IMPROVING THE EFFICIENCY OF RESIDENTIAL BUILDINGS IN RURAL ALASKA: AN ANALYSIS OF EXISTING INFRASTRUCTURE AND ITS IMPORTANCE IN CREATING ENERGY-EFFICIENT HOMES

By

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ABSTRACT

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Rural communities in Alaska, many of which have a high Alaska Native population, currently face significant housing challenges. In a climate that can become extremely cold, houses are generally lacking in energy efficiency. To date, there has been limited studies of rural Alaskan communities' housing, to better understand and quantify such housing challenges.

This research focuses on a detailed study of the rural Alaskan community of Unalakleet. Through collaboration with the housing authority, 27 energy assessments and 22 interviewswere conducted in the community. Blower door tests suggest that homes are usually small and tight, with leakiness around areas like the windows, where mold frequently was observed. Short-term indoor air quality monitoring suggests that some homes, especially those less than 46 m^2, had high CO_2 concentrations, relative to others.

The overall purpose of this research is to quantify the typical housing characteristics present in rural Alaskan communities, as well as to provide results that support opportunities for new, more efficient housing. The introduction discusses major housing challenges. Physical characteristics of assessed homes, followed by indoor air quality and air flow, are discussed in Chapters 2 and 3, respectively. Chapter 4 uses data collected from the assessments to create a building energy model, the results of which show where the largest improvements in efficiency can be made. The conclusion provides a brief overview of research contribution, limitations, and future work.

This thesis is dedicated to the wonderful people I met in Unalakleet, who helped me find my passion.

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PREFACE

The **Introduction Chapter** discusses the *purpose* behind this thesis, gives background to the housing challenges discussed in rural northern communities, and introduces the community of study, Unalakleet (pages 1-13).

Chapter 2 explains the *physical* characteristics of residential buildings in Unalakleet, as found in 27 assessments throughout the community. Examples of topics include foundation types, exterior siding, and common HVAC systems (pages 14-26).

Chapter 3 details the *indoor air quality and air exchange rates* of residential buildings in Unalakleet, as found in 27 assessments throughout the community. Examples of topics include air exchange rate values , mold, and CO_2 readings (pages 28-42).

Chapter 4 inputs assessment data into a *building energy model*, comparing outputs of total energy usage, utility costs, and CO_2-equivalent emissions of an existing, 'typical' home in Unalakleet with a hypothetical retrofitted home and new construction model (pages 43-71).

The **Conclusion Chapter** summarizes the work done in this thesis and the contribution it has made to the field of energy efficiency. Limitations of the research and potential for future work are also discussed (pages 73-75).

The **Appendices** contain a detailed data analysis of *physical* **(A)** and *interview* **(B)** data, by percentage of feature/response (pages 77-94).

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CHAPTER 1: INTRODUCTION

Purpose and Overview of This Thesis

Hidden inside an area of the world known for its beauty is a challenge that has been ongoing for centuries. Alaska and Northern Canada are full of nature and wonder, ranging from mountains and glaciers to oceans, volcanoes, and the Northern Lights. Many people visit those areas to experience the phenomena unique to the far North. But within the mountains, tundra, coastal areas, forests, and ice live people who have called the far North home before anyone else. Indigenous communities across Canada and Alaska have lived with the land far before western influence. Their dwellings were made from sod and other earthen materials, sometimes built underground [17]. While occupants did face some challenges, such as small spaces and risk of smoke inhalation from cooking, these dwellings worked to fit the lifestyle and culture of the many Indigenous groups of the North.

After Western culture began influencing parts of the far North, the nomadic life of many Indigenous groups became more stagnant, and communities appeared. In Alaska, the U.S. government required children to attend school, resulting in small, remote, and rural communities of Alaska Native people. Both Alaska and Northern Canada saw the architectural influences of Western culture. Homes were modeled after buildings built primarily farther south, and being in a cold, northern region, these homes did not fare well against the climate [17].

So, the central challenge explained in this paper is the lack of efficient, comfortable, safe, and healthy homes in some of the most beautiful, northern regions of the world. This affects primarily Indigenous communities in Alaska and Northern Canada, though other cultures or northern areas of the world may see similar challenges. Inefficient housing is also the basis for other challenges. Many communities also pay high energy costs for diesel-powered electricity and heating fuel due to being completely served by a community microgrid. Shipping of these fuels along with building materials add to higher costs for usage and construction, and many areas are seeing a lack of new housing due in part to these high material costs [18].

This thesis will first introduce the housing challenges present in the North. Note that rural northern Canadian communities face similar challenges to rural communities in Alaska. However, rural Alaska will be the primary focus of this thesis since on-site research took place in a rural Alaskan community, Unalakleet. Next, Chapters 2 and 3 will discuss the physical characteristics of residential buildings in Unalakleet and the indoor air quality characteristics, respectively. Data from both the energy assessments and the interviews that took place in Unalakleet was averaged, sorted, and compiled into summaries that are found in the Appendix. The physical data is summarized in Appendix A, and the interview data is summarized in Appendix B. These summaries have been used in grant applications submitted by the Native Village of Unalakleet (NVU) to various funding organizations to provide evidence that Unalakleet could benefit from new housing. Averaged data from these summaries are used in Chapter 4 as inputs into BEopt, a building energy modeling software that is used to compare efficiency of existing housing to proposed new, more efficient housing [47]. The conclusion to this thesis follows as Chapter 5, which provides a summary of the research, limitations, and possible future work.

Objectives of This Thesis

The primary objective of this thesis is to characterize and provide evidence of physical housing challenges in rural Alaska to know where improvements in building energy efficiency are most needed. Currently, there is very limited research on this subject in published work. While state- and region-wide surveys of housing exist, these provide an overview of the challenges seen in rural communities across Alaska [50]. This thesis focuses on data from individual houses and interviews, providing more specific and personal evidence of housing challenges in a rural Alaskan community. The state- and region-wide surveys, however, are a crucial component of this analysis in understanding how *widespread* the housing challenges across rural Alaska are [50]. This thesis strives to provide detailed evidence for those housing challenges by focusing on the research questions below:

Q1: What are the challenges seen by rural Alaskan communities, and how do they relate to inefficient housing? Examples include:

- High energy bills
- Poor indoor air quality
- Increasing effects of climate change on communities and homes

Q2: What are the typical physical characteristics of houses in rural Alaska? What does a prototypical home look like? Examples include:

- Roofing, siding, foundation types
- Common areas of damage
- Size and occupancy of homes

Q3: What are the indoor air quality challenges present in rural Alaskan homes? Examples include:

- Tightness of homes
- Lack of mechanical ventilation
- Natural ventilation habits
- Occupant perceptions on indoor air quality

Q4: How can this evidence be used to create a building energy model that will assess opportunities to increase energy efficiency in rural Alaskan housing? This is addressed by:

- Identifying the greatest areas for improvement in new and retrofitted construction
- Exploring efficiency of a typical home in Unalakleet based on assessment data

Q5: What are homeowner perceptions of housing and energy concerns in their home and community? This addressed by:

- Summarizing data from interviews based on percent prevalence of responses
- Making homeowner and occupant opinions, thoughts, and lifestyles a top priority in this research and beyond

A Brief History of Residential Infrastructure in Rural Alaska

Historically, Indigenous Northern communities have been self-reliant and mobile, migrating with their food. For example, the Iñupiat tribes inhabiting the northern coasts of Alaska and Canada built movable homes in the summer and sod dwellings in the winter. The sod homes were dug into sand dunes, hills, or embankments and were insulated by the land and animal hides. They contained entrance tunnels to prevent cold drafts from entering the living area, and the tunnels also served as refrigerators for storing food. Before using oil or burning wood, the inside of the home stayed about 60 degrees warmer than the outside temperature. Sea mammal oil lamps and body heat from the multiple inhabitants further heated the home [18]. Figure 1.1 below shows the structure of a traditional subterranean sod dwelling from Point Barrow on Alaska's north coast.

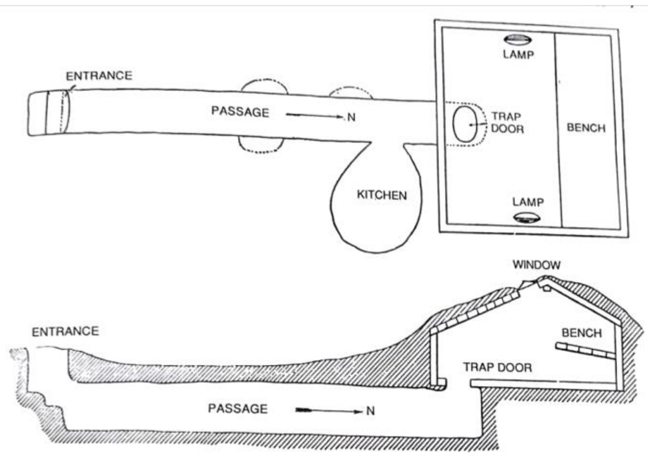

Figure 1.1: Plan and section of an early dwelling found in Point Barrow [17]

A change in subsistence hunting patterns as animals moved and settled in different areas brought changes in Native settlements along with the introduction of Western culture. Small villages began to develop around trading posts, and more permanent structures appeared [17]. When the United States bought Alaska in the 1800’s, the federal government required children to attend schools [18]. This further pushed once-mobile communities to form stationary ones. Subsistence activities became harder as communities did not move with their food, and the homes built by the government were not as well-insulated as traditional sod homes. More heating oil was used to warm the homes, increasing energy usage [18]. Many of the housing challenges seen in rural Alaskan communities today have been present for centuries, especially challenges in energy efficiency and high energy usage and costs [17].

Northern Housing Challenges Explored in This Research

Current Energy Habits of Rural Northern Communities

Diesel is the main source of power generation for the microgrid in Unalakleet as well as for many rural Northern communities across Alaska and Canada. Annually, rural Alaska consumes about 3,785 liters (1,000 gallons) of diesel per person [18]. To many residents of rural Alaskan communities, including Unalakleet, the cost of energy is what is driving them to consider renewable and alternative sources of energy [33]. Currently, the cost of electricity for rural Alaskan communities is very high, as many use mostly diesel to generate power. This requires transportation of the fuel to the remote community, driving up its cost [1]. Some rural communities in Alaska have paid up to $1 per kilowatt-hour for their electricity before the installation or supplementation of renewable energy. One example of such is the installation of wind turbines in Unalakleet, which supplement the community's diesel-run microgrid [33].

The residential rate of electricity in the community of study, Unalakleet, was $0.42 per kilowatt-hour (kWh) in 2015. This full residential rate is 89% higher than the average residential cost of electricity across Alaska. This rate was 216% higher than the average residential cost of electricity across the United States was in November 2020 [1] [31] [42]. Figure 1.2 below illustrates this difference. To aid in energy expenses, Unalakleet has been enrolled in a state subsidy called the Power Cost Equalization (PCE) program. This program provides enough monetary disbursement to the community to bring the cost of electricity down to about $0.22 per kWh [31]. However, as new programs become available for funding in Alaska, the PCE is at risk of defunding, as stated by residents in the community during research interviews in summer 2021. Many community members were interested in the possibility of more renewable energy, such as using solar panels on roofs, to reduce cost of electricity especially if the PCE loses funding.

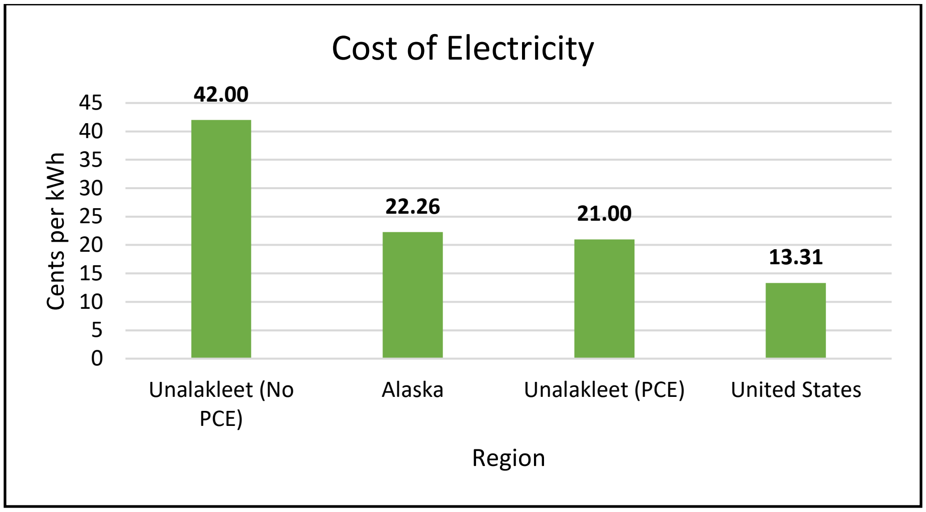

Figure 1.2: Average residential cost of electricity by kWh [1] [42]. Note: PCE = Power Cost Equalization program

Use of diesel fuel also poses environmental risk of harmful atmospheric emissions. Maintenance of power utilities in rural communities is difficult and costly because of the extreme weather and isolation. These utilities are generally outdated and require updating before the incorporation of cleaner renewable energy sources [4]. In addition, some diesel storage tanks leak oil into the environment, damaging ecosystems [18]. As a result of outdated utilities, power outages and energy losses also occur. Some communities have been without power for months after emergency fuel could not be delivered in time due to impossible travel or elevated costs after a storm [18].

This thesis focuses on housing infrastructure challenges present in rural Alaska. Energy costs and usage were not studied as extensively but were asked about in the interviews done in Unalakleet. A summary of the data collected in interviews is found in Appendix B, and energy usage and costs are discussed therein. However, energy usage in rural Alaskan communities is introduced here because efficient homes may relieve some of the energy burden put on many households. Building efficient homes is key to introducing renewable energy sources that may further alleviate energy burden, as these homes will use their inputted energy more effectively than an inefficient home does.

Existing Infrastructure

After the US government mandated Alaska Native children to attend school, small communities were constructed around the school building. Homes were built following the post-World War II cookie-cutter housing system. Builders believed this type of neighborhood building would help Indigenous people assimilate into Western culture [18]. These houses were built following federal standards and did not adhere to local construction standards; the houses were not suitable for the harsh Alaska climate. The homes frequently had inadequate insulation and inefficient fuel-oil appliances. Building supplies and oil needed to be imported, adding more cost to the community and its construction. Homes became overcrowded due to housing shortages and ventilation was inadequate, leading to mold growth [18]. Asthma and other upper respiratory problems were and still are common in rural Alaskan communities [29].

Today, problems stemming from inadequate infrastructure have remained prevalent. In 2005, over 21% of houses in the state of Alaska were unable to maintain a comfortable indoor temperature of 21°C (69.8°F) [18]. This was primarily due to poor maintenance of homes and inadequate construction that failed to suit the climate. Furthermore, out of the 21% of houses that struggle with keeping a comfortable indoor temperature, 45% of them had household incomes of $30,000 or less and may have been unable to afford an adequate amount of fuel oil [18].

Alaska’s 2014 housing assessment also revealed that homes in multiple regions are at risk of moisture problems. Many of these homes were found to have low air exchange rates but were lacking mechanical ventilation, resulting in stale indoor air and moisture infiltration [50].

Further affecting existing residential infrastructure is a changing, warming climate. Between 1949 and 2005, average annual temperatures across Alaska have increased by almost 2.2°C (4°F) [20]. If current worldwide fossil fuel habits persist, the west and north sides of Alaska are projected to have temperature increases of up to 5.3°C (9.5°F) from 2070 to 2099. With a warming climate comes challenges that directly impact infrastructure, from coastal erosion and permafrost thaw to stronger, more frequent storms. A decrease in precipitation between 1941 and 2020 has contributed to permafrost thaw since snow acts as an insulator to help protect permafrost from melting [20]. Permafrost thaw is not a threat to all infrastructure in Alaska, as not all infrastructure is built on permafrost. However, it is a threat in some places, especially where permafrost is continuous such as in the Alaskan Arctic. Thawing permafrost threatens degradation of infrastructure, especially through foundation damage [20]. Coastal communities such as Unalakleet on the Bering Sea and Unalakleet River are more threatened by erosion and storm surges, which could cause buildings and homes to break down or flood [20]. Flooding of homes closest to the ocean has taken place in Unalakleet, as told by participants in research interviews. One even lost their home in the middle of the night, having to move more inland and away from the Bering Sea's shore.

Importance of Efficient Homes

A 100% energy efficient home is one that uses as much energy as it is given, loosing none through areas such as leaks in the walls, windows, or appliances [44]. Homes that have areas in the exterior and interior wall assembly, or building envelope, which may unintentionally allow air to come in from outside are also allowing energy to escape. More energy must then be used for the home to maintain a sufficient temperature in the winter, for example.

For perspective on how important retaining heat is in a place like Unalakleet, observe the amount of heating degree days (HDD) for the region. Heating degree days express how many degrees the average outside temperature each day is below 65°F (18.3°C) in the United States. These degrees add up cumulatively for each day annually the temperature is below 65°F, giving a region's total HDD count [23]. For example, if the outside temperature for the day is a high of 20°F (-6.7°C) and a low of 4°F (-15.6°C), the average between the two is 12°F (-11.2°C). Twelve degrees Fahrenheit is 53 degrees below 65°F, giving that day 53 HDDs. Over the year, the number of days and their average temperature's difference from 65°F give the total amount of heating degree days, the days heating in homes is expected to occur. The state of New York averages 5,000 HDD, while the Bering Strait Region, where Unalakleet is present in Alaska, averages 14,000 HDD [23] [1]. Maintaining a warm home is a particularly important part of living in Alaska, for most of the year.

A decrease in energy use, leading to a decrease in costs, is not the only incentive for more efficient homes in rural Alaska. An efficient home somewhere as cold as Alaska will benefit from having a tight envelope, or a wall system that holds in heat and does not allow for cold drafts to enter the home. Strong insulation is an important factor in maintaining warmth, but a tight home comes with challenges. Without ventilation, indoor air quality could become poor and put occupants at risk of developing health problems. The home could also be at risk of mold growth resulting from indoor activity or air infiltration from small leaks in the envelope. A home that is continuously ventilated will provide fresh air to the occupants while maintaining a tight envelope [50]. A challenge with providing mechanical ventilation systems is the high costs of electricity in rural communities, further pushing for more efficient homes and less energy usage per home [1].

Introduction to Unalakleet

Unalakleet is a remote and rural community on the coast of the Bering Sea in the Norton Sound of western Alaska. The community is primarily built on sandy soil near the sea, with a few newer homes being built on the hill overlooking the coastal community. Unalakleet is in climate zone 8 as part of the Nome Census Area, which is a sub-arctic climate [5]. The winters are long and cold, and the summers are short and mildly warm. Sea ice keeps the western Alaska region from experiencing a maritime climate, resulting in a very cold winter [20]. Unalakleet is surrounded by the Bering Sea to the west and the Unalakleet River to the east, interspersed with areas of tundra and hills. Figure 1.3 below shows Unalakleet's location in Alaska and a topographic map displaying the river system [45] [46].

Figure 1.3: Unalakleet's location in Alaska (blue pin) (left) and Unalakleet's location along the Bering Sea and Unalakleet River (right) [45] [46]

History

Evidence of settlement in Unalakleet has been dated by archaeologists to be as far back as 200 B.C. The community was a popular trading post along the Kaltag Portage, where traders would stop on their way to the Yukon River. In the 1830's, a Russian-American trading company built a post at Unalakleet, continuing to trade. A few decades later, reindeer-herding practices were established after herders from Lapland, Finland were brought to the community. Finally, in 1974, the city of Unalakleet was incorporated, resulting in diverse cultures from the trade and activity of the previous decades [31].

Culture and Economy

According to research interviews with Unalakleet residents, the local economy is heavily subsistence-based, following the traditional Native Alaskan culture and subsistence lifestyle. Many residents hunt and gather their food, especially during the summer. Since Unalakleet is not accessible except by plane or boat (in the warmer seasons), subsistence becomes even more important to gather food, where local travel is mostly done using ATVs, snow machines, walking, or a car if owned [31]. Groceries are expensive as they must be barged or flown in. The local economy is the most active in the Norton Sound area. Commercial fishing takes place in the summer, and some residents have mentioned they leave the community to work on the Unalakleet River for the fishing industry. Others leave to fish and hunt to prepare food for the winter. The local economy also includes city infrastructure, such as utilities, a school, the Native Corporation, the Tribal Council, the city offices and public safety, a health clinic, a commercial fishing plant, two restaurants, two grocery stores, churches, an active airport, small hotels, and a post office.

The median household income in Unalakleet in 2020 was $70,000. About 80 people (10.5% of the population) live below the poverty line, and 110 people (14.4% of the population) live below 125% of the poverty line, meaning they make an income that is less than 125% of the income required to be considered living in poverty [9]. In 2020, the poverty rate across the U.S. was

11.4%, and the poverty rate across Alaska was 9.6%, reported by the U.S. Census [39]. Unalakleet has a poverty percentage less than the U.S. average overall but higher than the average across Alaska.

Demographics

The community has a population of approximately 765 people as of the year 2020 [31]. Much of the community identifies as American Indian or Alaska Native (AI/AN) (60.7%). The community is evenly split by biological sex, and age ranges are diverse [31]. Figure 1.4 below show race, biological sex, and age demographics in Unalakleet.

