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Energy-Efficient Technology in Cold Weather – Bridger View On-Site Research

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Executive Summary

Northwest Energy Efficiency Alliance (NEEA) supports the uptake of energy efficient technologies and practices throughout the Northwest. This research project was supported by NEEA to leverage the processes associated with the creation of a new housing development in Bozeman, Montana, called Bridger View, to document perceptions and challenges related to energy-efficient design and technologies from contractors, installers, homeowners, and other relevant market actors. To directly engage with these market actors at each phase of this project, JG Research and Evaluation conducted a mixed methods research study that included interviews with project consultants, contractors and installers, and homeowners; a series of on-site visits; and a quantitative cost analysis of home energy use and electricity utilization at Bridger View residences.

This research took place over a period of approximately two years and covered each phase of the construction of Bridger View, which included 1) planning and design, 2) construction, and 3) homeowner lived experiences in the homes. The research team focused primarily on understanding study goals for the following technologies as identified by NEEA for the project scope:

- Building envelope and insulation
- Triple pane windows
- Ductless heat pumps
- Heat pump water heaters

The primary goals of this project were to understand the influences of the climate and relative geographic isolation of Bozeman, MT on the adoption and performance of technologies that were of focus for this study. The project examined how the acquisition, installation, and use of each technology was experienced by the set of actors involved in each Bridger View residence, including project consultants, installers, and homeowners. Each of the three study phases focused on understanding perspectives on these process from a different constituency (planners/consultants, installers, and homeowners). Key findings are broken down below by project phase.

Phase 1: Planning Bridger View and technology decisions

In this phase, the research team engaged with consultants involved in the decision making, design, and energy efficiency processes for Bridger View.

- Perceptions of expected technology performance by project consultants are positive, and all consultants expect that the technologies will perform effectively in cold weather.
- Consultants anticipate that installers may be unfamiliar with or hesitant about some aspects of the design or technology being installed.
- Primary concerns about cold weather performance are for the DHP system, which could have trouble operating in the extreme low temperatures that Bozeman can have during winter. To mitigate these concerns, backup cove heaters are installed in all homes.
- This project is unique in that cost is a secondary concern due to funding from outside sources. However, to stay within budget, there was substantial emphasis on the building envelope and insulation of the homes, which the research team learned maximizes the efficiency of each technology.

Phase 2: Building process and technology installation

In this phase, the research team engaged with subcontractors and installers directly involved in the installation of study technologies and overall building process of Bridger View. We also conducted several on-site visits to document technologies being installed in homes. Key findings:

- There are mixed perceptions of energy efficient technology from subcontractors and installers. Primary concerns are due to expected performance in cold weather, unit costs, and market availability and presence in the area.
- The main hesitancy about installing technologies, particularly HPWHs and DHPs, is due to risk aversion. If the technology fails in cold weather, the burden falls back on the installer and their company. In the past, installers have experienced technological failure in this climate, sometimes due to improper installation.
- Installing and learning more about the technologies throughout the building process at Bridger View positively change perceptions of the technologies for many subcontractors.

Phase 3: Use of technology and homeowner perspectives

The final phase of the project was engaging with homeowners at Bridger View to understand their experiences living in the homes and utilizing the energy efficient technologies. Key findings:

- Homeowners have had good experiences living in their homes. Many of the interview participants had moved into their homes after the winter of 2022 and had not experienced living in the homes during cold weather. Those that had occupied the homes since the previous winter were impressed by the technology performance, lower energy bills, and ability of the homes to maintain consistent temperatures.
- There were some challenges and a learning curve for homeowners to understand how to operate the technologies correctly. Some homeowners required additional resources and engagement from self-directed learning, energy consultants,[1] and Homeowner Association (HOA) to learn how to use the technology in their homes.
- In the first several homes that people moved into, the settings on the heating systems were not correct, which led to higher heating bills initially for several homeowners. Energy consultants solved the issue by adjusting these settings for the technology to work properly.
- One of the main frustrations that homeowners expressed was the absence of DHP units in the upstairs bedrooms.

