham is 700 gallons a year, and the case study home uses zero, since it is heated minimally with the air-source heat pump. In 2017, the electricity rate was \$0.24/kWh plus account charges (Nugashak Cooperative, 2017) and as indicated above heating fuel costs \$2.54/gallon. The difference for electricity and heating costs when comparing the average house in Dillingham to the case study house at the 2017 rates would be \$2,433, as the case study house requires only \$768 annually for heating and electricity in this scenario.

Considering the material costs to build the highly energy-efficient house, not including the labor since the homeowners built the house largely themselves, aids in calculating a simple payback point. We created a model of a conventional counterpart home that has the same specifications except built to the Department of Energy's minimum R-standards. We converted the case study home's heating requirements to heating fuel if the house had an efficient oil boiler, burning roughly 35 gallons per year. In this scenario, the conventional counterpart home would burn 161 gallons per year. See table 1 for simple payback calculations, using the fuel oil price from 2010, 2014 and 2016.

Table D-1: Simple Payback Point - Highly Energy-Efficient Home in Dillingham, AK

	Building Materials	Heating fuel – 2010 price (\$4.41/gallon)	Heating fuel -2014 price (\$5.97/gallon)	Heating fuel – 2016 price (\$2.54/gallon)
Highly Energy-efficient home (35 gallons/yr heating fuel requirement)	\$37,690	\$154.35	\$208.95	\$88.90
Conventional Home counterpoint (161 gallons/yr heating fuel requirement)	\$19,390	\$710.01	\$961.17	\$408.94
Cost Differential	\$18,300	-\$555.66	-\$752.22	-\$320.04
Simple Payback Point		32.9 years	24.3 years	57.2 years

When comparing the highly energy-efficient home to its theoretical counterpart we can determine the rough payback period for the extra building materials that are required to upgrade a home to be highly energy-efficient. The difference in material costs in this case is \$18,300. Depending on the price of oil, the difference in material cost is paid off in heating oil savings anywhere from 24 to 57 years – based on the heating oil price fluctuations over a recent timespan of 6 years. This is a relatively big difference in payback time. If homeowners purchase a house and plan to live in it until retirement, they may be satisfied with the projection of a payback time of 24 years. However, if the price of oil changes and now the payback point isn't reached until 57 years into the future that may present less motivation to invest the additional upfront cost in the extra building materials. This uncertainty from an economic perspective is a deterrent to the uptake of this climate change mitigation technology.

References

Alaska Climate Research Center (2017). "Climate Normal." Retrieved February 9, from <http://akclimate.org/Climate/Normals>

- Department of Commerce, Community, and Economic Development (DCCED). (2010). Current Community Conditions: Fuel Prices Across Alaska, Department of Commerce, Community, and Economic Development; Division of Community and Regional Affairs.
- Department of Commerce, Community, and Economic Development (DCCED). (2014). Alaska Fuel Price Report: Current Community Conditions, Department of Commerce, Community, and Economic Development; Division of Community and Regional Affairs.
- Department of Commerce, Community, and Economic Development (DCCED). (2016). Alaska Fuel Price Report: Current Community Conditions, State of Alaska, Department of Commerce, Community, and Economic Development; Division of Community and Regional Affairs.
- Hossain, Y., Loring, P. A., & Marsik, T. (2016). Defining energy security in the rural North—Historical and contemporary perspectives from Alaska. *Energy Research & Social Science*, 16, 89-97.
doi:<http://dx.doi.org/10.1016/j.erss.2016.03.014>
- Nugashak Cooperative (2017). "Electric - Rates." Retrieved February 9th, from <http://www.nushtel.com/electric-rates.htm>.
- Rettig, M., & Maddan, D. (2016). Is Cheap Energy the Enemy of Efficiency? *Alaska Business Monthly*, 58-59.
- Smith, M. T., & Jones, P. (2003). The impact of energy efficient house construction on homeownership costs: a comparative study in Gainesville, Florida. *Family and Consumer Sciences Research Journal*, 32(1), 76-98. doi:10.1177/1077727X03255947