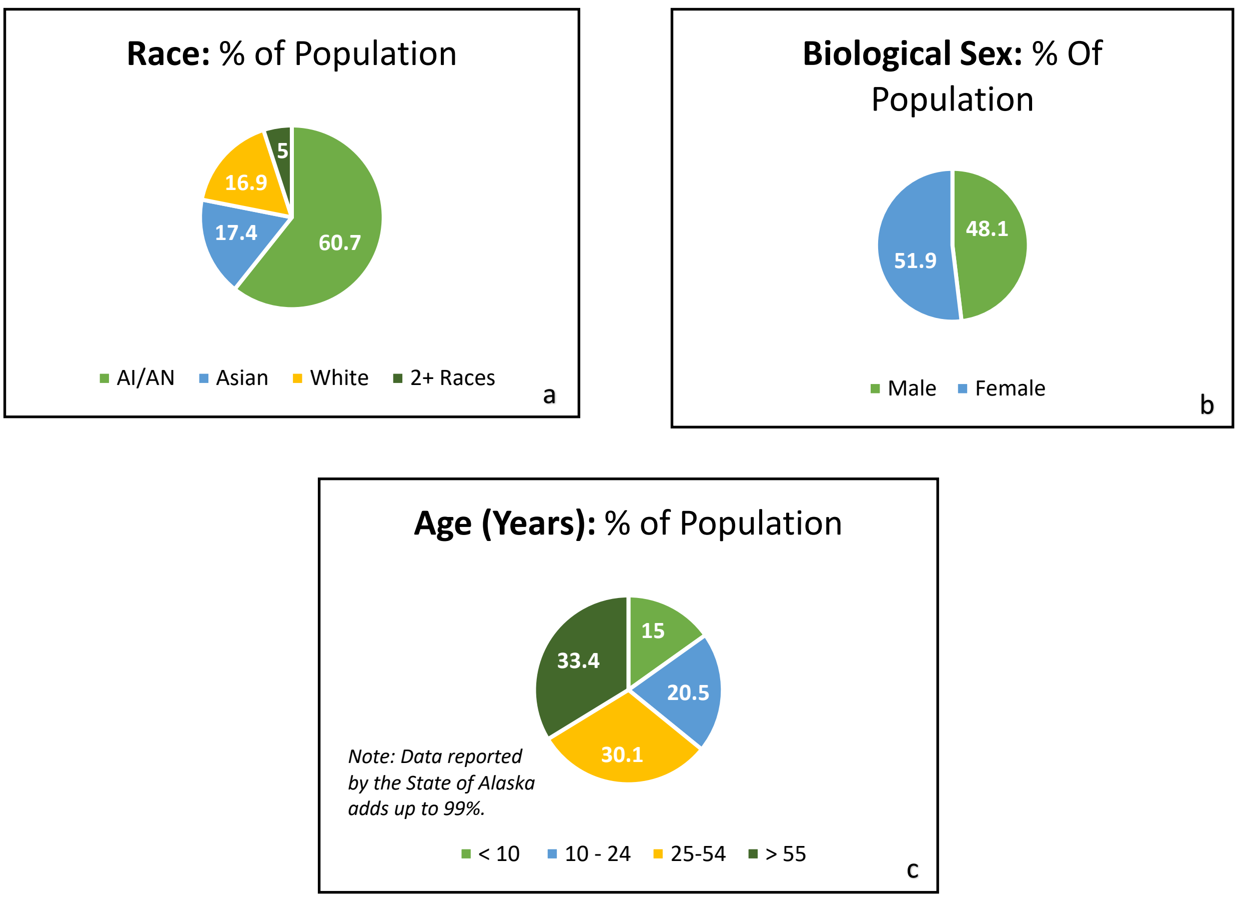

Figure 1.4: Race (a), biological sex (b), and age (c) distribution in Unalakleet [31]

CHAPTER 2: ADDRESSING THE HOUSING INFRASTRUCTURE CHALLENGES OF RURAL ALASKA IN A CHANGING CLIMATE: PHYSICAL CHARACTERISTICS OF RESIDENTIAL INFRASTRUCTURE

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Abstract

Rural Alaskan communities are presented with housing challenges unique from other areas in the United States. Many communities have limited access to the resources needed to build new housing or retrofit existing housing to improve living conditions and performance. As a result, many houses are highly inefficient, leaky, and improperly ventilated, contributing to high electricity and fuel costs. The progression of climate change has significantly impacted housing performance. Melting permafrost creates unstable foundation conditions that causes cracking, thus impacting the building envelope. Similarly, erosion and other climate change-induced challenges have caused many coastal communities to consider the building of new infrastructure on higher and more stable ground, or the retrofitting of existing structures to better perform under the new and more variable conditions.

As communities consider relocation of some or all their infrastructure, building energy-efficient homes and retrofitting existing ones is vital to the comfort, health, and sustainability of each community. To provide appropriate new and retrofitted housing, understanding the unique challenges faced by the North is vital. This paper introduces the challenges faced in rural Alaskan communities regarding climate change, inefficient housing and utility infrastructure, cost of electricity and fuel, and remoteness. It then focuses on an assessment of the housing characteristics of rural Alaskan communities in collaboration with Unalakleet, Alaska.

Information on building characteristics across the surveyed homes is compared to "typical" housing stock characteristics throughout the U.S. The results of this work will be used as inputs into the development of typical building energy models for the region, which will help to assess potential for energy efficiency improvements to residential buildings under current and future climate scenarios.

Introduction

Rural Alaskan communities face many unique challenges. In addition to ongoing climate changes, the infrastructure is many times inadequate for the harsh climate. Much of the housing built in rural Alaska was constructed in the post-World War II era, mimicking the housing construction more commonly found in the contiguous United States. This construction style was not adjusted to fit Alaska's climate or the needs and lifestyle of the Indigenous people who now inhabit a substantial portion of these homes. Such housing likely contains inadequate insulation and imported building materials that are not easily replaceable with local materials. Many homes also lack adequate ventilation. Today, numerous homes in rural Alaska face the same housing challenges as when the homes were first built historically [18]. In addition, due to the remoteness of such communities, the ability to repair and retrofit housing is limited. This has resulted in high heating and electricity bills for many homes, where electricity and fuel oil prices are 3 to 5 times and 1.8 times the rates in the continental U.S, respectively [4]. Given the generally lower household incomes in many rural communities, some estimates suggest the lowest income households use an estimated 47% of their income for home energy, while higher income households spend 6% to 13% of their income [28].

Resolving challenges that stem from the current state of housing infrastructure begins with an understanding of the current characteristics of housing in rural Alaska. This also requires knowledge of the overall Alaskan climate conditions that housing should be built to withstand, and an understanding of the lifestyle of the buildings' occupants. This information can help support appropriate planning for future housing in rural Alaska, including new construction and/or retrofits to existing homes. Future home construction in such communities, and in particular the location of study in Unalakleet, aims to be completed in locations less threatened by coastal erosion while also considering input from community members in their design.

The following section reviews Alaskan climate conditions and rural lifestyle, followed by an overview of rural Alaskan building characteristics, both from public sources. The remainder of this research discusses the methods used to collect more detailed housing data in Unalakleet and a summary of findings of such housing characteristics. This is then compared to U.S. housing characteristics to emphasize the need for a unique definition of rural Alaska home characteristics that can drive analysis of opportunities for efficiency improvements.

Background

Alaskan Climate

Alaska's many ecosystems and extreme climate make it a unique and challenging place to live. The state is home to differing landscapes, from coastal rainforests and flat tundra to glaciers and volcanoes. Permafrost covers 81% of the ground and controls many aspects of soil health while also supporting infrastructure. Over time, however, Alaska's climate has been suffering from the impacts of climate change. Average annual temperatures statewide increased by 2.2°C (4°F) between 1949 and 2005, most notably during the winter. Precipitation has also increased by 10% annually during this same period [20]. Both precipitation and temperature projections show continued increases across the next century, particularly if current world emission trends are not reduced. Another concern is the growing number of extreme weather events. Large waves contribute to erosion, threatening many coastal communities' shorelines [20].

Historically, Alaskan homes were better built for the climate. Alaska Natives, Russians, and Americans have populated Alaska, all of whom put their own architectural influences on the region [17]. Thousands of years before the Russians discovered Alaska, Alaska Natives built well-insulated homes that were designed for the winters and terrain. These homes varied by location and Native group. For example, in the coastal Arctic (north of the Arctic Circle), homes were semi-subterranean. The large room of the home was underground with a membrane-covered window in the roof that served as a smoke hole. Entrances to the home were at the end of a long cold-trapping tunnel that opened to the outside. The inside of the home was warmed sufficiently from the insulation of the ground, body heat, and seal oil [17]. Insulation consisted of sod, soil, moss, and sometimes an extra layer of animal hides on the inside. This kept homes up to 60 degrees warmer than the outside temperature [18]. Over time, dwellings began to change with subsistence patterns, and especially with the influence of other cultures. Newer homes were cold and drafty, requiring oil to be imported. Driftwood disappeared from consistent use for heating. Inefficient manufactured homes, usually shipped in by government agencies, also became common in many rural communities such as Unalakleet [17].

Introduction to Unalakleet, Alaska

Unalakleet is a small community of approximately 700 people on the west coast of Alaska, with origins from around 200 B.C [37] [31]. It is home to diverse cultures due to its history as a trading post for a Russian-American company. Approximately 74% of the community identifies as Alaska Native [31]. Many homes hold multiple generations or have been in families for generations. The economy is strongly reliant on subsistence activities such as hunting, fishing, and gathering berries. The community is also home to a commercial fishing company; thus, many residents leave during the months of May through July to go commercial fishing on the Unalakleet River. There are no roads to Unalakleet, so travel from elsewhere is by boat or airplane only. The median household income in the community is approximately $70,000, however, 42% percent of households make under $50,000 per year. The community consists of approximately 227 housing units, with 76% of homes being occupied, equating to an average of 4 people per housing unit [37].

Many buildings, as seen in Figure 2.1, are similar in structure. These buildings were commonly built by generations of families in the community or barged in fully manufactured. Methods of data collection and the resulting common characteristics of these buildings, especially from 27 homes analyzed through this research, are discussed in further detail below. Such characteristics include size, roof type and color, siding type and color, and percent of window coverage per exterior wall, among others that influence the energy efficiency and consumption of these buildings. This data collection was achieved through a partnership with the Native Village of Unalakleet.

Figure 2.1: Examples of homes in Unalakleet [16]

Data Collection Methodology

Remote

Remote data collected included home size, roof and exterior siding type, and percent of window area. In total, data from 227 homes, occupied or unoccupied, was collected using this method.

For *home size*, data was collected using aerial images from Google Earth and its measurement tool. Such methods have some error, given that not all images provided a clear close-up. Individual houses were identified by their North and West coordinates. Overhangs, if present, were counted in the measurement and may produce error in actual length of the house. *Roof type* was determined using Google Street View and included the observed roofing material, such as corrugated metal or shingles. *Exterior siding type* was identified and recorded following the same methods as for the roof.

Determining the *percent window area* was a time-intensive process. Of the 227 homes counted in Google Earth, 94 homes were sampled from the north, south, east, and western parts of the community. Each house was viewed from all cardinal directions in Google Street View. These were placed in AutoCAD, where they were measured using the area tool. Windows were measured individually, then the total window area was divided by the wall area to determine this percentage. Error includes snapshots of walls at an extreme angle, making measurement difficult. Partial obstructions of walls also required estimation of their dimensions.

On Site

On-site data collection occurred in July and August 2021 and was completed for 27 homes with homeowner consent. Participants were compensated for their time. Additional data collection included an interview on current housing concerns and future housing design considerations, as well as infiltration and indoor air quality data collection. However, this research focuses only on housing characteristics resulting from interior and exterior observation of the homes. Relevant comments from interviews pertaining to discussed topics are mentioned, as appropriate, to enhance discussion. Interior air quality and ventilation characteristics are discussed in a separate paper titled “Addressing the Housing Challenges of Rural Alaska: Air Flow and Indoor Air Quality Characteristics of Residential Buildings” [22].

Indoor data collection included a walkthrough of each home. Heating and ventilation systems were inventoried by name plate, efficiency, type, and energy source. Windows and exterior doors were assessed for proper sealing. Participants were asked about insulation in their walls, attic, and crawlspace. Visible mold and damage to the home was recorded for the interior and exterior building shell. The condition, type, and colors of the exterior walls, roof, and foundation was recorded. Outside, evidence of shifting ground, pooling water, and damage were also recorded. Potential errors or missing data occurred due to coverage of walls and appliances by household items, partially obscured exterior walls by a close building, blocked entry to the crawlspace, and/or partially unfinished homes.

Results and Discussion

Size of Homes

Measuring all visible homes on Google Earth (n = 227) averaged to 12.7 m (41.7 ft) in length by 8.6 m (28.2 ft) in width (109.2 m^2 (1175.9 ft^2)), including overhangs. This measurement did not include newly built homes overlooking the community or buildings that appeared to be apartments. For homes where assessments were conducted (n=27), occupants often knew the area of their home, reporting an average area of 97.5 m^2 (1049.5 ft^2). The smallest home was 29.7 m^2 (320.0 ft^2) consisting of a kitchen, a bedroom, and a bathroom; The largest was 250.8 m^2 (2700 ft^2). Thirteen of the 25 single-family homes assessed (2 apartments) were under 92.9 m^2 (1000 ft^2). Figure 2.2 shows average house size of houses assessed and in Unalakleet total, compared to Alaska and the U.S. overall. As shown, the on-site assessed homes averaged to be similar in size to the overall total single-family homes in Unalakleet. These were both substantially smaller than in Alaska and in the U.S.

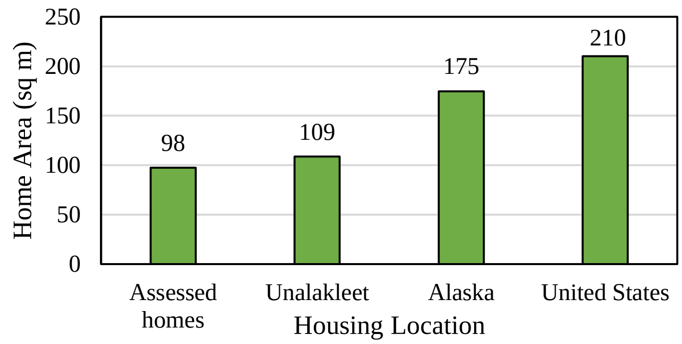

Figure 2.2: Average area of assessed homes in Unalakleet, Alaska, and the U.S. [50] [38]

A common housing concern among those interviewed related to housing size and lack of space. Of the 27 houses assessed, 7 held more than 4 people. The average occupancy of the 27 homes assessed was 3.08 people, not including the one home that currently or previously had no occupants. Figure 2.3 displays the average occupancy of both assessed homes and Unalakleet in total, as compared to Alaska and the U.S. As shown, the overall number of people per home is higher than in Alaska and the U.S. yet Figure 2.2 shows the houses are substantially smaller. The median size of assessed houses in Unalakleet (97.5 m^2 (1049.5 ft^2)) gives an average of 31.7 m^2 (341.2 ft^2) per person. In comparison, an average of 2.6 people per house in the U.S. gives approximately 83.4 m^2 (897.7 ft^2) per person, or a 55% increase in space per person compared to Unalakleet [37]. Such numbers are important to consider when evaluating indoor air quality concerns and ventilation requirements, as well as differences in internal loads and occupancy for energy modeling applications.

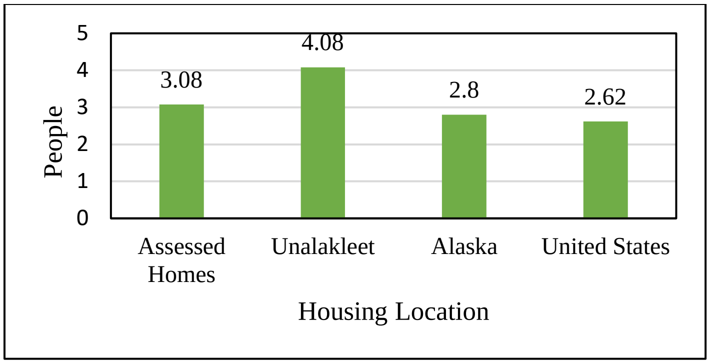

Figure 2.3: Occupancy of assessed homes and Unalakleet total vs Alaska and U.S. [38] [40] [41]

Roofs

Seventy-eight percent of the homes observed using remote methods had corrugated metal roofs; however, some had shingles (4%) or large wooden boards (4%). Others were unavailable in Google Street View or hard to view. From onsite data collection, all homes had corrugated metal roofs. The most common color across the community was gray or dark blue/green. Roof pitch was most frequently north to south, including 78.6% in the community from Google Earth observation and 70.4% of on-site assessed homes. A north/south pitch meant the roof sloped to the north and south. One participant mentioned the importance of the roof pitched north to south, where overhangs provide shade from the sun in the summer. Such data on roof characteristics is important as it is a required input for energy modeling purposes, and, as mentioned by one participant, impacts shading and solar gains. For example, a study done in a cold climate in Spain found that roofs pitched north to south and dark-colored corresponded to less energy loss than light roofs [14].

Crawlspace

Nearly all homes assessed on site (78%) had crawlspaces as their foundation. Six homes (22%) had a slab-on-grade foundation. Many homes were built on level ground; some did have evidence of shifting ground such as cracked foundations, uneven porches (Figure 2.4), and sloped ground around the foundation, which can affect the building's envelope by causing cracks and air infiltration into the home. Some participants explained that their foundation had to be leveled after the ground shifted. The community and the homes on the hill above it are not built on permafrost; however, the main community is located just off the Bering Sea and built on primarily sandy soil. One participant clarified that shifting of the foundation usually occurred in the spring and winter, and that the house shifts significantly. To avoid pooling, some residents placed rocks as drainage around their crawlspace, however, pooling of water was present around some homes (Figure 2.4).

Figure 2.4: An uneven porch crawlspace (left); pooling water around a foundation (right)

Nearly all crawlspaces were covered by a skirt commonly made of wood. When an opening was present to allow for visual inspection, fiberglass insulation was typically observed to be placed around the skirt of the crawlspace. Some homes also had rotten wood boards due to water damage from the bathroom floor. Two of the 21 crawlspaces were vented. Crawlspace skirts usually matched the color of the exterior siding or were plain wood. Wintertime ventilation through a crawlspace can cause an increase in heat loss for the home and put pipes at risk of freezing, especially if the floor and pipe insulation is not sufficient. For non-vented crawlspaces, it is recommended to condition crawlspaces with insulation around their perimeter and a sealed ground cover as a vapor and air barrier [19]. However, such systems were lacking in homes with observable crawlspaces.

Exterior Walls

Exterior siding consisted mainly of vinyl (37%) and wood paneling (44%). A few homes had visible water damage to the wood paneling (Figure 2.5). Chipping was present on the vinyl siding, also shown in Figure 2.5. Siding was mostly light colors (59%). Of the homes where onsite assessments were conducted, all exterior walls were insulated per participant comment. Foam board was often used on the exterior, with spray foam or fiberglass on the interior. Two homes had cellulose insulation; one new home contained densely packed cellulose. One participant talked about how the fiberglass insulation dropped within the wall cavity, leaving the bottom of the wall much warmer than the top and impacting the effectiveness of the insulation.

Figure 2.5: Rusting and peeling of wooden panels around a window (left); damage to vinyl siding from a snowbank (right)

Window Placement and Area Coverage

The south side of many homes was commonly the side most covered by windows, allowing for more solar gain in winter. Whether builders and designers intentionally built and/or placed many of the homes in the community for this reason is unknown. However, some participants who built their own home confirmed that they purposefully placed windows on the south side. The average window coverage on the southern side of the 94 homes analyzed remotely was 10.5%. Next largest was the west, at 8.1%. The east side of homes had the least coverage, averaging 6.1%. Some homes had sides of their house with no windows, most often occurring in the east or west orientation. A probable reason for lack of windows on the east side is to prevent the strong eastern wind that blows in winter from infiltrating into the home. As many homes had leaky windows, whether old or new installations, windows lacking on the east wall makes sense to reduce infiltration.

Interior Characteristics, Appliances, and HVAC

As mentioned above in the section on size of homes, many homes lacked space to comfortably accommodate the number of people who live there. Several homes used open space in each room for storage or had beds on the living room floor and/or multiple people staying in one room. Water heaters and laundry appliances were sometimes found in the bathroom or kitchen. Interior doors were lacking in some homes, and when asked why, occupants explained that they were damaged or would not shut all the way due to shifting of the foundation.

Boilers were usually observed to heat most homes and their water. Heating appliances generally included a furnace (e.g., L-73 Toyostove Laser) in a central area and a boiler connected to baseboards that ran through the home. Participants with a central heating system often stated the home would be cold in the winter, unless the home was extremely small or had a wood stove as back-up. Out of the 25 participants of occupied homes, only 2 mentioned using the cooking stove to heat their home if the heating system was insufficient. For water heaters, some homes used the same boiler for heating while others had a separate boiler (e.g., Burnham and Toyotomi Oil Miser Model OM-122DW). Two homes had on-demand water heaters that only heated the kitchen sink or the bathroom water, and 5 homes had electric water heaters. Bathroom and kitchen exhaust fans were common forms of mechanical ventilation, and some homes built after the 2000s had heat recovery ventilators (HRVs). A common trend among smaller homes (less than 92.9 m^2 (1000 ft^2)) was a lack of sufficient mechanical ventilation, which can negatively impact indoor environmental conditions and cause mold growth (Figure 2.6). Such mold was most observed around windowsills and in the corners of wall/floor and wall/ceiling joints. Participants noticed that it tended to grow in areas of the home that collected moisture or felt colder.

Figure 2.6: Apparent black mold growing up a wall near the entrance to a home (left); towel placed to seal exterior door (right)

Frequently, the interior of homes also had damage, such as floors missing tiles, walls with holes, and exterior doors that did not seal well. An example is shown in Figure 2.6 of a home that used a towel to improve air sealing around the door.

Conclusions

Through combined remote and on-site data collection, typical energy-related characteristics of homes were observed in Unalakleet, Alaska, a rural community. Given the high energy burden for households in rural Alaska, as well as the limited data available on housing characteristics in this region, this study focused on determining a more comprehensive picture of housing characteristics. As observed, homes are generally smaller and more densely inhabited as compared to the continental U.S. These observations are like those found in statewide housing surveys, especially for the Bering Strait region where Unalakleet is located [50]. In many cases, homes are in significant need of repair and/or retrofits. Many participants recognized this and explained that repair in such a remote area was expensive and took a long time, as maintenance and materials had to be shipped from outside the community. Many did repairs themselves. Research on this subject is ongoing, and future funding will provide more opportunity to collect additional data on rural Alaskan housing characteristics. The characteristics observed in this effort can be used to better characterize the housing stock in this area. Further analysis of the physical and interview data collected in Unalakleet will be done to simulate retrofitting opportunities for housing and new construction using building energy modeling methods. Such improvements to housing can help to ensure comfortable, efficient, and affordable homes for residents.

CHAPTER 3: ADDRESSING THE HOUSING CHALLENGES OF RURAL ALASKA: AIR FLOW AND INDOOR AIR QUALITY CHARACTERISTICS OF RESIDENTIAL BUILDINGS

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Abstract

Residential housing in rural Alaska faces many challenges, from a harsh climate to inadequately built infrastructure. Some homes are inefficient and leaky while others lack mechanical ventilation to support indoor air quality, among other concerns. Furthermore, progressing climate change brings new threats to housing, including erosion, stronger winter storms, and warmer summers. Many coastal communities are considering relocation of housing or retrofitting existing housing to further protect against the changing climate. However, many of such coastal communities are highly isolated from mainland Alaska; most are only accessible by plane or boat. Given this, the limited availability and high cost of supplies and skilled labor restricts the level of repairs and improvements made for most of the housing stock. Similarly, many homes are highly energy burdened due to high costs of fuel and electricity. To support and motivate improving housing in this region, it is first important to quantitatively characterize the state of housing conditions.

While there are state-level surveys, these do not focus specifically on rural communities. In this research, housing assessments were done in the Native Village of Unalakleet, located on the west coast of Alaska. These included an interview of homeowners, a visual inspection, indoor air quality measurements, and blower door testing. Such information, across a random sample of 27 homes, helps to identify the extent of the challenges and needs present in these homes. This

paper specifically focuses on the challenges of adequate air circulation throughout homes and maintaining healthy indoor air quality. These characteristics will become key inputs for building energy modeling that will be used in future papers to determine cost-effective efficiency improvements to homes.

Introduction

Alaska's harsh climate creates home-building challenges that are unique as compared to other regions in the United States. In addition, rural areas in the state face even more challenges than urban areas. Being remote and isolated, many communities do not have easy access to the resources needed to repair their homes or build new ones. Most resources that are not available through subsistence hunting and gathering activities are imported, leading to high living and energy expenses. Furthermore, many homes are inefficiently built for the extreme climate, making fuel oil a high and frequent expense, particularly during the winter [18].

During periods of extreme cold, maintaining a sufficiently warm home is a top priority for households. When people are inside their homes, especially for prolonged periods of time, indoor air quality becomes an important measure of how healthy a home is for its occupants. Poor indoor air quality often goes unnoticed, yet it is a leading cause of allergies, asthma, other respiratory diseases, and even some cancers [34]. To reduce this risk, homes must be ventilated. In cold climates, natural ventilation through windows and doors becomes a challenge when outside temperatures reach levels that could quickly cause major heat loss in the home. Mechanical ventilation, such as with heat or energy recovery ventilators (HRV/ERV), is lacking in a vast majority of homes due partly to the high costs of shipping, labor, and electricity as well as the tendency for rural artic communities to disable HRV/ERVs because of thermal comfort or energy concerns [32].

To support implementation and development of new technologies for improvement of indoor air quality in rural Alaskan and other circumpolar homes, an understanding of current indoor air quality conditions is important; yet available data is lacking. This research begins with a background in housing in rural Alaska and an introduction to indoor air quality challenges. The community in which this research took place is introduced next, followed by a review of data collection methods. Results include both indoor air quality measurements and air exchange rates. In addition, interview data for 22 households where the assessments took place is also discussed and compared to the physical data. This will characterize homeowner perceptions of indoor air quality. The purpose of this research is to provide background knowledge needed in the development of efficient housing and ventilation systems appropriate for rural Alaskan households.

Background

Importance of Indoor Air Quality

In areas of the world that face both extreme temperatures and increased effects of climate change, healthy indoor air quality is becoming increasingly important to understand and maintain. Extreme weather events, such as storm surges and stronger winter storms, put many households at risk of erosion and flooding [20]. With a growing frequency of storms comes more reason to stay inside, thus making indoor air quality a strong priority in efficient home-building as the climate continues to change.

Today, many rural communities are home to Indigenous people. Historically, indoor air quality has been a concern in Alaska Native households. Homes used smoke holes to release cooking fumes [17]. However, indoor air quality still faced challenges due to high occupancy and smoke production from burning oil. Poor indoor air quality has been identified as a probable cause of emphysema (a disease of the lungs) in some pre-Western contact Alaska Native people [18]. Today, indoor air quality remains a concern in Alaska Native homes, which are now more influenced by Western culture [17]. A study conducted over 4 years surveyed households of Alaska Native children with respiratory diseases and found that 73% of homes where the children lived were overcrowded, contributing to high indoor CO_2 levels; this is compared to only 3.2% of households throughout the U.S. being labeled as overcrowded. Some of these homes used woodstoves as heat sources (16%), and almost half included an occupant who smoked (49%), both activities adding particulate matter into the air. These statistics are much higher than their average for the U.S. household stock. These and related factors impact indoor air quality, becoming possible contributors to disease [30].

Indoor air quality is often measured considering CO_2 levels in parts per million (ppm), volatile organic compounds (VOCs), particulate matter, and relative humidity, among other parameters. CO_2 levels higher than 1000 ppm in a household have been correlated with lower respiratory tract disease, especially in infants and young children [30]. VOCs are air pollutants that can be carcinogenic or contributors to diseases such as asthma. Particulate matter are small particles released during polluting activities such as smoking, burning wood, or cooking. They can also cause respiratory disease. High relative humidity can lead to mold growth, especially with increased indoor occupant activity [30]. Low relative humidity can lead to respiratory illness and dry skin [6]. Important also is the measurement of other air pollutants like carbon monoxide (CO), ozone (O_3), and nitrogen oxides (NO_x).

While the above-described challenges are of significant concern in rural Alaska, there is little data available that helps to provide a detailed characterization of buildings' physical and indoor air quality-related characteristics. This research thus uses CO_2, temperature, and relative humidity readings as short-term indicators of indoor air quality. A gas detector for carbon monoxide and oxygen (O_2) levels sounded an alarm if CO was detected during the assessment or O_2 levels dropped below 20%. This alarm never went off during assessments. Indoor temperature was also taken to compare with relative humidity, and blower door tests were used to measure exchange of outdoor air with indoor air. This research was done in the community of Unalakleet, located on Alaska's west coast, similar in many ways to other rural Alaskan communities.

Introduction to Unalakleet, Alaska

Unalakleet is a small community located on Alaska's Norton Sound, off the Bering Sea. It includes approximately 700 people of diverse cultures [37]. These cultures stem from the community's Alaska Native history as well as its history as a Russian-American trading post. About 74% of the community's people identify as Alaska Native [31]. Many homes hold multiple generations or have been passed down over time. The community's economy consists mostly of subsistence activities such as fishing, hunting, and gathering berries, while commercial fishing occurs in the summertime. Unalakleet is inaccessible by road and relies on its small airport for travel, therefore supplies come in by air or barge. The community's median income is approximately $70,000, but 42% of households make less than $50,000 per year. Occupied housing units total approximately 224, with 76% of homes being occupied with an average of 4 people per household [21].

Unalakleet is in a transitional climate zone, surrounded by tundra and scattered boreal forests. The winters are long and cold, and the summers are short and warm [31]. Most homes are built alike to each other. Some were built by families while others were barged in by state and federal housing authorities. Common physical characteristics of these homes include crawlspaces, corrugated metal roofing, wooden or vinyl exterior paneling, and small building size. The homes are placed near to one another, especially in the main area of town by the ocean [21]. Figure 3.1 below shows homes that are close together and similar in structure.

Figure 3.1: A group of homes in Unalakleet, Alaska [16]

Methodology

Data collection was achieved through a community partnership with the Native Village of Unalakleet. Data was collected for 27 homes throughout a three-week period in July and August of 2021. Participating households were identified using random sampling and were compensated for their participation following MSU's IRB STUDY00005947. Participant households were from both the main community on the ocean and the hill outside of it. Housing assessments included the collection of both physical data on housing characteristics and interview data of household member(s). Physical data collection consisted of a walkthrough of the home's interior and exterior, noting building characteristics and other elements such as mold, damage to the home, and presence of appliances and other energy-consuming devices. Blower door tests were done on homes to assess air exchange rates and to identify areas of leakage. Indoor air quality data was collected using ONSET dataloggers for CO_2, relative humidity, and temperature [25] [26]. This paper focuses on the infiltration, ventilation, and indoor air quality data collection and analysis; physical building data is discussed in "Addressing the Housing Infrastructure Challenges of Rural Alaska in a Changing Climate: Physical Characteristics of Residential Infrastructure" [21].

Infiltration and Leak Identification

A blower door test was used to locate air leaks and measure air exchange rates in homes in units of CFM50, where CFM50 refers to the amount of indoor air exchanged with outdoor air when the pressure difference between the inside and outside is 50 pascals [8]. During this test, an infrared camera and a smoke pencil were used to identify where air was leaking into the home. Configuration of the blower door fan opening size was adjusted by house based on the size of the home and how tight or leaky the envelope was. A manometer was connected to the fan, using tubes to measure the pressure difference between the outside and inside of the home before the test. This baseline pressure fluctuated according to the weather, where rainy weather provided the largest pressure difference between the inside and outside environments. Before the fan was turned on, all windows and exterior doors were closed, and all interior doors were opened to provide the most representative airflow within the conditioned living space. Last, combustion appliances were turned off and wood stove dampers were shut and sealed. The test ran for about 10 minutes depending on the amount of air leaks identified and the size of the home. Error in airflow measurements include sudden jumps in CFM50 readings due to someone opening an exterior door or window, or an unusually high CFM50 value resulting from a recently broken window that could not be sealed. Both errors happened rarely during the data collection period.

Monitoring Indoor Air Quality

Indoor air quality data was collected using dataloggers connected by Bluetooth to a mobile phone [25] [26]. The CO_2 monitor was first calibrated outside for five minutes. Temperature and relative humidity were also monitored. Throughout the day, the dataloggers were transported in a backpack then placed openly in each participant's home. Unalakleet experienced rainy, cool weather for most of the on-site data collection period. This made most indoor air quality readings more representative of the interior environment when natural ventilation methods are not in use (i.e., most windows were shut); most often occurring in the winter. However, throughout the 3-week data collection period, 4 days were warm and sunny with clear skies. During this period, 4 participants had their windows open, impacting indoor air quality measurements. Readings were also taken after all windows were closed for the blower door test, however clean air from the open windows was still present in the home. CO_2 readings were often 500 ppm or lower in this situation, jumping up by about 100 ppm in the brief period when windows were closed before the blower door test began.

Results and Discussion ‑ Part One: Indoor Air Quality Data

CO_2 Levels

Elevated levels of carbon dioxide were considered to be above a 1000 ppm threshold [30]. Of the 27 houses, 23 had their windows closed during the assessment, the results of which are shown in Figure 3.2. Of these 23 homes, 11 (47.8%) had recorded CO_2 levels above 1000 ppm. Carbon dioxide levels much higher than 1000 ppm were also observed. Seven homes had CO_2 levels above 1500 ppm, and 2 had levels above 2000 ppm, with a maximum observed reading of 2330 ppm. Homes where CO_2 levels reached above 2000 ppm had multiple occupants living in a small space. One home had 5 people living in a 2-bedroom home of 90.3 m2 (972 ft^2), and the other had 2 people living in a 1-bedroom home of 37.2 m2 (400 ft^2). The overall average CO_2 reading across the 23 homes was 979 ppm; the average across all homes was 906 ppm, and an average of 13 CO_2 readings were collected per home.

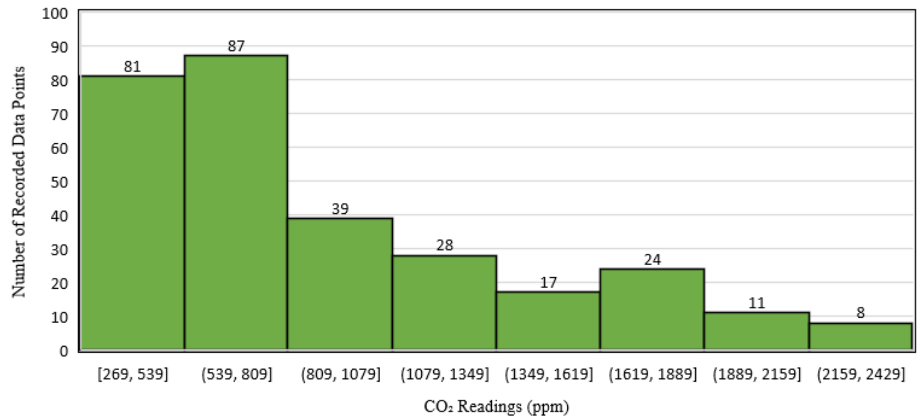

Figure 3.2: CO_2 measurements of homes, taken every 6 minutes during assessments

Indoor Relative Humidity and Presence of Apparent Mold

Fourteen of the 27 assessed homes (51.9%) had visible apparent mold present, most commonly black in color. Some homeowners said they managed the mold by cleaning it, but many said it consistently grew back. Mold was observed around windows and in bathrooms; in one home it was present on the walls (Figure 3.3).

Figure 3.3: Apparent black mold on an interior wall

Of these 14 homes, half had relative humidity (RH) levels above 65% during the home assessment, which is outside of the 30-60% range recommended for optimal human comfort and minimized biological growth [6]. Three homes had a relative humidity above 70%, including the home with apparent mold on the walls. The highest recorded relative humidity was 77%. Also noted is that homes with apparent mold present in multiple areas had air exchange rates of 4.5 ACH50 or lower and yet did not have mechanical ventilation installed. Overall, 11 of the 27 total homes assessed (40.7%) had a relative humidity of over 65% (no windows were open); 6 homes had over 70% RH recorded. Figure 3.4 shows a histogram of all relative humidity readings sorted by range. Note that these readings were taken every minute inside the participants' homes, and visits on average lasted two hours. Throughout most of the data collection period, the weather was rainy, with an outdoor humidity of around 60%.

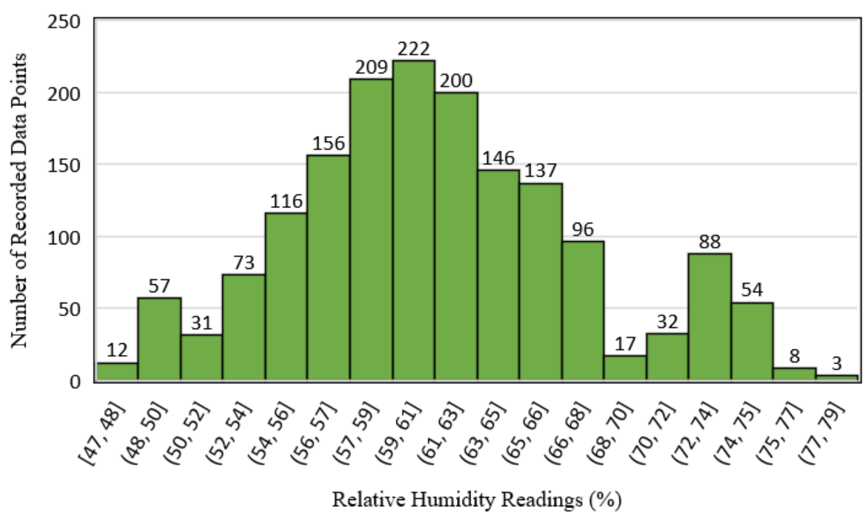

Figure 3.4: Individual relative humidity readings taken every minute during assessments (average 73 readings per house)

Indoor Temperature

The average temperature observed across all homes was 22.8°C (73°F), with a maximum of 31.7°C (89°F) and a minimum of 17.2°C (63°F). During the data collection period, the average outdoor temperature was 16.1°C (61°F), with a maximum of 26.7°C (80°F) and a minimum of 11.1°C (52°F). In many cases, participants had the boiler on in their homes, making indoor temperatures between 21.1°C (70°F) and 23.9°C (75°F) common. On warmer days, boilers were turned off and windows were opened. Four of the 27 homes had windows open. Overall temperature data are shown in Figure 3.5 below as a histogram. This data was taken every 6 minutes during each assessment; an average of 12 readings were taken per home.

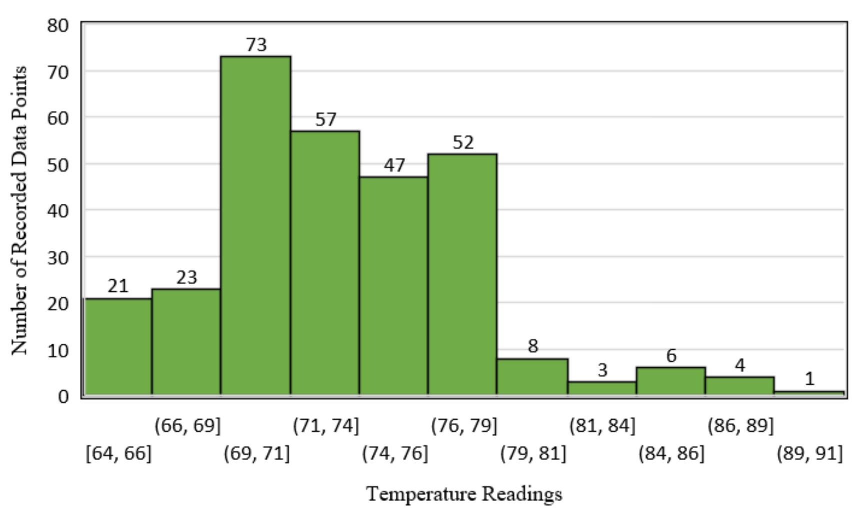

Figure 3.5: Individual indoor temperature readings taken every 6 minutes during assessments

Air Flow

Twenty-four of the 27 assessed homes had blower door tests done, and 23 of the 24 had CFM50 values recorded during the test. The missing value was due to incorrect configuration of the blower door fan. Most homes were tight when compared to ASHRAE's Building Airflow Standards (BAS) [10]. These standards are different for each home based on square footage, location, and occupancy. A home is considered "tight" if its CFM50 value is lower than the one calculated using the Building Airflow Standards calculation [10]. The standards are based on ASHRAE Standard 62.2, which states that homes should receive 0.35 air changes per hour total but not less than 15 cfm per person, both at normal home pressure [6]. Every house had a different required CFM50 value based on volume, occupancy, height of the building, and proximity of neighboring buildings. The average calculated and required BAS value for sufficient airflow across the tested homes in Unalakleet was 823.4 CFM50. High occupancy was a common reason homes were considered tight; their air exchange rate was calculated as not sufficient for the home's occupancy. Table 3.1 below summarizes overall results from the blower door testing.

Table 3.1: Air Exchange Rate Characteristics Across 23 Homes

Measure	CFM50 Value	ACH50 Value
Mean	832	6.1
Median	645	5.9
Maximum	2789	12.6
Minimum	106	0.62

Over half of the homes were considered "tight," where mechanical ventilation is recommended to be installed. However, only 2 of these 12 homes had mechanical ventilation installed. About 34.8% of homes were considered "leaky," with the leakiest having a window that was recently damaged and could not be closed. This consideration was determined when the recorded CFM50 value was significantly higher than the calculated BAS value. About 17.4% of homes were neither considered "tight" nor "leaky." Note the 0.62 minimum ACH50 value may be considered an outlier as compared to the remaining homes; this was observed in a newer home built purposefully tight, which also included an HRV for mechanical ventilation. The next smallest ACH50 value observed was 2.24 on a single-family home and 1.76 in a loft. Both did not have mechanical ventilation installed.

Air Leaks

Twenty-four homes were scanned with an infrared camera during the blower door test for locations of air leaks [36]. Leakage was observed as a dark streak through the infrared camera, representing infiltrating cooler air. A smoke generator helped to confirm air leakage, and sometimes leaks could be felt by hand. Common locations of observed leakage are summarized in Figure 3.6. In this figure, a “seam” refers to the edge of the home where the wall connects with the ceiling or floor.

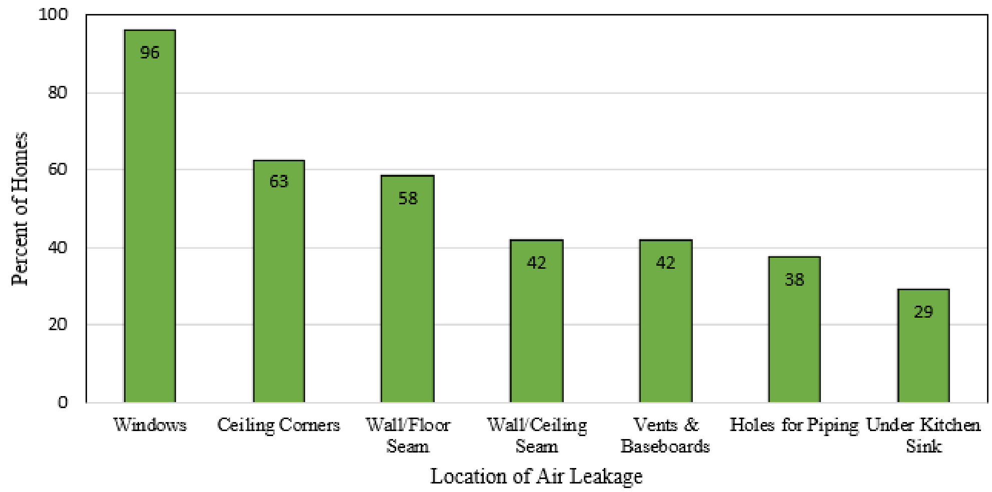

Figure 3.6: Common areas of air leakage observed across 24 homes, by percent

All but one home had at least one leaky window. Many times, homes had multiple windows that were leaky enough that incoming air could be felt by hand, even though many homes had their windows recently replaced. Ten interviewees mentioned that they could feel drafts from their windows in the winter. Since leaks and drafts were observed in nearly all homes, the number of homes considered “tight” per Building Airflow Standards was interesting and likely due in part to the higher-than-normal occupant densities [10]. Mold-like growth was also common around windows and in ceiling corners. It was found in some homes in floor corners, where leakage occurred in 5 of the 24 homes (20.8%). Leakage was also noticed from bathroom and kitchen exhaust fans; this is interesting to observe given that several participants mentioned they did not use these ventilation mechanisms because they bring in cold air.

Results and Discussion – Part 2: Community Perceptions of Indoor Air Quality

Seventeen interviewees stated if they did or did not have concerns with their indoor air quality. Nine of the 17 interviewees (52.9%) said they had no concerns with it. However, 11 out of 23 home assessments done when windows were closed had CO_2 readings above the 1000 ppm threshold for health concern [30]. The remaining 8 interviewees did express they had concerns with their air quality. Two of the 8 said they noticed their home feeling hot and humid, and 2 more said that they open windows to improve the indoor air quality. Two interviewees said their indoor air quality improved after they had air vents installed on their walls that could be opened with a string to let in outside air. These are small and circular, often referred to as "arctic vents." Of the 9 interviewees who said they have no concern about indoor air quality, 3 of them (33.3%) had consistent CO_2 levels above 1000 ppm, with one above 2000 ppm. This indicates that poor indoor air quality may be hard to notice or quantify, or the readings for that day were due to a higher than usual amount of people in the home especially in smaller homes less than 46.5 m^2 (500.0 ft^2). Eight interviewees had concern about their indoor air quality, and 3 of them (37.5%) had CO_2 readings recorded above 1000 ppm throughout the assessment. All three of these homes had visible evidence of poor indoor air quality, like dust or mold.

Some newer homes had heat recovery ventilators (HRVs) installed, however few were used. Six interviewees mentioned having HRVs, but only 2 indicated they used them consistently (33.3%). One interviewee said that with so many people coming in and out of the house and frequently providing natural ventilation, they do not use their HRV. Another HRV did not work properly. The main barrier mentioned by interviewees to using the HRV is the perceived high cost of operation due to high cost of electricity. One interviewee said they would like an HRV, but expensive installation makes it not feasible for them. Four interviewees said they open the windows in the winter for short periods of time to allow in fresh air.

Conclusions

Maintaining indoor air quality in rural Alaska is a challenge for many reasons, from high occupancy in small homes to the high cost of shipping and materials used to install mechanical ventilation, among others. Observations made by collection of physical and interview data in Unalakleet, Alaska confirmed the challenge ventilation and indoor air quality poses for the community. Many homes were found to be tight and small. Mold was common throughout homes in the community. Almost half the assessed homes had recorded CO_2 levels higher than 1000 ppm during the assessment, and some had levels higher than 2000 ppm recorded. Mechanical ventilation was lacking in most homes that needed it, and ventilation in the winter by opening windows is a challenge with the cold climate. Interviews indicate that some occupants are not aware of poor indoor air quality, and the importance of mechanical ventilation is not well-understood. They also indicate that the high cost of electricity and fuel makes saving money a priority.

Understanding where communities need improvements in their homes is the first step to helping them achieve better indoor air quality and building performance overall. Knowing where homeowners would benefit from education on ventilation and other air quality topics is also key to introducing healthy habits. The data in this paper will be used to help consider retrofit opportunities for homes in Unalakleet and rural Alaska in general. As technologies improve, new efficient and cost-effective ventilation systems are being developed to help communities reach healthy indoor air quality levels [32]. The importance of indoor air quality, especially in a cold, harsh climate like Alaska's, is critical. Data collection like the one that took place in Unalakleet is the first step to building and retrofitting more efficient, healthier homes.

CHAPTER 4: BUILDING ENERGY MODELING OF A TYPICAL HOME IN RURAL ALASKA AND OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS

Abstract

Research completed in the rural community of Unalakleet, Alaska during the summer of 2021 provided evidence to support the need for more efficient housing. Interviews with home occupants revealed housing challenges, from high fuel and electricity costs to cold drafts felt through windows. More space, a warmer home, a home that fits the occupants' lifestyles, and lower energy bills were mentioned multiple times in interviews when asked about future housing considerations. However, currently there is no existing building energy models that have been developed to represent typical existing homes in rural Alaska, nor is there an energy model that represents planned retrofitted or new construction homes. This research therefore focuses on the development of a residential building energy model of a 'typical' home in Unalakleet using data from 27 housing assessments. The model is then used to assess potential opportunities for energy savings from efficiency retrofits and to compare to models representing a retrofitted and newly constructed home. The new construction model was developed based on discussions with the Unalakleet housing authority, including efficient insulation, appliances, and physical building materials. Materials were chosen according to feasibility, using case studies and prototypes of efficient homes built in rural Alaska. The models of these new and retrofitted homes can be used as a guide in developing efficient homes and retrofits in rural Alaskan communities.

Introduction

Rural Alaskan homes are presented with challenges unique to other areas in the United States. Cold, long winters make heating and home efficiency significantly important. While homes benefit from being built with low air exchange rates to prevent loss of heat energy or intrusion of cold drafts, mechanical ventilation is important to maintain a healthy indoor air quality. In addition, strong building materials and quality construction help prevent damage to the outside of the home from strong winds and/or storm surges, both of which are becoming increasingly common as the climate changes and warms [20]. The remoteness of rural Alaskan communities makes maintenance of homes a challenge; the costs of supplies and labor are substantially higher than in most other parts of the U.S. because of necessary shipping over long distances and limited shipping windows [32]. This combination of challenges with a changing climate makes efficient homes a significant need and strong priority for rural Alaska.

To build an efficient home, an understanding of housing challenges present in rural Alaskan communities is necessary to create an accurate model of a typical residential home. In partnership with the Native Village of Unalakleet, a coastal community on the Bering Sea, both remote data collection and in-person energy assessments were completed in the summer of 2021 by a research team at Michigan State University and Iowa State University. Unalakleet’s climate is categorized by ASHRAE as Climate Zone 8, in which the winters are long and cold, and the summers are short and warm [4] [20]. The community has a population of 765 people as of 2020, with the leading demographic being Alaska Native. The local economy is heavily subsistence-based, with many community members hunting and fishing for their food as well as gathering berries and greens [31].

Remote analysis of homes on Google Earth was used to identify the dimensions and area of homes along with the proximity of neighboring buildings [16]. In the community, 27 energy assessments were completed by Michigan State University and 22 interviews were completed by both Michigan State University and Iowa State University. Key initial findings on physical building characteristics and indoor air quality are discussed in two separate papers [21] [22].

The purpose of this research is to develop a building energy model that can be used to represent a 'typical' rural Alaskan home in Unalakleet. A second model represents a possible retrofitted home, and a third represents planned new construction in this community. The 'typical' model of existing homes in Unalakleet is used to evaluate potential opportunities for energy efficiency retrofits; the new and retrofitted building models are used to understand opportunities to improve new and existing homes prior to construction or retrofitting. These models are used to highlight where the most significant energy savings can be achieved.

This paper is organized as follows: after the introduction, the methods section discusses the building energy model development and their inputs. The results and discussion include predicted energy use, home utility cost savings, and CO_2-equivalent emissions reductions from home energy usage. This is followed by the conclusion and future work section.

Data Collection

For three weeks in July and August of 2021, energy assessments and interviews were conducted in the rural community of Unalakleet, Alaska. Their results are summarized in this section [31]. Tables 4.1 through 4.3 below summarize the most typical physical characteristics, indoor air quality readings, and air exchange rates determined from energy assessments. Note the CO_2 and relative humidity (RH) readings were done over 1-2 hours during the interview and indoor portion of the energy assessment. Readings were taken every 6 minutes for CO_2 and every minute for RH.

Table 4.1: Most Common Physical Results by Percentage of Homes Across 27 Energy Assessments

Key Characterizing Results over 27 Assessed Homes		
Topic	**Most Common**	**Homes (%)**
Foundation	Crawlspace	81.5
Esterior Siding	Wood Panel or Vinyl	81.4
Siding Color	Dark	63
Roof	Corrugated Metal	100
Roof Color	Dark	92.6
Gutters	None	63.0
Windows	Double-Paned	59.3
Space and Water Heating	Boiler	55.6; 38.5
Square Footage	< 92.9 m^2 (1000 ft^2)	50.0
Avg. Occupancy	3.08 people/home	---

Table 4.2: Indoor Air Quality Characteristics Across Homes by CO_2 Readings in Parts per Million (ppm) and Relative Humidity Readings in % (note RH values were taken in summer, at an average outdoor tempeature of 16.1°C (61°F))

	Homes	
CO_2 Reading (ppm)	**Number**	**Percent**
Houses Over 1000	11	40.7
Houses over 1500	7	25.9
Houses over 2000	2	7.4

	Homes	
Relative Humidity Reading	**Number**	**Percent**
Houses over 65%	11	40.7
Houses over 70%	6	22.2

Table 4.3: Summary of Air Exchange Rate Readings from Blower Door Tests

Air Flow Values		
Measure	**CFM50**	**ACH50**
Mean	832	6.1
Median	645	5.9
Maximum	2789	12.6
Minimum	106	0.62

Interviews revealed that the main challenges many community members faced were lack of space in their home (55.4% of interviews), drafty windows (50.0%), concerns around mold (50.0%), high energy bills (36.4%), insufficient boiler heating capacity in winter (36.4%), and concerns about poor indoor air quality (47.1%). Concerns around indoor air quality were often reported as having a humid home, mold, high dust levels, or difficulty breathing and having to open a window. Of the 9 interviewees who had no concern with indoor air quality, 3 of them had CO_2 readings above 1000 ppm, a level that may threaten respiratory health [30]. Also worth noting is the blower door test results for areas of air infiltration; all but one home had at least one leaky window. Blower door tests also revealed that per the ASHRAE 62.2 Standard for homes in the United States, 8 of 23 tested homes resulting with flow values were too tight (34.8%), and thus they require mechanical ventilation [5] [10].

Methods

BEopt Energy Model Development

BEopt is a residential energy efficiency modeling software developed by the National Renewable Energy Lab in Golden, Colorado and uses the building energy simulation engine, EnergyPlus. EnergyPlus is a widely vetted and commonly used software program for building energy modeling [24]. Data from the 27 assessments in Unalakleet was used to determine the inputs required to develop a residential building energy model representative of a typical Unalakleet home.

BEopt and EnergyPlus have thousands of variable inputs. This requires that many input variables be quantified for accurate simulation results. For determining these inputs, some variables, such as infiltration rates, were averaged across test results. Other categories, such as foundation type, were inputted as the most observed type throughout assessments in Unalakleet.

Figure 4.1 shows the extensive inputs BEopt requires to create an accurate energy usage model of a home. The left screen (blue) shows all categories of energy model inputs. Highlighted is the “Wall” category. Once “Wood Stud” was chosen, the right screen populated with many different types of insulation. For this model, a custom insulation not found in the default list was created as “R-19 Fiberglass Batts, 2x6, 40.6 cm (16 in) on center (o.c.)” Six interviewees (27.3%) reported having fiberglass insulation in their walls, making it the most frequently reported type of insulation, when insulation type was known. This is like how other inputs were determined, such as foundation with 22 assessed homes having a crawlspace (81.5%).

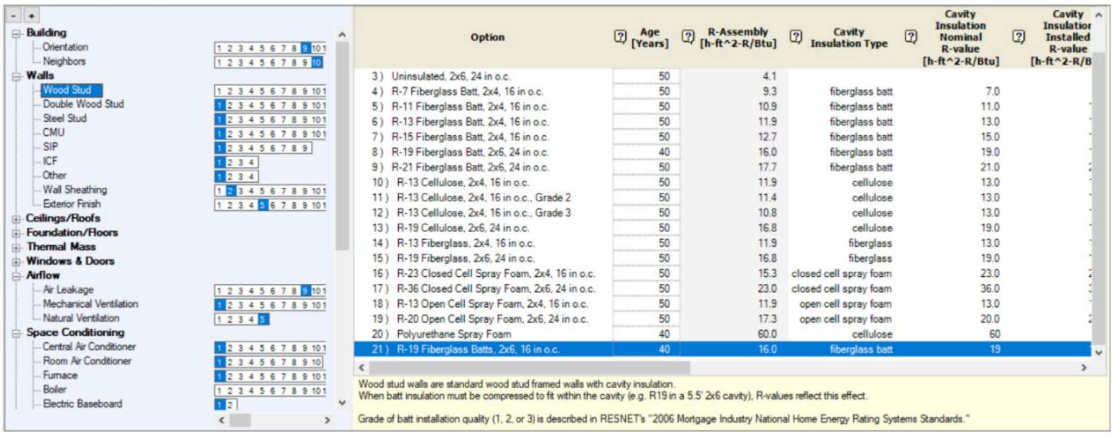

Figure 4.1: Input screen for BEopt focusing on choices for insulation in a wood-stud wall

The next input window in BEopt details climate data and energy costs. A climate data file for the nearby city of Nome was used as public climate data for Unalakleet was unavailable for download online. Nome is north of Unalakleet on the northern tip of the Norton Sound, the bay Unalakleet is located in.

The second input screen is where residential utility costs are inputted. Utility costs for Unalakleet in 2020 was $0.22 per kilowatt-hour (kWh), which is subsidized by the Power Cost Equalization (PCE) program from $0.40 per kilowatt-hour. The PCE is a state-wide fund that brings electricity costs in rural communities down to match the cost in Alaska’s urban areas [31]. Some interviewees feared that the PCE would soon be de-funded due to the state choosing to fund other programs over it. However, the utility costs for all home models in BEopt are inputted as the current cost of \$0.22 per kWh for electricity and \$4 per fuel oil gallon to keep consistent with the community's current bills [31].

Note from Figure 4.1 above that each input variable included many other sub-inputs, from age to total R-value of the wall assembly. Sub-inputs are defaulted into the BEopt program based on material properties. Each separate sub-input will not be discussed unless critical to understanding the wall assembly or home model. For example, in Figure 4.1 above, the R-value of the total wall assembly is a critical property and thus is discussed as part of the wall inputs.

Inputs

Size of Home

The average size of a home in Unalakleet was estimated using Google Earth. The average dimensions (length and width) were determined after all visible homes were measured. The average area of a home in Unalakleet is 104.1 m^2 (1120 ft^2), or 12.2 m by 8.5 m (40 ft by 28 ft). Since BEopt uses a grid system to assign home area, the closest area that could be configured was 106.7 m^2 (1148 ft^2), which was used as the input for home area of a typical existing home.

New homes modeled for Unalakleet were sized at 130.1 m^2 (1400 ft^2) with 3 bedrooms and 2 bathrooms. This is based on discussions both with the housing director and residents. Many interviewees said they would like more space in their home, especially those with high occupant density. More rooms were a common desire for future housing, as well as larger kitchens and living rooms. Note that a larger home is harder to heat than a smaller one; thus, the home size chosen for a new home in Unalakleet was based on the proposed plan the community has for new construction and mentioned in discussion with Unalakleet's housing director.

Occupancy

A typical existing home in Unalakleet contains an average of 4.08 people per home, taken from Alaska's 2014 statewide housing survey [50]. The assessed homes held an average of 3.08 people per home. Occupancy cannot be directly inputted into BEopt; rather, an algorithm within the program is used to determine occupancy based on total number of rooms (N_{br}). This algorithm is shown in the equation below [48].

$$N_{occupants} = 0.59 \text{ x } N_{br} + 0.87$$

To best match the average occupancy of homes in Unalakleet, an input of 3 bedrooms and 2 bathrooms was used, resulting in a simulated occupancy of 2.64 people per home.

Age of Home

Many homes in the Bering Strait Region, which includes Unalakleet, were built in the 1970's and 1980's [51]. Energy assessments in Unalakleet revealed an average house age of approximately 40 years. Therefore, age of home was inputted in BEopt as 40 years. New construction home models were assumed as 1 year old to reflect that the house was newly built.

Building Orientation & Neighbors

Google Earth's Street View was utilized to find the orientation of each visible home in Unalakleet [16]. Most homes were oriented south; this allows for higher solar gain, as mentioned in interviews in Unalakleet. In addition, 78.6% of homes visible in Google Earth had a roof that was sloped on the north and south sides of the home. In all building energy models, a south-facing orientation was used.

Homes in Unalakleet were observed to be very close together. To quantify this, neighboring building distances were measured for each home in Google Earth. Homes on the hill were built farther apart, but most homes were near others in the coastal part of the community. Some homes had close neighbors to the north and south but not east or west, and some homes had the opposite configuration without neighbors north or south of them. Other homes had close neighbors except for in one direction. All these different configurations resulted in the following average neighboring building distances:

- North: 15.1 m (49.6 ft)
- South: 14.2 m (46.6 ft)
- East: 21.5 m (70.4 ft)
- West: 21.3 m (69.9 ft)

These numbers were rounded in BEopt. Note that this is building distances only and not lot sizes. Many lots were filled with materials like transportation vehicles, shipping containers, boats, etc. For all building models, the same neighbor distances are used. Though more lot size per home is desired from interviews, this decision was made based on the recent proposed construction plan Unalakleet has for a new neighborhood. To maximize the number of new homes being built, each house will have a smaller plot of land to itself as mentioned in discussion with Unalakleet's housing director.

Neighboring building distances are important because they affect building air exchange rate calculations. When converting to CFM50 (cubic feet per minute at 50 Pascals (Pa) of pressure), which is a standard airflow value used in the United States, a conversion value is used to represent natural airflow at a normal pressure. This value is referred to as the "N" value, and it is multiplied with the calculated ventilation requirement based on a building's size and occupancy. The "N" value changes according to climate zone, building's stories, and shielding. A building that is shielded from the wind by neighboring buildings or objects may have a lower natural airflow than one that is in a more open area, where wind can more easily enter through leaks in the building's envelope [10].

Walls & Insulation

Homes in Unalakleet had wood stud walls, which is typical of residential construction. In addition, the alternative steel studs form more thermal bridges, or cold areas in the wall that lead to loss of heat energy [35]. The most frequent type of insulation mentioned during interviews and assessments was fiberglass batts, at a value of R-19. Many different types of wall insulation were mentioned when known, but fiberglass was stated most often by residents during 27.3% of assessments. Attics and wall cavities were not accessed during energy assessments due to privacy of participants. The R-value of 19 was mentioned during three separate assessments, which was significant given many participants were understandably unaware of the R-value of their insulation.

The insulation in the building energy model for existing homes is characterized as being R-19 fiberglass batt insulation between 2x6 studs at 40.6 cm (16 in) o.c. This configuration was chosen based on BEopt's default inputs for R-19 fiberglass batts and on standard residential construction in the United States having studs that are 40.6 cm (16 in) apart [48]. BEopt has many inputs for each topic, so insulation includes inputs such as the nominal vs installed R-value, with nominal being 19 and installed being defaulted to 17.3. This means that though the insulation may be purchased as R-19, the actual value of it, once installed, could be lower due to compression in the cavity. The wall assembly has an R-value of 16, including studs, which is lower than the overall insulation value due to increased conductivity through studs.

The retrofitted home and new construction model have different insulation from the existing home model. The type of insulation is based on research from the Cold Climate Housing Research Center following the minimum 2018 IECC (International Energy Conservation Code, version 1) requirements for residential wall insulation for Climate Zone 8 (R-30). Insulation used is polyurethane spray foam with an R-value of 40, providing a wall assembly R-value higher than the IECC minimum [2].

Wall sheathing for all home models is oriented strand board (OSB). Many homes in the United States are built with OSB. Since homes in rural Alaska, especially older homes, are modeled after homes found in the contiguous United States, OSB was assumed as part of the wall assembly.

The exterior finish for the existing home model is wood, which was present on 44.4% of the assessed homes in Unalakleet. It was often painted darker in color. The proposed new and retrofitted home models are proposed to have metal siding, which was recommended during interviews as a sturdier type of siding fit for extreme climate conditions such as strong storms and surges [13]. Many interviewees without it mentioned that they wanted it on a future home.

Ceilings & Roofs

Assessments and interviews revealed that most homes had an attic or roof cavity that was insulated with "blown-in" insulation, assumed to be fiberglass. The R-value was not discussed in many interviews, but one interviewee with a home that was alike to many other assessed homes within the coastal portion of the community said the attic had R-19 insulation, thus this value was used for the existing home model. In the new and retrofitted home models, closed-cell polyurethane spray foam attic insulation at R-60 is proposed based on a prototype created by the Cold Climate Housing Research Center in Quinhagak, another rural community similar to Unalakleet [11]. Since 70.4% of assessed homes had attic ventilation in the form of soffit, gable, or ridge vents, all building model attics included ventilation.

All assessed roofs and 78.0% of roofs observed on Google Earth were corrugated metal, thus corrugated metal was used in the existing and retrofitted home models. The new construction model has a corrugated metal roof also, as many interviewees indicated they liked the way the snow slid off the roof and how sturdy their roof was. The color of the roof used for the existing home is a ‘medium’ color, as many assessed homes had gray roofing. Ideally, roofs in new construction would be dark in color to reduce heating demand in winter due to higher absorbance of heat from the sun [14]. Finally, no radiant barrier was used for any of the energy models.

Foundation & Floors

Crawlspaces were chosen as the foundation type in all energy models, as 81.5% of assessed homes in Unalakleet had a crawlspace. The retrofitted and new construction models were modeled with crawlspaces because the community is very close to the ocean, resulting in a high water table. Insulation in crawlspaces, when known, was frequently reported as cellulose insulation (41.7% of interviewees), but observation of crawlspaces generally revealed insulation appeared to be fiberglass. Fiberglass batt insulation was thus chosen for the existing home model with a value of R-19, as reported in an interview. New and retrofitted home models include polyurethane spray foam insulation in the crawlspace at R-60 based on the Quinhagak prototype [11].

The crawlspace in the existing home model is unvented since most observed crawlspaces did not have vents. Retrofitted and new construction models also do not include vents as wintertime ventilation through a crawlspace may cause accelerated heat loss in the home and put any piping that is close to the crawlspace at risk of freezing [19]. Lastly, floors were observed to be primarily uncovered in homes; a non-carpeted floor was assumed in the existing home model. Some interviewees suggested they would like to have a carpet or rug on the floor; therefore, in the new and retrofitted construction models, carpet is included at 20% floor coverage. This is chosen since many people have children and suggested they may not want a fully carpeted floor, yet many also mentioned they had cold floors. The 20% floor covering can be used to represent a rug in the living area, for example, where home members would most likely be walking around.

Windows

For models of the existing and retrofitted homes, the percent area of each exterior wall covered by windows are as follows:

- North (Back): 25%
- South (Front): 34%
- East (Right): 18%
- West (Left): 14%

These percentages were determined using Google Earth's Street View, measuring approximately 94 homes throughout the community. Homes' exterior walls were viewed from the north, south, east, and west. Homes on the hill overlooking the community were not considered as they were not available in Street View. In new construction, the percent of each exterior wall covered by windows are as follows:

- North (Back): 21%
- South (Front): 38%
- East (Right): 5%
- West (Left): 5%

This configuration provides more light and solar exposure to the south side of the home while allowing light to pass through. In Unalakleet, many interviewees were concerned about the strong wind that blows from the east in the winter. Therefore, the east side of the new construction model is proposed to have a minimal number of windows. The west orientation is proposed to have similar window area as the east because the Bering Sea to the west can produce strong storm surges in the fall and winter, which may hit homes especially close to the sea. As climate change progresses, these storms become stronger and more frequent, risking water intrusion in homes close to the ocean [13].

Window type for the existing home model was chosen based on assessment observations. Clear, double-paned, vinyl-framed windows were observed in 59.3% of the assessed homes. BEopt includes air in between the frames of the window inputs, so the final input for window type was chosen as “Clear, Double, Non-metal (frame), Air.” Interior shading was used in most homes (70.4%), as either curtains or blankets. All models will use the assumed default interior shading value of 0.5 in the summer and 0.7 in the winter, following observed occupant shading habits. Fractions closer to 1 represent no reduction in solar gain. Eaves provide minimal shading in 81.5% of assessed homes, and most appeared to be about 0.3 m (1 ft) long. The existing and retrofitted models include these eaves. Eaves will be present on new home models at 0.6 m (2 ft), the default in BEopt for eave length.

Window type in new and retrofitted construction was determined based on data from the construction site of a new home in Unalakleet. New and retrofitted home models include double-paned, argon gas-filled windows with a low solar gain coefficient and low emissivity factor. Figure 4.2 below shows the windows’ relevant information, taken from the site of a new home currently being built in Unalakleet.

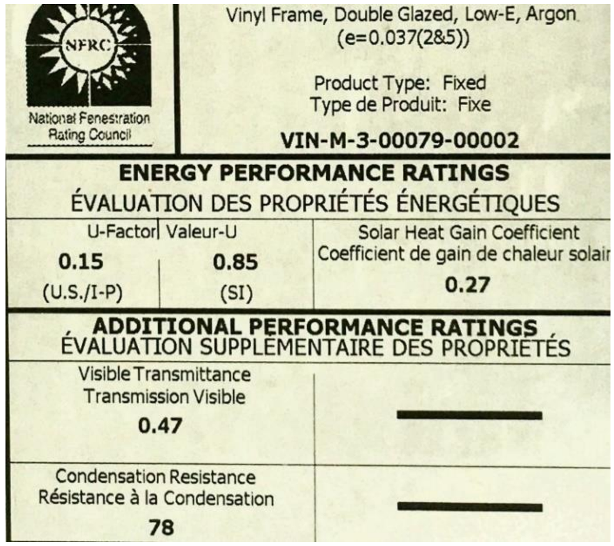

Figure 4.2: Window tag showing label with energy and performance ratings

A low U-value is recommended for climate zone 8 (where Unalakleet is located), but solar heat gain coefficient does not have a requirement [7].

One interviewee explained their choice of solar panels as an extended eave, doubling as shade and energy generation in the summer. Renewable energy, especially as solar panels, is something 81.8% of interviewees said they would like to see. This analysis looks at efficient home design before incorporating renewable energy, which is a key step towards full utilization of energy generated from a renewable source.

Doors

Door area is an assumed parameter. Most homes had two exterior doors: one connecting to the arctic entry or porch and one in the back. Many times, the back door was not used, or it was damaged. Doors were wooden, which remain the same in all models. Door area will also remain the same at about 1.9 m^2 (20 ft^2) of exterior wall, the first available input option for door area in BEopt.

Air Exchange Rates

The average airflow value resulting from the blower door tests in Unalakleet was 6 ACH50, which is inputted as the air leakage value in new and retrofitted home models. New construction is proposed to be built tighter but require mechanical ventilation. The value used in the new construction model is 3 ACH50, which is tight construction assuming use of mechanical ventilation. A rating of 4 ACH50 or less is considered energy efficient in Alaska according to the Building Energy Efficiency Standard (BEES) [3].

New and retrofitted construction models include mechanical ventilation as a 2013-model HRV (heat recovery ventilation system), which recovers 70% of the sensible heat it takes from exchanged indoor air with fresh outdoor air. This model is included in BEopt. Blower door test results found that 34.8% of assessed homes needed mechanical ventilation but did not have any. This was associated with small homes that had high occupant densities. New and retrofitted models assume that occupants use their HRV in the winter, but many interviewees with HRVs in Unalakleet said they did not use it, citing the high cost of electricity or cold air drafts. Natural ventilation was used mainly in the summer as opened windows. To account for rainy days or days in which home occupants did not open the windows, all energy models assume that natural ventilation was used during the cooling months at 5 days per week. BEopt assumes windows are open during the specified season until the inside temperature falls below 21.7°C (71°F).

Space Conditioning

No space conditioning occurred apart from heating, based on the housing assessments in Unalakleet. With 55.6% of assessed homes having a boiler, even if they also had a wood stove, a boiler was used as the heating mechanism in the existing home model. All boilers observed used oil to heat water and were assumed to be a forced draft model due to their age and annual fuel utilization efficiency value (AFUE) being below 90%. An efficiency rating of 85% for the boiler was assumed in the model, based on an average of the nameplate efficiencies observed during assessments. Decreased efficiency of the boiler with age is discussed in the sensitivity analysis section. The temperature setpoint for heating is maintained at 23.9°C (75°F) in all models, the average temperature set by interviewees in the winter.

The new and retrofitted construction models include condensing boilers that are oil-fed and operating at 95% AFUE, a more efficient replacement for the forced-draft boilers found in most existing homes. Interviews in Unalakleet discussed a desire to retrofit their homes with newer, more efficient boilers that had a high efficiency rating (around 90-95%).

While new, oil-free technologies are being developed to be used in sub-Arctic and Arctic climates, research is ongoing in their feasibility and climate-specific design. Air and ground-source heat pumps, for example, perform well in moderate climates but face challenges in Alaska's extreme cold climate [15]. In addition, if decarbonization is also a priority, electric boilers produce less Scope 1 (on site) emissions than oil-fed boilers, but Scope 2 emissions (indirect from electricity consumption) will vary based on the electricity generation source. In the case of Unalakleet most of the electricity is produced from diesel generators, which are among the most inefficient and carbon-producing electricity production systems. Further, residents who already pay a very high electric bills may not see the benefit of this switch as the boiler is used very often throughout the year and especially in winter.

Water Heating

Boilers (combustion and electric), heat exchangers, and small on-demand water heaters were observed in assessed homes. Boilers were found in 38.5% of homes, the most common type of water heater. These boilers were either the same one that heated the house or a separate boiler for heating water. A tank for storage was also present in some homes with separate water heater boilers. The existing home model thus includes use an oil-powered water heater tank in which water is distributed through a standard R-2-insulated copper pipe, as pipes are required by IECC 2018 to be insulated [2]. Pipes in many assessed homes were placed in the walls surrounded by exterior insulation as well. The oil tank in BEopt is not a boiler, but its fuel source is the same. The new and retrofitted home models include water heating systems that are more efficient and with the same piping type as the existing home model. This includes 50-gallon electric water heaters with an efficiency factor of 0.95 out of 1 (100% efficient) compared to the oil tank's of 0.68. The choice to use an electric water heater but not an electric-powered boiler comes from interview results. Water usage, as reported in interviews, was split by season and by occupancy, but the boiler was often used all year with increased use in winter. In the summer, households with children indicated they used more water than in the winter, as the kids were out playing more. Households without children claimed they used less water all year. The mean water usage was assumed as the national average, described below in *Appliances and Fixtures* [24].

Lighting

While many assessed homes included LED lighting, not all lighting was fully LED. CFL lighting was common as well, but LED took precedence. Lighting input for the existing home model is proposed to be 60% LED hardwired and 34% CFL plugin lighting, with the remaining percentage being incandescent lighting. New and retrofitted construction input is 100% LED.

Appliances & Fixtures

If an appliance had an efficiency tag (e.g., EnergyStar) that was visible during the assessment (most did not), efficiency rating was noted. Since most appliances were of an unknown efficiency, standard efficiency values were assumed for the existing home model. Refrigerators were listed with an energy efficiency value (EF) of 14.1, or a middle value between higher efficiency (21.9) and lower efficiency (4.4). These efficiency values represent how well the refrigerator utilizes the energy it receives from electricity to keep the inside cool. Cooking stoves in assessed homes were all electric except for one, and clothes washers and dryers appeared to be of standard efficiency, with an occasional EnergyStar-rated appliance observed. All but 4 homes had at least one separate freezer to store food gathered during the summer months, so an extra freezer was inputted for all models.

In terms of appliance and water fixture usage, all models are assumed to be the same to reflect the occupancy schedule in the existing home model. Appliance and hot water usage was assumed as the national average, or as “Standard” in BEopt since some interviewees stated they did not use their appliances more than once or twice a week while others, especially those with multiple household members, used their appliances more. These numbers are based on an occupancy activity study done in the Pacific Northwest region in 1989 [27]. Later studies have confirmed that this occupancy schedule study remains relevant to today [12]. Plug loads, such as electronics, were assumed at a usage value of 50% of the national average due to a small number of electrical appliances found in assessed homes.

The new and retrofitted homes are assumed to have similar appliances. Refrigerators and freezers are assumed to have an average efficiency factor of 14.1 and 24, respectively. The stove is assumed to be electric, but the clothes washer will be switched to an EnergyStar-rated appliance, using less energy to wash clothes than the non-EnergyStar washer does. The clothes dryer is assumed to be the same as in existing home models (electric).

Results and Discussion

Existing Home Output

The energy simulation results for a typical existing home in Unalakleet are shown in Figures 4.3 through 4.5 below. Note (O) represents an oil source and (E) represents electricity.

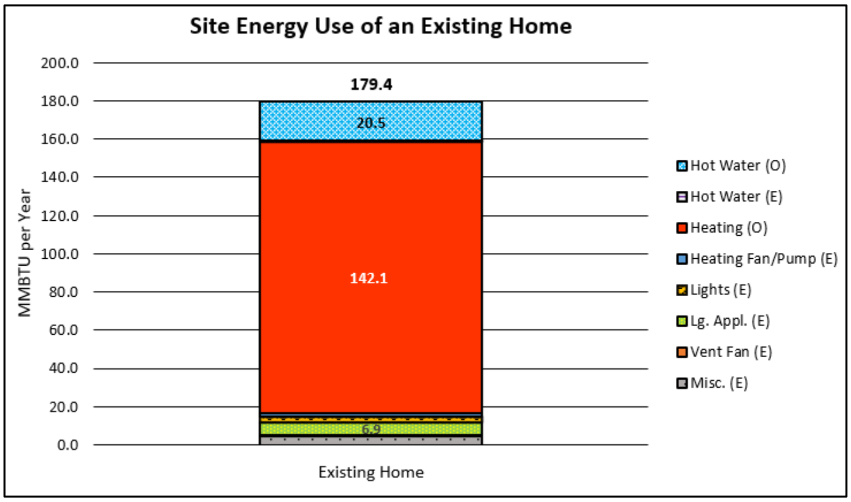

Figure 4.3: Existing home model annual site energy use in MMBTU (1 million British thermal units)

In total, the energy use estimate for an existing typical home in Unalakleet is 179.4 MMBTU/yr. Energy use in an average single-family home in the United States in 2015 was 77 MMBTU/yr. [43]. A housing study completed in 2018 found that the average home energy usage throughout Alaska was 227 MMBTU but 161 MMBTU for the Bering Strait region, which includes Unalakleet. Thus, BEopt provided an energy use estimate that was close to the average measured in the Bering Strait region. These numbers also suggest that some regions in Alaska may experience higher energy usage per home than in Unalakleet [49].

Two considerations should be accounted for when comparing energy use numbers in the existing home model, Alaska, and the U.S.: potential error in the BEopt model inputs, which are based on a sample of 27 homes, and the extreme climate in Alaska requiring significant home heating.

Still, the average amount of energy used in Unalakleet is much higher than in the United States overall. The west region of the U.S., which includes Alaska, used an average of 60 MMBTU per household in 2015 (U.S. Energy Information Administration 2021).

In this model, space heating accounts for 79.2% of total energy usage. This suggests that energy savings and decarbonization opportunities are potentially greatest in reducing heating energy needs, such as through a tighter envelope or increased insulation. For example, changing the wall insulation to polyurethane spray foam with a value of R-40 but keeping all other parameters the same results in an energy savings of 15.3 MMBTU per year. Polyurethane spray foam is easy to ship due to its low bulk size [11].

Considering daily savings, 179.4 MMBTU divided over 365 days is about 0.5 MMBTU used per day. Changing just the wall insulation saves 15.3 MMBTU annually, or the equivalent of 30.6 days of energy savings. By only switching the insulation to be new and more efficient at keeping in heat, the house will save as much energy as it took to power it for a month.

Space and water heating accounts for 79.8% of total energy costs, shown below in Figure 4.4.

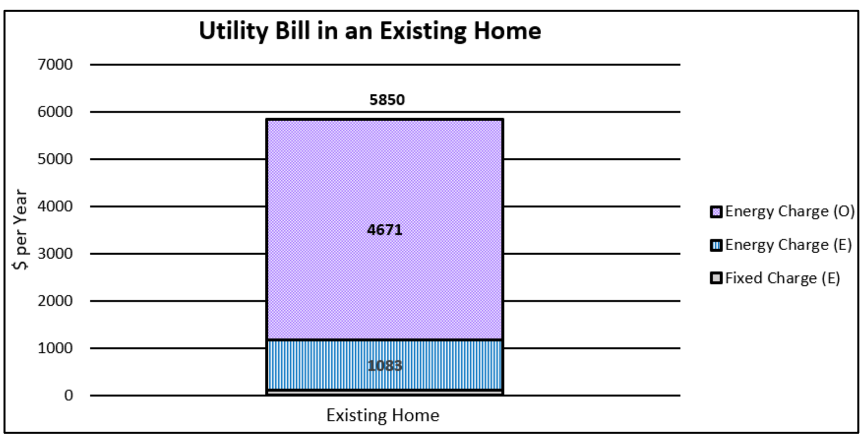

Figure 4.4: Annual utility bill estimate for the existing typical home model in Unalakleet

BEopt breaks the utility analysis up by fuel type, but Figures 4.3 and 4.4 show most of the utility cost comes from heating. This model gives annual energy costs at $5,850, or $487.50 monthly energy costs. Note the electricity bill is lower than the average reported in interviews ($172.86), however this may be due to variations in weather patterns between the typical meteorological year data use for this simulation and the weather experienced in the particular year of data collection. The average value from interviews is also only an estimate and may not be reflective of the actual averaged amount over a year. Using the example of changing only the wall insulation to be more efficient, $442 can be saved annually in utility bills.

Building a more efficient home will have an impact on the environment as well. Figure 4.5 below shows the amount of CO_2-equivalent (CO_2-eq) emissions produced by the typical existing home model in Unalakleet. Each year, an estimated 18.0 metric tons (19.8 tons) is emitted. This estimate is based on the CO_2-eq emissions resulting from burning a gallon of fuel oil (27.37 lb. CO_2-eq emissions/gallon) and using fossil fuel-generated electricity in the household (1.53 lb./kWh) [24]. Creating a more efficient home will reduce the amount of CO_2-eq emissions produced per year as energy usage and loss will be lower. Switching the wall insulation from R-19 to R-40 results in a 1.4 metric ton (1.5 ton) decrease in CO_2-eq emissions every year.

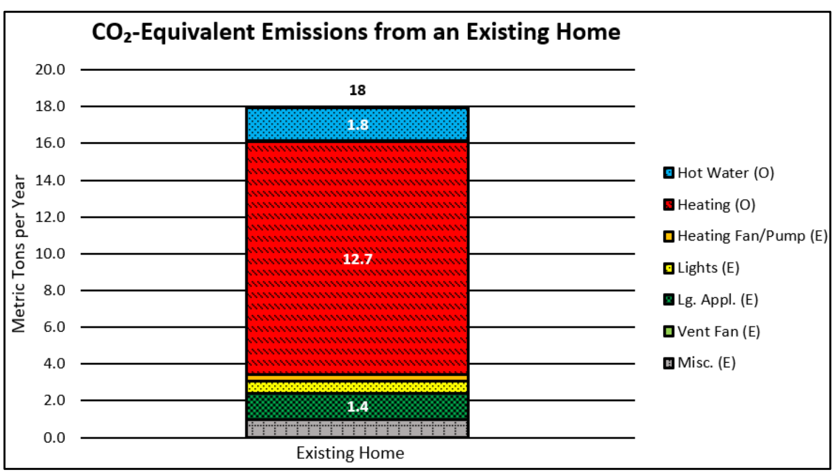

Figure 4.5: CO_2-equivalent emissions from the typical existing home model in Unalakleet

Retrofitted Home Output

Changes made to the retrofitted home from the existing home model are summarized in Table 4.4 below:

Table 4.4: Inputs of Retrofitted Home vs Existing Home Model (eff. = efficiency)

Topic	Category	Existing Home	Retrofitted Home
Insulation	Wall	R-19 Fiberglass Batts	R-40 Polyurethane Spray Foam
	Crawlspace	R-19 Fiberglass Batts	R-60 Polyurethane Spray Foam
	Ceiling	R-19 Fiberglass Batts	R-60 Polyurethane Spray Foam
Siding	Ext. Wall	Wood	Metal
Rug	Floor	0% coverage	20% coverage
Fenestration	Windows	Clear, double-pane, non-	Low-E, double=pane, non-
Mech. Ventilation	HRV	None	2013 HRV 70% efficiency (eff)
Appliances	Space Heating	Forced draft oil 85% eff.	Condensing oil 95% eff.
	Water Heating	Oil-premium 0.68/1 eff.	Electric-premium 0.95/1 eff.
	Clothes Washer	Standard	EnergyStar
Lighting	Bulbs	60% LED	100% LED

The output graphs for a modeled retrofitted home in Unalakleet are displayed as Figures 4.6 through 4.8. The overall site energy usage is less than the existing home model by 30.1%.

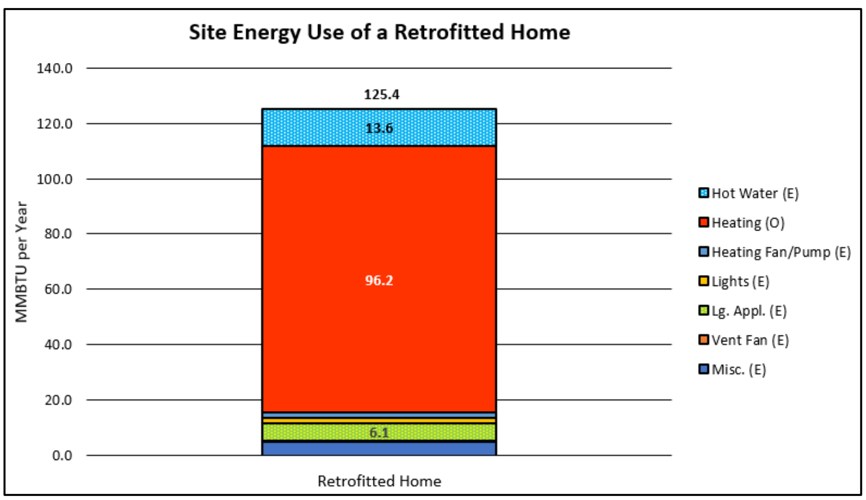

Figure 4.6: Retrofitted home model site energy use in MMBTU

Compared to the existing typical home model, a retrofitted home would save 54 MMBTU in a typical year. This savings amount would differ if the changes in Table 4.4 above were varied. In the retrofitted model, space heating continues to be the largest annual energy use, accounting for

76.7% of energy usage. This is a similar amount to the existing home model. The retrofitted home has an energy usage from space heating that is 32.3% less than the existing home model. Cost savings in the retrofitted home model versus the existing was $1,106 per year, or $92.17 per month. The utility break-down by energy source is shown in Figure 4.7 below.

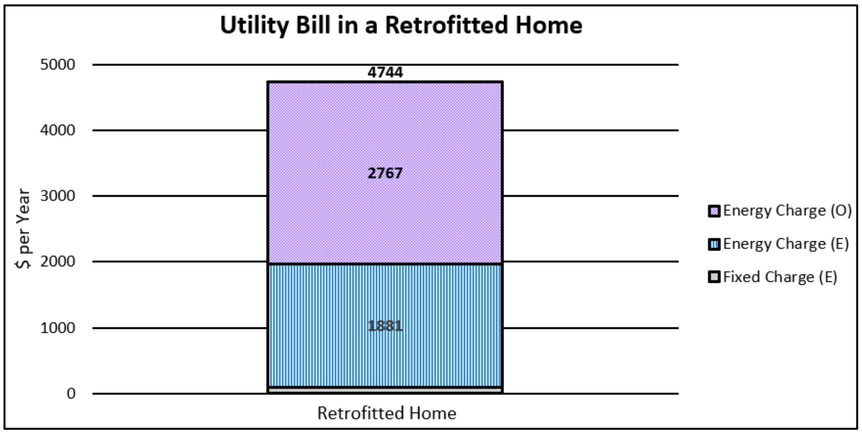

Figure 4.7: Annual utility bill estimate for the retrofitted home model in Unalakleet

Electricity costs increased in this model compared to the existing home because the water heater was switched to electric from oil. The increase is by $798 per year, but the overall utility cost is less than that of an existing home. Much of this change is from installing high R-value insulation in the walls, attic, and crawlspace ($702 per year).

The CO_2-eq emission reduction between the existing and retrofitted home models is estimated as 3.5 metric tons (3.9 tons). Higher R-value insulation in the walls, floor, and attic account for 62.9% of this reduction. Figure 4.8 shows the CO_2-eq emissions of the retrofitted home model.

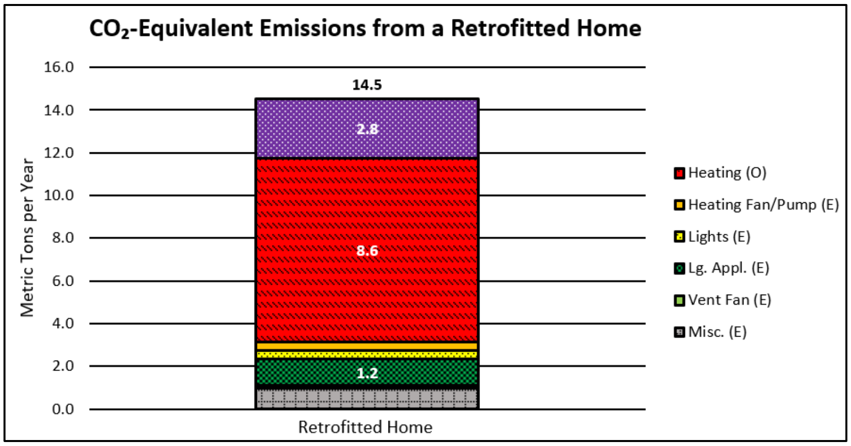

Figure 4.8: CO_2-equivalent emissions from the retrofitted home model in Unalakleet

The retrofitted home model thus suggests that increasing the insulation R-value in the walls, ceiling, and attic will provide the greatest reductions in energy usage, utility costs, and CO_2-eq emissions compared to the existing typical home model.

New Construction Home Output

All inputs used in the retrofitted model were used in the new construction model. Table 4.5 below shows the additional changes between the existing and new construction models.

Table 4.5: Inputs for the New Construction Model That Differ from the Retrofitted Model

Topic	Category	Existing Home	New Home
Building	Size	106.7 m² (1148 ft²)	130.8 m² (1408 ft²)
Roof	Metal	Medium-Color	Dark
Windows	% Area of Wall	34 S, 25 N, 18 E, 14 W	38 S, 21 N, 5 E, 5 W
	Eaves	0.3 m (1 ft)	0.6 m (2 ft)
Air flow	ACH50	6	3

As many of the inputs for the new construction and retrofitted models are the same, the energy usage outputs are similar. Given that the new construction model is a larger home, the energy output being close to the retrofitted home is a success. This also suggests the importance of efficient insulation in the walls, attic, and crawlspace. Many community members talked about the need for more space in their home, so having a new home that is larger but can perform efficiently and keep occupants warm is important when considering the new versus retrofitted homes. Figure 4.9 below shows annual energy usage for an estimated new construction model.

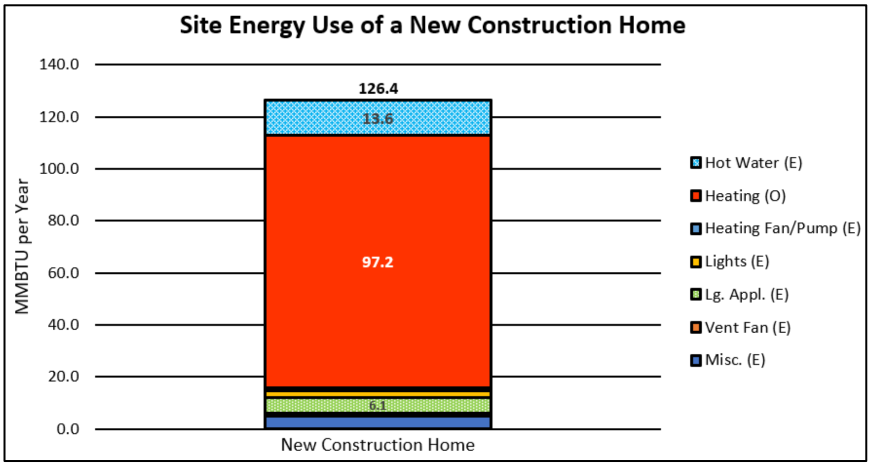

Figure 4.9: New construction model site energy use in MMBTU

The energy usage for estimated new construction is 1 MMBTU more per year than usage in a retrofitted home. This is likely due to larger home size and more fuel needed to heat this additional space. Compared to the existing home model, this model saves 53 MMBTU per year, or 4.4 MMBTU per month. Total energy usage from space heating is 31.6% lower than in the existing home model, largely due to increased R-value insulation.

Figure 4.10 below displays annual estimated utility costs for a new construction model. The costs are $35 more per year ($2.92/month) than in a retrofitted home most likely due to heating a larger space. This is still much less than the utility bills for an existing home at $1,071 less annually, or $89.25 less per month. Electrical charges increased from the retrofitted model by $6 per year and from the existing home model by $804 per year, but the overall utility costs have decreased from the existing home output.

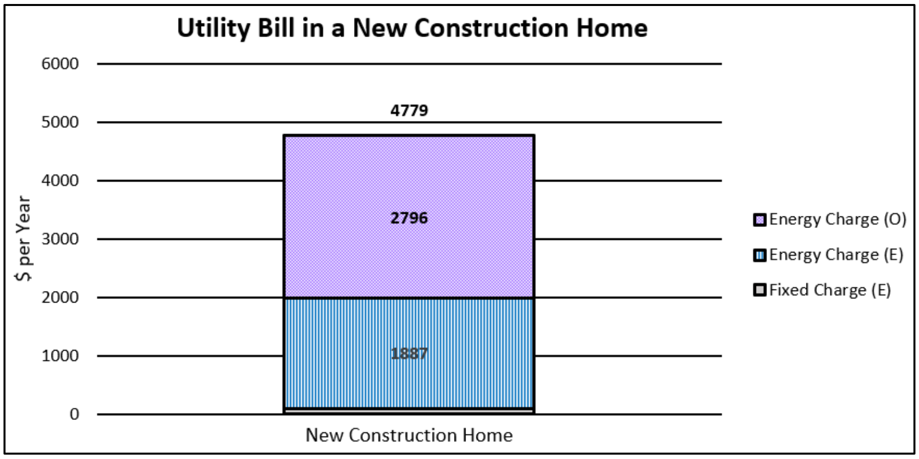

Figure 4.10: Annual utility bill estimate for the new construction model in Unalakleet

Last, Figure 4.11 shows estimated CO_2-eq emissions resulting from energy use in a newly constructed home. The home produces 0.1 metric ton (0.1 ton) of CO_2-eq more than the retrofitted home model, assumedly due to size, but 3.4 metric tons (3.7 tons) less annually than the existing home model.

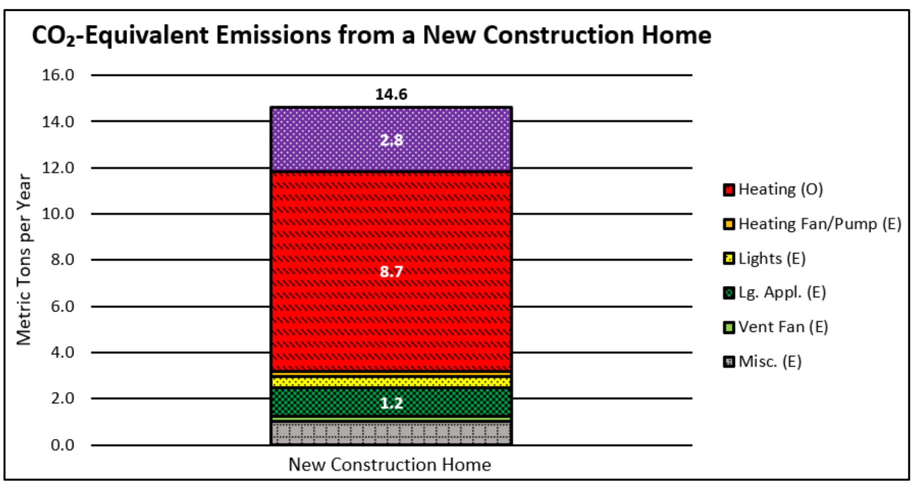

Figure 4.11: CO_2-equivalent emissions from the new construction model in Unalakleet

Sensitivity Analysis

The building energy models include inputs that can be varied to check for differing results. The insulation used in the existing home model is based on a few interviewees' reported R-values. A sensitivity analysis in which the existing home model's insulation R-value was varied slightly showed that the site energy use was still higher than the retrofitted and new models. When using R-13 fiberglass batt insulation in the walls, crawlspace, and attic, the site energy use increased from 179.4 MMBTU to 190.3 MMBTU per year. If the insulation value in existing homes was closer to R-21, the site energy usage decreased by 5.4 MMBTU. Minor differences in R-values, such as R-13 to R-19, or R-19 to R-21, do not provide much of a difference in site energy usage. Again, the interviewees that reported R-19 insulation had homes that were like many other assessed homes in the community, which is why R-19 was chosen. Another variation may have been in the efficiency of boilers in homes, as many boilers were older and could have decreased in efficiency from what was listed on their nameplate and used in the existing building energy model. Changing just the boiler efficiency to be lower than originally used (72% compared to 85% efficient) but keeping all other parameters the same shows an increase in site energy usage of 15 MMBTU per year, which is significant. However, this result further supports the conclusion that new and retrofitted homes will provide a decrease in site energy usage.

Last, the retrofitted and new home models include windows that are double-paned instead of triple-paned. These double-paned windows are more efficiently built than those in the existing home model. The retrofitted and new model windows were chosen from windows specially made for Unalakleet in a new home being built in the community. If triple-paned windows were chosen and all other window design parameters, such as emissivity and framing, remained the same, the decrease in site energy usage in the retrofitted and new home models is 1.3 and 0.9 MMBTU, respectively.

This sensitivity analysis was meant to look at variations in a few inputs that could occur due to differing responses from interviewees or changes in appliance efficiency due to age. If inputs are varied, the site energy usage remained close to the original model homes' output, or it increased. The other outputs, utility cost and CO_2-eq emissions, are dependent on changes in site energy usage, which is why site energy usage only is analyzed in this section.

Conclusion and Future Work

Physical home characteristics of homes in Unalakleet were averaged across 27 homes and used as inputs into BEopt, a residential energy modeling software, to develop a typical building energy model of a residential home for this location [24]. This model was used to evaluate the possible energy and cost savings from retrofitting these homes and for new construction. Results showed that the model of an existing home in Unalakleet has an estimated energy usage of 179.4 MMBTU per year, over twice the national average and largely due to extreme climate. Efficiency improvements displayed in the retrofitted and new construction models lowered this energy usage by 30.1% and 29.5%, respectively. Utility costs were lowered by 18.9% in the retrofitted home model and 18.3% in the new construction model. CO_2-equivalent emissions decreased in the retrofitted and new construction models by 19.4% and 18.9%, respectively, as well. Based on results, retrofitting existing homes creates a significant decrease in energy usage, mostly from replacing insulation to be more efficient. For perspective on what one efficiency improvement can do, switching only the wall insulation from R-19 fiberglass to R-40 polyurethane spray foam resulted in a 7.5% decrease in energy usage and 7.7% decrease in utility costs.

Overall, Unalakleet and other rural communities in Alaska will benefit from newer, more efficient housing in many ways. From improved thermal comfort in the winter to lower utility bills and more space per occupant, there are many benefits to new housing in these remote areas. Future studies can consider a cost-benefit analysis of new construction, between initial construction costs and energy savings over time. If new construction is not feasible for the community, retrofitting existing homes with more efficient insulation will also decrease energy usage. Building homes in rural Alaska is very expensive due to shipping of materials and labor, so a funding source or another type of financial assistance could support construction and weatherization. However, the health, comfort, and other non-energy benefits associated with more efficient homes and cleaner indoor air quality are also important to consider [21].

A longer assessment study will be helpful to assess both a wider range of homes and collect long-term indoor air quality and occupancy schedule data. All information collected over time can be used to create more accurate energy efficiency models. For now, the purpose of this paper was to provide evidence that newer, more efficient homes will greatly benefit rural Alaskan communities.

CHAPTER 5: CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

Summary of Research Completed

This research conducted field data collection, including home energy assessments and interviews in the rural, primarily Alaska Native community of Unalakleet, located on the west coast of Alaska. This data collection was completed to quantify housing energy and indoor air quality performance, as well as to obtain input and feedback from residents on these challenges and opportunities for improved housing. Results suggest that there are both energy and indoor air quality challenges that could be improved, including lack of mechanical ventilation resulting in high CO_2 concentrations and relative humidity levels in some homes, high energy bills, damaged interiors and exteriors, water damage, and mold growth. Interviews revealed that many people are aware their home would benefit from repairs, but that maintenance is expensive and generally must be self-performed. High energy bills are a burden in the community, making renewable energy use attractive to some members to support lower utility bills. Finally, a building energy model was developed to represent a prototypical existing home in Unalakleet, using inputs from energy assessments. This was used to estimate the potential benefits of efficiency improvements to new and retrofitted housing. Data collected from the community was used in the models, providing more accuracy to what a typical assessed home in Unalakleet may experience regarding energy use and costs. The models suggest energy savings opportunities are greatest in replacing insulation with higher R-value insulation in the walls, attic, and ceilings of existing and new homes.

Research Contribution

While statewide summaries of the housing need in Alaska exist, they are not done on a community level despite still being an extremely valuable tool in addressing housing concerns.

The scale of this thesis's research was on the community level, specifically aimed at providing evidence that rural communities in Alaska can benefit from more efficient housing. Thus, the contribution this research made to the field of energy efficiency is the direct evidence of need for efficient housing in rural Alaska. An overview of research contribution achieved by this thesis is listed below:

- Completed 27 housing assessments in a remote, rural community in Alaska including indoor air quality monitoring and blower door testing, among others, providing more detailed data than is currently available on the state of rural Alaskan housing
- Collected interview data from community members on what they believe to be housing concerns in their community, as well as what they would like to see in future housing
- Created an energy model based on data collected through 27 assessments in the community of Unalakleet, Alaska, enabling the ability to assess and quantify energy savings potential of various retrofits

Limitations

Although this research is unique and has contributed understanding to housing concerns in rural Alaskan communities, some limitations exist. Twenty-seven homes were assessed in a community of about 200 homes, and in one rural Alaskan community. However, Unalakleet is a large, primarily Alaska Native community that is similar to many other rural communities in the state. Further research and in-depth comparison could study if housing characteristics in Unalakleet are alike to the housing stock in other rural Alaskan communities. Sampling was random and distributed throughout both the coastal and hill portions of the community; still additional testing could be completed to confirm that 27 homes' data is sufficient to represent the whole community building stock. Time constraint was another limitation as the research took place over three weeks in the summer of 2021. This window was open between the commercial fishing and hunting seasons, both in which many community members leave the area.

These assessments were also completed in the summer season. Additional air exchange rate and indoor air quality readings could be completed in winter when the inside and outside conditions are vastly different. Many homes open windows in summer for natural ventilation, providing fresh air indoors, in comparison to winter when windows are generally closed. This creates indoor environmental conditions that are more likely to be conducive to indoor air quality concerns. During the summer assessments, the weather was rainy, and many people had their windows closed, which created an indoor environment similar to what may exist in the winter. Long-term indoor air quality and occupancy schedule monitoring would also provide a more accurate representation of a home's indoor environment in Unalakleet.

BEopt provided some limitations to the study as well. There is no input for wood stoves as they are not common in most U.S. homes. Given that the community supports the addition of wood stoves in new homes, modeling them in future building energy models would be beneficial in understanding total site energy usage. In addition, climate data for Unalakleet was estimated in BEopt based on climate data for Nome, a nearby community.

Future Work

As mentioned in the limitations section above, long-term monitoring of housing conditions in Unalakleet could provide more accurate indoor air quality and occupancy schedule data. Monitoring additional air quality parameters, such as particulate matter, will give a better representation of the indoor and outdoor air compositions, especially when considering wood stoves and mechanical ventilation. Similar research done in other communities would also help to identify housing concerns that are unique to each community or common between them.

Future work could consider more in-depth energy modeling using EnergyPlus or similar software. New and developing, more efficient technologies for heating homes and water or for providing electricity could be considered in future models and homes as well.

Spreading awareness of housing concerns in rural Alaska can help gain support from governmental organizations, researchers, engineering firms, architects, and the general population. More knowledge of housing concerns leads to more awareness, ultimately supporting the design and construction of new efficient homes in rural communities across Alaska.

APPENDICES

APPENDIX A: COMMUNITY SUMMARY – PHYSICAL ASSESSMENT DATA

APPENDIX A: COMMUNITY SUMMARY – PHYSICAL ASSESSMENT DATA

Maria Milan, Kristen Cetin, Jessica Taylor, Cristina Poleacovschi

Data collected and compiled by Maria Milan

This summary focuses on the physical housing characteristics data collected from July 27th, 2021, to August 11th, 2021, in the Native Village of Unalakleet (NVU). Interview data collected during this same period will be compiled separately. This summary is based upon collaborative work between Michigan State University and Iowa State University, which is supported by the National Science Foundation project 1928105. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the research team and do not necessarily reflect the views of the National Science Foundation.

Sample Pool of Homes

The housing data collected and summarized in this document includes a random sample of homes in Unalakleet. Homes were visited after initial contact by an interested participant. Some of the assessments were follow-ups from the interviews conducted in May 2021. Twenty-five of the assessments were done in the main area of Unalakleet near the Bering Sea, while two were done on houses on the hill. Participants were compensated for their time.

Contact

Maria's email for any questions, comments, or concerns: **milanmar@msu.edu** (expires 5/2024) or **mlmilan1221@gmail.com**

PHYSICAL CHARACTERISTICS

The average year a house was built was 1984. The oldest house was built in 1940, and the newest in 2016.

Average occupancy in the assessed homes was 3 people. The home with the greatest occupancy had 7 people living there; a few homes had 1 occupant. Density ranged from 13.8 m^2 (148.6 ft^2) per person to 99.0 m^2 (1066 ft^2) per person (single occupant).

Only 3 homes were more than 1 story tall (11.5%). Average square footage was 98.0 m^2 (1055 ft^2) for single-family homes, with a range of approximately 29.7 m^2 to 250.8 m^2 (320 ft^2 to 2700 ft^2), not including attached garages on 3 of the homes.

The most common orientation of the homes' front entrance was south (40.7% of homes). Seven homes faced north (25.9%), 5 faced east (18.5%), and 4 faced west (14.8%). The average area of the south wall covered by windows was also highest, at 9.8% windows. The maximum area covered by windows was on a house with 19.4% of the south wall covered by windows. Other walls are as follows:

- North: Average of 6.1% window area coverage with a maximum of 15.3%
- East: Average of 3.5% window area coverage with a maximum of 14.1%
- West: Average of 8.6% window area coverage with a maximum of 16.5%

Neighboring buildings were in proximity as follows:

- North: Average of 12.8 m (42.1 ft) away and a minimum of 1.2 m (4.0 ft) away
- South: Average of 12.5 m (41.1 ft) away and a minimum of 4.0 m (13.0 ft) away
- East: Average of 12.2 m (40.1 ft) away and a minimum of 0.3 m (1.0 ft) away
- West: Average of 15.6 m (51.2 ft) away and a minimum of 1.8 m (6 ft) away

EXTERIOR ASSESSMENT

Foundation

A crawlspace was the most common type of foundation (22 homes: 81.5%). The rest of the foundations were a concrete slab-on-grade (5 homes: 18.5%).

Shifting of the ground was evident in 9 homes (33.3%). Twenty-one homes (77.8%) sat on what appeared to be level ground, while 6 homes (22.2%) did not. These homes appeared to be on a slope or uneven ground. Damage that was observed in some homes potentially due to shifting ground included the following:

- Roof of porch shifted upward
- Exterior doors close on their own or are difficult to shut
- Stabilization of home had to take place by placing planks or dirt under foundation
- House is on an uneven grade (front may be higher than back, or opposite)
- Ground under porch is uneven

Twelve homes (44.4%) had visible damage in or on the crawlspace. Of homes that had damage, the most common were cracks, chips, or holes in the crawlspace skirt (shield around crawlspace) (6 homes: 50%). Some other observations include:

- Rotting of support beams likely due to leaking water from plumbing inside the home
- Moss and/or rust in places around the crawlspace skirt
- Missing insulation (not present around crawlspace skirt)

Pooling water was not visible around most homes. However, there was generally a lack of gutters and downspouts designed to limit pooling near the homes' crawlspace or foundation. Since weather was rainy throughout much of the July-August 2021 assessment trip, water was commonly present in the community. Only 5 homes (18.5%) had pooled water near the foundation at the time of the assessment. One of the 5 homes mentioned had water pooling under the foundation.

Exterior Walls

Most exterior walls were painted a dark color (17 homes: 63.0%), while a smaller number had lighter-colored walls (10 homes: 37.0%). In heating dominated climates, darker-colored exteriors absorb more heat from the sun as compared to lighter colors [14].

Exterior siding varied, but most homes had either wood paneled siding (12 homes: 44.4%) or vinyl siding (37.0%). Vinyl siding was common in the Happy Valley neighborhood. According to homeowners, the best-performing siding against the climate and weather included metal paneling (3 homes: 11.1%) and T1-11 siding (1 home: 3.7%).

Water stains, such as rust or water-stained siding, were present on the siding of almost half the homes assessed (13 homes: 48.1%). Rust was present on the siding of 9 of these 13 homes with water staining (69.2%). The rust was generally found on the siding around holes from nails and piping.

Sixteen homes (59.3%) had damage to the exterior siding such as the following:

- Cracking and chipping of siding
- Broken siding panels
- Rotting and damaged exterior porches or siding panels
- Damage that appeared to be from being hit by an exterior object or force

Roof

All assessed roofs were made of the same material: corrugated metal. As indicated by participants, this type of roof lets snow slide off easily.

The average year a roof was built was 1986. Twenty homes (83.3%) had roofs that were the same age as the house. Four of the 7 homes with different-aged roofs had their roof remodeled after the house was built (57.1%). The other homes (42.9%) had the roof set up before the rest of the house was built.

Damage was not visibly present on most of the roofs (20 roofs: 74.1%). Of the roofs that did have damage (7 roofs: 25.9%), the damage noted was rust.

The roof orientation was most commonly with the slopes of the roof facing North and South (19 homes: 70.4%).

The roof color was dark for 25 of the 27 roofs (92.6%), while the remaining portion were lighter in color. Like darker colored exterior siding, this may help to increase solar heat gains in winter for these homes [14].

Roof vents were present on some homes. Nineteen homes (70.4%) had some type of attic/roof venting. Of these 19 homes, fourteen (73.7%) had only gable vents (box-like structure at the arch of the roof's frame, on the exterior wall). Three of the 19 homes (21.4%) had gable and ridge vents (a raised vent running along the arch of the roof on the actual roof), and 1 home (7.1%) had both soffit and gable vents. One home (7.1%) had all three vents present (soffit, gable, and ridge). The combination of a soffit (small slits under the roof's overhang) and a gable vent may help prevent ice dams and icicles on the roof in the winter. Vented roofs can also help prevent moisture buildup in the attic and roof from interior activities [7]. Error may have occurred in the amount of ridge vents observed as they are often made to blend in with the roof and can be hard to see.

The presence of an attic was challenging to measure physically; rather, data collected is based on whether participants noted if they had an attic or not. Most participants (18: 66.7%) indicated that there was an attic in their home. Other homes had an inaccessible attic, indicated by participants (9 homes: 33.3%). The attic access hatch, when placed inside the home, can be a source of air leakage if it is not sealed correctly. When performing the blower door test to assess infiltration, 3 of the 24 tested homes showed air infiltration around the attic access hatch (12.5%).

Most bathroom vents vented to the outside (19: 70.4%). This is suggested to limit the possibility of moisture build up in the attic. Three homes (11.1%) had bathroom exhaust that was either on the exterior wall and thus vented outside, or the vent was inside and vented into the attic. Other vents commonly observed include plumbing, boiler, oven, dryer, and wood stove exhaust vents.

Gutters were not present on many homes (17: 63.0%), and downspouts were not present on all but 2 of the homes that had gutters (80% without downspouts). Gutters were often only present above porches and doors (7 of the 10 homes with gutters: 70%). Some participants used a large bin to collect the rainwater (4 of the 10 homes with gutters: 40%).

Windows

Though a few homes (3: 11.1%) had two different types of windows (i.e., both single pane and double pane) and have been counted twice, most homes had double-paned windows (16 homes: 59.3%). Triple-paned windows were also common (13 homes: 48.1%). Many of the homes' windows appeared to be new, however homeowners indicated that some windows caused problems such as cold drafts in winter and mold growth on the windowsill. Out of 24 blower door tests, 23 homes (95.8%) had observable air leakage at the windows, which is generally not desirable.

Damage to windows in poor condition (8 homes: 29.6%) included:

- Cracking of one or both windowpanes (6 homes: 22.2%)
- Condensation between windowpanes
- Mold growth on the windowsills

- Reinforcement with screws to seal the window

Window shading was mostly provided by interior curtains (19 homes: 70.4%) or blinds (5 homes: 18.5%). Some homes had no interior shading (1 vacant home: 3.7%) or used blankets (2 homes: 7.4%).

Eaves were often about 1 foot in width if they were present (22 homes: 81.5%). Usually, they were present over the pitch of the roof; if the roof was sloped North and South, the eaves were present on the North and South sides of the home (12 out of 22 shaded homes: 54.5%).

Most homes had windows that sealed shut (closed and latched) (22 homes: 81.5%). Some homes had plastic covering their windows or homeowners mentioned using plastic covers over windows in the winter to help keep out the cold air (2 homes: 7.4%). A few homes included windows that sealed but had cracked panes (3 homes: 11.1%). Of homes where windows did not seal shut (5 homes: 18.5%), some were broken to the point they could not be sealed, some latches were broken, and some had to be screwed shut.

Exterior Doors

The exterior door sealed shut for most of the homes (closed firmly and locked) (15 homes: 55.6%). This is the door that leads into the home from the arctic entry. Some doors sealed but had to be pushed forcefully to do so (2 of 15 homes: 13.3%). Of the homes with doors that did not seal (12 homes: 44.4%) the following observations where noted:

- Use of a blanket or towel between the door and frame
- Broken lock
- Visible damage to the door, appearing to be from physical force
- Large gaps between lock and wall
- Door expanded in summer, making it hard to push closed

- Handle needs to be jiggled to lock the door in place

INTERIOR ASSESSMENT

Appliances

The appliances were similar across homes. These included a refrigerator, an electric stove (1 propane), multiple freezers per household, a radio and/or TV, a clothes washer and dryer, and a microwave, coffee maker, and toaster. Some homes had multiple TVs (14 homes: 52.9%). A few homes had air purifiers (5 homes: 18.5%). Some appliances may not have been counted if they were put away in a closet or elsewhere. Some participants mentioned they did not have internet because it is very expensive.

Plumbing

Some homeowners mentioned problems related to plumbing, including the following:

- A small toilet
- Toilet that is too forceful when flushed and causes the floor to visibly sink down
- Plumbing leaks in the wall that required repairs
- Frozen pipes in the floor that burst and caused rotted floorboards

Each comment was mentioned once by separate participants.

Lighting

The average number of lighting fixtures in the 27 assessed homes was 10 fixtures. Most of these were overhead lights with an average of 9 fixtures. The most common lightbulb used was an LED lightbulb, found in 14 out of 25 homes where lightbulb type was recorded (56%). Some homes had multiple types of lightbulbs. The second-most popular lightbulb was a CFL bulb (11 homes: 44%). Incandescent bulbs were present in a few homes (5 homes: 20%).

Damage to lighting fixtures was present in a few homes (6 homes: 24%). Damage included:

- Missing or no bathroom lightbulb
- Lights do not work though bulb is new
- Tripped circuits causing appliances and lights to go out for short periods of time
- Broken, cracked, or missing overhead lightshades

Heating

Over half of the homes assessed heated their house with an oil-burning boiler (15 homes: 55.6%). Many different brands existed, but the three most common were Burnham, Weil McLain, and Oil Miser. Heat from the boiler is distributed by baseboards (13 out of 15 boilers: 86.7%) or radiant floors (2 out of 15 boilers: 13.3%). Participants indicated there were issues with their boilers, as follows. Note that these observations were not verified during the assessments:

- Burns oil at 189.3 liters/week (50 gallons) in winter
- Cheap and inefficient
- 340.7 liters/month (90 gallons) in the winter

The next most common was an oil-burning wall furnace, specifically a Toyostove Laser 73 (9 homes: 33.3%). The heater was in the kitchen/living room area. It runs at 40,000 BTU/hr. on high. Participant comments are as follows:

- Only heats living room
- Wood stove heats home better
- Heats a small space well

Wood stoves were not present in over half of the homes (15 homes without wood stoves: 55.6%). Some participants who did not have a wood stove stated they would like one. Most wood stove exhaust pipes were in good condition, as many have recently been replaced as stated by participants (7 of the 12 stovepipes: 58.3%). Those that were not in good shape (3 out of 12 stovepipes: 25%) were rusted or leaky at the ceiling joint, observed during the blower door test.

Water Heaters

All but one (unfinished) home had a water heater. Water heater type varied. Ten of the 26 water heaters present (38.5%) were boilers like those used for heating. Other common types included:

- Electric water heaters (7 out of 26 heaters: 26.9%)
- Heat exchangers (5 out of 26 heaters: 19.2%)
    - Sometimes connected to or stated on the boiler
- On-demand water heaters (2 out of 26 heaters: 7.7%)

The efficiency of water heaters varied with type. The on-demand heaters only heated what they were connected to (ex. only bathroom or kitchen water). Electric water heaters ran using 4721 kilowatt-hours (kWh) of electricity per year out of a possible 4939 kWh/year. This was observed on the water heater's name plate. Some boilers heated water too hot, as stated by participants (3 out of 10 boilers: 30%).

Water heaters that had tanks for storage (5 out of 26 heaters: 19.2%) held an average of 151.4 liters (40 gallons). For boilers and heat exchangers, 19.3 liters (5.1 gallons) was a common heating capacity at one time.

Ventilation

Nineteen of the 27 homes assessed did not have mechanical ventilation (HRV or ERV) (19 homes: 70.4%). Both are forms of mechanical ventilation that exchange indoor air with outdoor air, transferring heat or energy from the indoor air to the fresh outdoor air; HRV = heat recovery ventilation and ERV = energy recovery ventilation. Blower door tests were performed on 24 homes, with 23 resulting in an air flow value. However, blower door tests indicated that 8 out of

23 air flow calculations performed (34.8%) found mechanical ventilation must be installed to maintain a healthy indoor air quality for occupants. This conclusion comes from building airflow calculations done using national guidelines and standards for residential buildings [10]. Three of these 8 homes (37.5%) have an HRV installed, but a few participants indicated they were not using their HRV because it was expensive to run due to the high cost of electricity.

Windows were used as ventilation in most occupied homes (14 homes of 22 with interviews), especially in the summer based on participant comment. A few participants noted they do not open their windows in the winter, but this was mentioned in interviews. Some windows were inoperable due to being broken.

As stated by participants, bathroom fans were used as ventilation in most homes where they were present (17 out of 23 vents: 73.9%). Common reasons for not using the bathroom fans as ventilation are as follows:

- Does not work or was hooked up wrong (4 out of 6 unused vents: 66.7%)
- Electricity is too expensive (2 out of 6 unused vents: 33.3%)

Some bathroom fans worked but were shut off in the winter because they leak cold air (3 out of 17 used vents: 17.6%).

Other ventilation includes arctic vents with a pull-string inside (2 of 27 homes: 7.4%).

Insulation

Insulation data in the wall, attic/ceiling, and crawlspace was based on participants' knowledge.

Wall insulation type varied greatly. Fiberglass batt was common among known types (6 out of 22 known types: 27.3%). Some homes had two types of insulation in the walls (6 homes: 27.3%). Other types included:

- Spray foam or rigid foam board (7 out of 22 homes: 31.8%)

- Cellulose (4 of 22 homes: 18.2%)
    - Note that this type appeared to be correlated with comments from participants of the house feeling cold

Crawlspaces were often insulated with what was told or appeared to be cellulose around the skirt (5 of 12 homes where crawlspaces had known insulation: 41.7%). However, this could have been mistaken by assessment or interview for fiberglass batts. Some participants commented that their crawlspace was not insulated (3 out of 22 crawlspaces: 13.6%). Problems were indicated to have occurred in two homes with no insulation in the crawlspace, specifically:

- Mice infestation
- Insulation fell off the skirt and onto the ground

Houses with known attics or roof cavities commented theirs was more likely insulated than not (22 of 23 homes with attics/roof cavities: 95.7%). Of known types, 7 homes of 14 had blown-in insulation (could be fiberglass or cellulose) (50%). When participants reported R-values, they ranged from R-19 to R-100 (1 home). R-values measure how well the insulation reduces heat transfer between the interior and exterior of the home.

Interior Mold and Moisture

Mold (or what appeared to be mold growth) was present in 14 of the 27 homes assessed (51.9%). The most common type was black in color (11 out of 14 homes: 78.6%); one house had green-colored mold and one had an unknown type since it was recently cleaned, as told by the participant. Most homes with mold had it on the interior windowsills and bathtub/bathroom floor area (12 of 14 homes: 92.3%). Thirteen of the 14 homes with mold had visible staining from it (92.9%). One house had mold present on nearly all the walls.

Thirteen of the 27 homes had some marks from moisture and water around the house (48.1%). Of these homes, 4 houses had moisture staining on the windowsills, usually as dark marks or chipping in the wood (30.8%). Some homes had rust present around windowsills or on boiler and wood stove exhaust pipes (2 homes: 15.4%). The most extreme form of moisture damage was a house that had rotted floorboards.

Indoor Air Quality

CO_2 levels above 1000 ppm (parts of the specific gas inside each million gas particles in the atmosphere) during the interior assessment and interview were measured in 11 of 23 homes with windows closed (47.8%). Note that some homes kept their windows open during the assessment, making the CO_2 value less than it would be in the winter assuming the windows would be closed at that time (4 homes: 14.8%).

Increased CO_2 levels can be indicative of insufficient ventilation [8]. Eight of the 14 homes where mold was present had a CO_2 level above 1000 ppm (57%). The following was also noted:

- 7 of 11 homes with CO_2 concentrations over 1000 ppm also had CO_2 levels over 1500 ppm (63.6%; 26% of total assessed homes)
- 2 of 11 homes with CO_2 concentrations over 1000 ppm also had CO_2 levels over 2000 ppm (18.2%; 7.4% of total assessed homes)
- The average CO_2 level recorded throughout the duration of the home assessments was 905.6 ppm
- The maximum recorded was 2330 ppm

Elevated relative humidity levels can be indicative of mold and moisture issues in the house [32]. Of the 27 homes assessed, mold was present in 14 homes (51.9%). Seven of the 14 homes with mold had a relative humidity above 65% without the influence of cooking (50%). Three of the homes had a relative humidity above 70% (21.4%).

Interior temperature correlated with that of the outside temperature on warm, sunny days during the assessments. Interior temperature averaged 22.7°C (72.9°F), and exterior temperature averaged 16.3°C (61.4°F). This data would be more significant in the winter when cold drafts through windows and cracks are more evident.

Air Exchange Rates ("Leakiness")

A blower door test was performed on 24 of the 27 assessed homes (88.9%). This test measured how much air is exchanged between the interior and exterior of a home. It also enables the identification of location and pathways of air leakage. Air exchange rates were reported in CFM50 in 23 of the 24 homes, or cubic feet of indoor air per minute exchanged with the outside air when a building is operating under 50 pascals of differential pressure (difference between interior and exterior air pressure). This value is used to keep all tests consistent; it is later converted to ACH50, a value more indicative of tightness and leakiness. ACH50 stands for air changes per hour at 50 pascals of pressure.

The leakiest home had an ACH50 value of 12.63. This home had multiple areas of air leakage. The tightest home had an ACH50 value of 0.62, with mechanical ventilation.

More commonly, homes were too tight, per the ASHRAE 62-89 standards for building homes in the United States (set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers) [10]. These homes did not receive enough outdoor air through ventilation (8 homes: 34.8%). Other homes had air exchange rates between 3.64 and 5.4 ACH50, in which mechanical ventilation is recommended to be installed based on ASHRAE 62-89 (3 homes: 13.0%) [10].

Commonly, higher occupant density was the reason the home was found to be too tight as opposed to square footage (11 out of 22 occupied or previously occupied homes: 50%).

The leakiest component in most homes was the windows, though many were newly installed (23 out of 24 homes: 95.8%). Air was observed to infiltrate around the perimeter of windows and in the lower corners by an infrared camera and a smoke generator. Mold was also commonly observed around windows or in leaky areas on the walls. More areas of air leakage are as follows (out of 24 homes where a blower door test was performed):

- Corners of wall and ceiling (15 homes: 62.5%)
- Joint between the wall and the floor, including under cupboards and beds (14 homes: 58.3%)
- Plumbing penetrations in the walls, ceiling, or floor, including under the kitchen sink (14 homes: 58.3%)
- Around vents such as baseboards and arctic vents (10 homes: 41.7%)
- Joint between the wall and the ceiling (10 homes: 41.7%)
- Boiler or wood stove exhaust ceiling/wall joint (10 homes: 41.7%)

APPENDIX B: COMMUNITY SUMMARY – INTERVIEW DATA

APPENDIX B: COMMUNITY SUMMARY – INTERVIEW DATA

Maria Milan, Kristen Cetin, Jessica Taylor, Cristina Poleacovschi

Data collected by Maria Milan and Jessica Taylor and compiled by Maria Milan

This summary focuses on the housing concerns interview data collected from July 27, 2021, to August 11, 2021, in the Native Village of Unalakleet (NVU). Some components of the full interview are used in separate research applications. Physical housing data collected during this same period is summarized in a separate document. This summary is based upon collaborative work between Michigan State University and Iowa State University, which is supported by the National Science Foundation project 1928105. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the research team and do not necessarily reflect the views of the National Science Foundation.

Sample Pool of Homes

The housing data collected and summarized in this document include a random sample of homes in Unalakleet. Homes were visited after initial contact by an interested participant. Some of the assessments were follow-ups from the interviews conducted in May 2021. Twenty-five of the assessments were done in the main area of Unalakleet near the Bering Sea, while two were done on houses on the hill. Interviews did not take place in every house in which a housing assessment was completed, however 22 of the 27 housing assessments completed did include interviews with the occupants. Participants were compensated for their time.

Numbers in **bold** represent number of interviewees.

HOUSING CONCERNS

Electricity

Electricity Usage – **Sixteen** of the 22 interviewees (72.7%) discussed whether they had electricity concerns beyond cost. Of those 16, **2** had concerns with high electricity usage, **2** had concerns with old or faulty wiring, and **1** had concerns with both. **Eleven** (68.8%) had no concerns with either electricity usage or faulty wiring.

Electricity Cost – **Eight** of the 22 interviewees (36.4%) reported having concerns about the cost of their electrical bill. Out of **20** interviewees that reported their electrical bill for both summer and winter, the average was $172.86 per month. **Seven** interviewees said their bill goes up in the winter, and values reported for winter monthly electrical bills ranged from $100 (**3** interviewees) to up to $400 (**2** interviewees). Many interviewees reported between these two numbers at about $200 per month (**5** interviewees).

In 2019, the average electricity bill in the United States was $115 per month [42]. The average annual electrical bill reported by 20 interviewees in Unalakleet is 50.3% more than the average electrical bill throughout the U.S. was in 2019 [42]. Still, one interviewee noted that Unalakleet's bill is less expensive than in some other rural communities throughout Alaska.

Power Cost Equalization Program (PCE) – The PCE is a program funded by the state of Alaska that helps rural communities pay for their high cost of electricity. The funds applied to communities reduce their electricity cost by making it equal to that of urban areas in Alaska [31]. **Nine** of 22 interviewees (40.9%) in Unalakleet expressed recent concerns over losing the PCE. **One** interviewee explained that the PCE is now in competition with other areas of funding throughout the state, which puts it in jeopardy of losing funding.

Community Power Outages – **Nine** of 22 interviewees (40.9%) said power outages were more frequent during the winter, usually due to strong winds that may twist or knock down power lines. **Three** interviewees said power outages can sometimes happen for short periods multiple times a day, depending on the area of residence, how many people are using appliances in that area at once, and if maintenance on utilities is happening close by. As for frequency, **7** interviewees said a few outages happen per year, **4** said 6-12 per year, **1** said 10 per year, and **1** said 20 per year. These power outages last from a few minutes (**5** interviewees) to a few hours (**5** interviewees). **Four** interviewees mentioned power outages lasting 8-12 hours.

To help supply power during an outage, **5** interviewees indicated they would like to use or have used a generator, **2** interviewees would like to use a wood stove but do not have one, and **1** uses their gas oven. **Two** interviewees had concern around freezing pipes during an outage.

Home Power Outages – **8** of the 22 interviewees (36.4%) had concern about appliances tripping the circuits in their home or failing to work. **Four** said some of their outlets do not work.

Energy Efficiency

Adapting to Efficiency Issues – **Five** of 22 interviewees (22.7%) reported that they cover windows in plastic to keep out cold drafts in winter. Other comments were made once, including building better homes to adapt to climate change, covering up holes in the walls, using snow to block wind from entering the house, and conserving oil by taking warm but not hot showers.

Improving Efficiency – **Five** of 22 interviewees (22.7%) said they wanted more insulation, with **1** of these 5 saying they would prefer spray foam insulation. Some interviewees would change physical elements of the exterior of the house, like switching to metal siding (**1**), adding triple-pane windows (**3**), fixing exterior doors (**3**), building with thicker walls (**2**), and adding skirting around the crawlspace (**1**). For the interior, air sealing was suggested by **1** interviewee, as well as switching to LED lighting (**1**) and doing maintenance on heating appliances (**2**).

- <u>Barriers</u> to performing these efficiency improvements were also discussed by **4** interviewees, including lack of maintenance crews in the community, lack of materials needed to update or retrofit parts of the home, renting the home and thus not being able to perform repairs, and cost of lumber and supplies.

<u>Insulation</u> – **Four** interviewees (18.2%) considered their insulation to be "good," or sufficient to maintain warmth. **One** interviewee reinsulated the house less than 10 years ago. Insulation type is discussed in the physical data summary, with the most common reported type being <u>fiberglass</u> in the wall (27.3% of homes) and what appeared to be <u>cellulose or fiberglass batts</u> in the crawlspace (41.7% of homes), as reported by interviewees and recorded on the energy assessment sheet. **Two** interviewees (9.1%) said their walls were 0.3 m (1 ft) thick, while **2** more said that the insulation that used to be in the wall had dropped to the floor. The top of their wall was then cooler than the bottom. **One** interviewee thought that mildew could be affecting their insulation.

<u>Perceptions of Efficiency of Home</u> – **Thirteen** interviewees (59.1%) thought their home was energy efficient. Reasons for this include good insulation (**4**), exterior structures or trees blocking wind (**1**), and new heating systems (**1**). The other **9** interviewees (40.9%) said their home was not efficient, or that it was drafty (**6**).

Foundation

Six interviewees out of 22 (27.3%) said they notice <u>shifting</u> in their foundation. **Two** said this affects the efficiency of their home by causing more cracks in the walls and floors for heat to escape through.

Heating

Efficiency – **Eight** interviewees (36.4%) reported problems with their boilers or furnaces. **Three** of the 8 said that their Toyostove Laser 73 furnace does not heat the entire house; just the room it is in. **Four** said they were burning a lot of oil in their heating appliance every month in the winter, and **1** mentioned that their boiler does not work well in general. To cope, **1** interviewee said that their household members wear coats inside, **1** uses their oven as secondary heat, and **2** use an electric space heater. Wood stoves were found in 44.4% of the 27 total assessed homes, and **5** interviewees said their wood stove heats the house very well. **Three** interviewees said that their small space heated well with the centralized Toyostove furnace. **Two** interviewees said they would like to have or already have a house that allows for high solar gain.

Heating Appliances – Appliances are discussed in the physical data summary, Appendix A. Boilers were found in **15** of the 27 assessed homes (55.6%), and Toyostove Laser 73 central furnaces were found in **10** of the 27 assessed homes (37.0%). These were the two most common appliances. However, **1** house relied on solar gain and only an efficient wood stove, which has been successful in heating the home. **Six** of the 22 total interviewees (27.3%) rely heavily on their wood stove in the winter, and **3** mentioned using space heaters as needed.

Distribution – Most homes with boilers distributed their heat around the home using baseboards. **One** home used radiant floors, which has proven successful in distributing heat effectively around the home. Those homes with Toyostove Laser 73 furnaces had central heating, directly from the furnace into the room it was located in.

Temperature – When set temperature on boilers or furnaces was discussed, **5** interviewees stated they keep their boiler or furnace at 21.1°C (70.0°F), with one at 21.1°C in the summer. Either 22.1 °C or 22.8°C (72.0°F or 73.0°F) was set by **4** interviewees in the winter, and **2** say that they set their appliance to 26.7°C (80°F) or higher. **Three** interviewees said that their heating appliance heated their home higher than the set temperature, and **1,** who lives in an apartment, said they are unable to change the thermostat.

Winter Use – **Seven** of the 13 interviewees with boilers (53.8%) said that they use them all year, but **2** said they shut it off if the outside temperature is warm enough (unspecified temperature). Interviewees who had record or estimation of winter oil usage reported it in varying amounts, summarized below from least to most in liters/month (gal/month):

- 82.1 (21.7) (**1** interviewee)
- 113.6 (30.0) (**2**)
- 189.3 (50.0) (**1**)
- 252.5 (66.7) (**1**)
- 340.7 (90.0) (**1**)
- 378.5 (100.0) (**1**)
- 757.1 (200.0) (**2**)

Two interviewees with boilers (15.4%) said they fill their oil drum every two weeks as a precaution, and **4** of the 10 interviewees with boilers and wood stoves (40%) said they use their wood stove in the winter instead of the boiler.

Water

Problems with household water were discussed by **5** interviewees, mentioning one problem each:

- Cold water is hot
- No water in the house, as it is unfinished
- Freezing pipes in winter
- Regular maintenance of house’s individual well needed to prevent freezing pipes

- Getting water from a house on the hill as the coastal community's water infrastructure is outdated

More often, a discussion around the community's outdated water infrastructure took place, as the system was being searched for a leak and thus the water was shut off often throughout the day.

INDOOR AIR QUALITY

No Concerns

Nine interviewees out of 17 expressing direct concern with indoor air quality (52.9%) stated they have no concern, however, during interviews in homes with closed windows, **11** out of 23 (47.8%) had CO_2 readings above 1000 ppm at any point, the building standard threshold for when health problems may begin to occur [30]. **One** interviewee said they "live with it" when asked about their indoor air quality, and another said they deal with it by opening their windows and thus do not have a concern.

Yes (Concerns)

Eight out of 17 interviewees expressing direct concern with indoor air quality (47.1%) said they have concerns. **Two** said they notice their home feels hot and humid sometimes, **2** use an air purifier to keep dust levels down, and **2** more reported having to open the window because the air quality was poor, or they could not breathe in their home.

Separately from those who indicated concern, **2** interviewees said they no longer have air quality concerns in their home after installing arctic vents on the walls.

Relative Humidity

Though the interview did not include questions that asked about relative humidity directly, comments during the indoor air quality section suggested that some interviewees may have concerns about high relative humidity in their home. **Two** interviewees noticed that their windows fog up or condensate in the winter because of indoor activity. **One** said they have rotting wood in the walls of their home, and **1** mentioned having a humid house.

Self-Stated Health Problems

Questions asking about health issues were not included in the interview. However, **4** interviewees mentioned that they had health problems that could be related to indoor air quality. **One** interviewee mentioned having asthma, **1** said they often cough from dust, **1** mentioned their children getting sick from mold in a previous home, and **1** stated that coughs are common in the community in winter.

MAJOR REPAIRS THAT HAVE BEEN DONE TO THE HOUSE

Appliances

Two interviewees said they had repairs done to their heating appliances after moving into their home, **2** had their cooking stove repaired or replaced, **1** had the water heater replaced, and **1** had their wood stove replaced.

Electrical and Lighting

Most interviewees who talked about major repairs done on their lighting or electrical systems said they did it themselves. **Two** interviewees had their entire lighting systems changed, **2** had their outlets changed, **3** changed out their breaker or meter box, and **3** had to replace the wiring in their house for various reasons, including blown fuses and old electrical systems.

General

General repairs refer to doors, siding, roofs, and other physical aspects of the house. The homeowner did many repairs, and some were done through weatherization programs discussed in a later part of the interview. **Five** out of 22 interviewees (22.7%) had their roof repaired at least once since moving into the house. **Four** interviewees had their insulation replaced, **3** their siding or windows, and **2** interviewees had an entire wall changed out, one of them contaminated with asbestos. **Two** interviewees had their exterior doors changed or repaired, and **1** interviewee had their floor repaired.

Plumbing

Three interviewees had their plumbing systems changed or repaired.

Rooms

<u>Bathroom</u> – **Two** interviewees had their bathroom floors replaced, with one floor having rotted out before repair. **One** had their toilet repaired.

<u>Kitchen</u> – **One** interviewee had their kitchen increased in size, and another had their cabinets changed out.

<u>Living Room</u> – **One** interviewee had their walls, ceiling, and windows changed in their living room.

<u>Porch</u> – **One** interviewee had both their porch steps repaired and the porch releveled after it shifted with the ground. In total, **2** interviewees had their porch releveled.

MISCELLANEOUS

While in interviews, some interviewees mentioned barriers to getting their homes repaired that did not fit in any other section. None of these were from targeted questions. All of these are <u>social</u> issues. **Three** interviewees mentioned poverty was a large barrier to getting repairs done. **Three** interviewees said that damage to their home was the result of violence. Some of these interviewees said the violence was domestic and/or done by intoxicated community or family members.

MOLD

No Concern

Seven of 22 interviewees (31.8%) said they have no concern of mold in their house.

Yes (Concern)

Eleven of 22 interviewees' homes (50.0%) had what appeared to be mold in at least one location, and **15** interviewees (68.2%) stated they were concerned about mold in their home. Some of these interviewees had concern with mold potentially being in the attic (**2**), or in the walls (**3**). Interviewees were mostly concerned about mold in the following locations:

- Windows (**7** interviewees)
- Bathroom (**4**)
- Crawlspace (**2**)

Managing mold was noted to be a challenge for many interviewees, with **6** interviewees saying they <u>cleaned it repetitively</u> as it grew back. **One** interviewee said they drilled circulation holes under the tub to allow for airflow that they hoped would reduce or prevent mold. **Two** interviewees said that their clothes smelled like mold, and **1** said that they or someone in their household had become sick potentially from mold exposure. Some interviewees suggested more than one place in which they suspected or knew mold was growing.

RENT OR OWN

Own

<u>Owning a home</u> – **Sixteen** of the 22 interviewees (72.7%) owned the home that the physical assessment was done on.

<u>Ownership Process</u> – Common reason interviewees owned the home they stayed in was inheritance (**4** interviewees out of **16** homeowners (25.0%)) or having built the home themselves

(**2** out of 16 (12.5%)). **Two** interviewees said they waited a long time to buy their home due to an application process through the city. **Three** interviewees said they bought their home, **1** of the three with help from someone else. **One** interviewee mentioned they received their home from disaster relief services after losing their other home in town due to storm events.

Availability of Housing – Many interviewees commented on the availability of housing in Unalakleet. **Nine** of the 22 interviewees (40.9%) stated that Unalakleet has no housing available to buy, and any housing that is available is unaffordable (**5**). More reasons for no housing available include:

1. Too much area in town taken up by old buildings (**2** interviewees)
2. No funding for homes (**1**)
3. Many people are lined up for any housing that becomes available through a lottery, application process, or auction (**5**)

Barriers – Cost of shipping, materials, and construction were all mentioned as the most common barriers to building a new home (**11** out of 22 interviews (50.0%)). Rough climate for building, unreliability of shipping, complexity of construction, cost of moving a home onto inherited land, and lack of local building codes were mentioned 1 time each by a different interviewee as barriers to building a new home. Flood risk in town was mentioned twice by different interviewees.

Rent

Six of the 22 interviewees (27.3%) said they were renting their home. **One** interviewee rented around Unalakleet for a long amount of time before purchasing a home. **One** interviewee disclosed how much their rent costs at about $900 per month.

Space and Occupancy

Twelve interviewees out of 22 (54.5%) stated that they either wanted more rooms added onto their home or wanted larger rooms. Interviewees were asked about their homes now and growing up, and **7** interviewees of 22 (31.8%) said that their home was crowded at some point in their lives. **Three** interviewees said they or someone in their household sleeps in the living room. More space concerns are as follows:

1. Wanting more appliance and storage space per home (**4**)
2. Wanting more lot space (**3**)
3. Wanting more space in general in the home (**3**)

From the community summary on physical data collected, the average occupancy out of 27 homes assessed is 3 people per home, with a maximum of 7 in a 4-bedroom and 5 in a 2-bedroom home. **Three** homes had areas of 400 square feet or less with a maximum of 2 people per home. For comparison, the average occupancy of homes throughout the United States in 2020 was 2.62 [41].

REPAIRS THAT NEED TO BE DONE

Bathroom

Three interviewees said that their bathroom fan does not work or that it sucks out heat and brings in cold air, so they don't use it. **Two** interviewees want to get their toilet changed because it leaks or does not work properly, **1** wants to change their sink, **1** their shower, and **1** said that the beams under their bathroom have rotted due to bursting pipes.

Bedroom

Three of the 5 comments on repairs that need to be done to bedrooms were to add more rooms. The other **2** mentioned finishing paneling and painting their bedroom.

Kitchen

Two of the 4 comments on repairs needing to be done in the kitchen were to add more counter/storage space, and the other **2** were to replace counter tops.

Porch

Two of the 6 comments on porch repairs were to fix leaks. **Two** were to build a porch extension so that it is bigger, **1** was to repair the porch in areas where it has shifted with the ground, and **1** was a general comment saying the porch needs to be replaced.

Entire House

One interviewee said they would like their entire house repaired, and **one** other was living in an unfinished home.

General

Ceiling – **Two** interviewees said their ceiling needed repair due to water damage and leaks.

Exterior Door(s) – **Eight** interviewees out of 22 (36.4%) said they wanted at least one of their exterior doors replaced. Common reasons include:

1. Damaged by someone in the town or family (**2** interviewees)
2. Drafty (**3**)
3. Does not shut properly due to a shifting foundation (**1**)

Flooring – **Four** comments were made on replacing flooring. Reasons include cracks and dents (**3**) and adding carpet and tile **(1).**

Heating Appliances – Heating appliances were often mentioned as needing repair (**15** interviewees out of 22 (68.2%)). The most common reason was both wanting a wood stove or another supplementary heat source for the winter (**4**) and replacing an old appliance with one that works more efficiently (**5**). **One** interviewee mentioned wanting an Oil Miser boiler. **Two** interviewees said they wanted a better damper on their wood stove to protect from backflow from burning wood. Other comments were made once, including fixing broken baseboards, wanting a warmer home in general, fixing the hot water tank because it stops working on its own, and fixing the furnace because it makes the home too hot.

Plumbing – **Eight** out of 22 interviewees (36.4%) said that they want their plumbing replaced. Leaks and freezing pipes were common reasons. **One** interviewee wanted a new hot water tank, **1** wanted more accessible plumbing, and **1** had no running water.

Walls – **Eleven** interviewees said they want their siding or walls replaced. Reasons include:

1. Wanting better insulation or thicker walls (**3** interviewees)
2. Having cracked or damp siding (**2**)
3. Their current siding is plastic, and it could burn in a fire (**1**)
4. Wanting metal siding (**1**)
5. Having mold behind their walls (**1**)

Roof – **Three** interviewees said that their roof leaks and needs to be fixed. **Two** said the roofing paper they have used blew away in the wind, and **1** wants to add an overhang to the roof.

Windows – **Eleven** interviewees out of 22 (50.0%) said that their windows are drafty, and they can feel cold air come through in the winter. The blower door test done for air flow and air leakage confirmed that **23** out of 24 homes that had a blower test done (95.8%) had some leakage around the windows. **Five** interviewees said they need to replace the windows in their home that are broken or cracked. **Three** interviewees said some of their windows will not open, and **2** interviewees said some of their windows will not close properly. **Three** said they would like to upgrade to triple-pane windows, and **2** said they do not have screens on their windows and would like some so the bugs do not fly in.

Electrical Wiring – **Three** interviewees said they want to replace all their electrical wiring because it is old, or because some lights and appliances do not work. **One** interviewee said they have corroded wires, **1** said they are missing wiring in some part of the house, and **1** wants a new breaker box.

Adapting

Many interviewees said that they have multiple repairs that need to be done to their home but cannot afford to do so. They have then found ways to adapt to what needs fixing. **Five** interviewees out of 22 (22.7%) said they put plastic over their windows to block out drafts in the winter. **Four** interviewees have placed blankets around drafty doors or windows to keep out cold air, **3** collect and haul out water from leaks in their house or porch, **2** use surge protectors to keep appliances from shorting, and **2** use foldable chairs and tables due to lack of space. Some interviewees said that a few habits have been adapted throughout the community, such as using bedsheets or curtains to shield from too much sun exposure in the summer and building the bathtub a foot off the ground so that air can move underneath it and help prevent damage from moisture. Here are some other measures taken that were mentioned once each:

1. Placing rocks to protect the house against storm surges
2. Using a hair dryer to thaw out frozen pipes
3. Foam sealing around windows and porches
4. Putting carpet on a cold floor

Barriers to Getting Repairs Done

The largest barrier to getting repairs done is cost (**11** out of 22 interviews (50.0%)). Availability of materials is also a common barrier (**6** interviewees), as well as finding people to do repairs (**4**). **Three** interviewees said shipping materials was a barrier, and **2** said that the time taken to do the repair themselves is too much. **Two** renters out of 6 (33.3%) said that renting was a huge barrier to getting repairs done. **Two** interviewees said they need to wait until they become an elder for their repairs to happen. **One** person said the climate makes repairing homes tough, especially in the short summer. **One** person was concerned with maintenance people being uneducated in proper maintenance of homes, and **1** person said their house was too small and thus they could not fit in the repairs or new appliances they wanted.

UTILITIES

Repairs

<u>Community</u> – All 22 interviewees were asked about their opinions on the repair of community utilities. **Thirteen** interviewees (59.1%) stated the <u>water lines</u> need to be updated, with the main reason being that they are old and outdated. **One** interviewee explained that Unalakleet was one of the first rural communities to get water lines, and those lines are still being used. **Eleven** of 22 interviewees (50.0%) thought <u>electrical wires</u> throughout the community should be updated, with the main reasons being high winds twisting the wires. **Three** interviewees thought that the electrical and water utilities did not need to be updated.

<u>Barriers</u> – **Three** interviewees said that <u>cost</u> was the main barrier to fixing the utilities. Other barriers were mentioned as well:

a. Lack of training of city employees (**1** interviewee)
b. The unknown amount of time updating the utilities will take (**1**)
c. The utilities are old and may be hard to update (**1**)

Perceptions on the Wind Turbines

Interviewee perceptions on the wind turbines were mixed. **Four** interviewees said that their electricity prices stayed steady even though field prices have increased, which is a positive perception. **Two** interviewees said they have noticed less power outages throughout the community, and **2** more said the turbines have benefited them in some way.

Many interviewees did not notice a change in the cost or reliability of their electricity (**7** of 22 interviewees (31.8%)). **Three** interviewees said that the community's electrical wiring needed to be updated for the wind turbines to reach their full capacity.

More Renewable Energy

Eighteen interviewees out of 22 (81.8%) said that they would like to see more renewable energy in the community. Solar panels were favored by **15** of the 18 (83.3%) for reasons such as lots of sun in the summer and lowering electrical bills. **Two** interviewees said that the river might be a good source of hydroelectric power, and **1** interviewee said they would like to see more wind turbines.

VENTILATION

Bathroom Exhaust

Seven of the 22 interviewees (31.8%) said they use their bathroom exhaust fan as ventilation. Six of the rest of the 22 interviewees talked about why they did not use the bathroom exhaust fan as ventilation. **Three** interviewees said that their bathroom fan sucked out heat or let cold air in. Blower door tests showed the bathroom fan as a source of air infiltration in **4** of the 27 assessed homes. **Two** interviewees said their bathroom fan did not work, and **1** more was unsure if it worked because it was quiet when turned on.

Kitchen Exhaust

Two interviewees with a kitchen exhaust fan said they consistently used it as ventilation, especially when cooking, and **1** more said that they used to use their fan before it broke. **Three** said that the fan sucks heat out and lets cold air in, like with the bathroom fan. **One** of these three interviewees said that gnats fly in through their kitchen exhaust. Not every house had a kitchen exhaust fan; **2** interviewees said they would like to have one.

HRV

Six interviewees of 22 (27.3%) had HRVs, but only **2** of the 6 used them (33.3%). Reasons for not using the HRV include high cost of electricity, the HRV is broken, and consistent natural ventilation through exterior doors being opened and closed frequently throughout the year. **One** person without an HRV said they would like one, but it is too expensive to install and run due to high cost of shipping, labor, and electricity.

Arctic Vents

Five of 22 interviewees (22.7%) had little circular holes on opposite sides of the living room from each other. These were referred to as “arctic vents,” and they were used as ventilation in most homes except one, in which they were broken.

Other Forms of Ventilation

Four interviewees used box fans to help cool their home in the summer. **Two** interviewees used air purifiers to help clean up dust in the house, although they are not a form of ventilation.

Windows

Fifteen of the 22 interviewees (68.2%) used their windows as natural ventilation. Although not directly asked in most interviews, **4** of the 15 interviewees who opened their windows (26.7%) said they also open windows in the winter for ventilation, if only for a short time. Reasons for some interviewees not using windows as ventilation include broken or inoperable windows (**2**) or having no screens on the windows to keep the bugs out in summer (**3**).

WEATHERIZATION AND OTHER ASSISTANCE

Weatherization That Has Been Done on Homes – Most interviewees who had weatherization services on their home had them done through RurAL Cap (**19** of 22 interviewees (86.4%)). Some work done on homes include:

- Insulation in wall, crawlspace, floor, or attic (**6** interviewees)
- Bathroom fan (**2**)
- Windows (**2**)
    - Note here that some interviewees mentioned that many community members had recently gotten windows replaced by RurAL Cap.
- Other parts of the house mentioned once each by interviewees:
    - Accessibility measures
    - Ramp
    - Heating appliances
    - Doors
    - Arctic vents

NVU was also mentioned to have done weatherization services. **One** interviewee said NVU had recently changed their wood stove pipe, another said NVU installed arctic vents, and a third interviewee had their heating appliance switched out for a new Oil Miser.

Perceptions – **Eight** of the 19 interviewees who had RurAL Cap weatherize their home (42.1%) had negative perceptions of RurAL Cap. Some of the issues they found are as follows, with some interviewees mentioning more than one issue:

- The final product was installed or done poorly (**5** interviewees)
- Windows installed poorly (**3**)

- The floor was not replaced; a new one was placed over the old (**1**)
    - Another interviewee had a similar problem with windowpane glass
- Wanting to have more done on their house (**2**)

Two interviewees had positive experiences with RurAL Cap. **One** interviewee said that they wish Unalakleet had more local weatherization programs.

Two interviewees had negative perceptions of NVU; one saying that they did not pay attention to renters. But another **2** interviewees had positive perceptions of NVU. **One** interviewee said that they appreciated the HUD homes in the community.

One interviewee had negative experiences with a church missionary that did not install their pipes correctly, resulting in frozen pipes and rotten floorboards.

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