Energy Efficiency and Cost Analysis

To analyze energy costs and potential savings at Bridger View, the research team acquired energy bills from several homeowners, daily detailed energy data from one Bridger View home, and pre-construction cost and energy use models for approximately half of the Bridger View homes. This allowed for comparison of actual energy use to projected energy use, as well as cost savings relative to average U.S. homes. Overall, the models and estimates show that there are substantial cost savings at Bridger View in terms of energy use. Additionally, actual energy use was significantly lower than modeled projections of energy use.

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[1] The energy consultants referenced here are the consultants responsible for choosing the energy efficient technologies and energy efficient design components of the homes.

1 Background, Objectives, and Research Methodology

This research project examined the implementation of a set of energy efficient technologies within a new housing development in Bozeman, Montana, called Bridger View, to understand perceptions of the selected technologies and their performance in a cold weather climate. The study technologies include the overall building insulation and envelope, triple pane windows, ductless heat pumps (DHP), and heat pump water heaters (HPWH). Research started in the beginning phases of construction for Bridger View and focused on perceptions of the selected technologies from a variety of stakeholders involved in each phase of the project.

1.1 History and Background of the Bridger View Development

The Bridger View development will eventually consist of 62 energy-efficient homes in a well-designed, walkable community, located on eight acres of land near Story Mill Park in Bozeman, Montana. At the time of the writing of this report 45 out of the 62 homes have current owners, with 7 more homes also under contract. A few key details pertaining to the Bridger View development:

- The project aids the City of Bozeman's goal of carbon neutrality by 2050.
- The project includes 62 homes, including 31 long-term affordable homes sold at below market-rate through a land trust model (850-1500 sq. ft. – not including unfinished basement spaces), and10 condos (5 buildings, on slabs).
- Construction began in April 2021 and was divided into three phases, with the first, second, and third phases originally planned to complete in spring 2022, fall 2022, and spring 2023, respectively.
- Supply chain issues associated with the COVID-19 pandemic slowed some of the initial buildling processes, which resulted in some delays in the timeline for phase 1 home completion. The first homes of phase 1 were finished in December 2022, with the first round of homeowners moving in shortly after.
- Homes are compact enough that they qualify as Department of Energy (DOE) Zero-Energy Ready (ZER) Homes and for Leadership in Energy and Environmental Design (LEED) programs for hot water.

1.2 Project Objectives

This market research project was designed to align with the construction of the Bridger View homes and gather information on the technologies from stakeholders at each phase of the building process. At the outset of this project, there were four primary research objectives, each of which corresponded to the specific energy efficiency technologies and building practices:

1. Identify and estimate the components of any cost delta (labor, materials or equipment, local permitting, etc.) associated with installing the energy efficiency measures in a cold climate and, separately, in a rural[2] location.

2. Describe installers' challenges, work-around solutions, and experiences installing each measure. Document which challenges are weather-related (cold climate) and how installers mitigate or adapt to these challenges.

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[2] By rural, NEEA was conveying that the site location is not in proximity to most manufacturers of energy efficiency technologies and may not be easily accessible for shipments.

3. Characterize homeowners' or residents' perceptions of each measure in their homes upon move-in and compare them to perceptions after 6-12 months to provide real-world consumer feedback for NEEA energy efficiency programs.

4. Document perceptions of performance (from installers and residents) related to the measures (in general and in cold climate scenarios) to support programs' conversation with supply chain actors.

As mentioned in Section 1.1, there were a variety of barriers faced in the construction of the Bridger View homes, including supply chain issues, COVID-19 pandemic related delays and challenges, and availability of stakeholders, that subsequently altered the timeline and objectives of this research project. The research team approached this project with flexibility in order to achieve project objectives.[3] Due to the supply chain issues and construction delays, there were some barriers to achieving objectives one and three. These barriers and work around solutions are outlined as follows:

Objective 1 – Barrier and update:

- *Barrier:* Due to supply chain issues and frequent changes in the construction process, installers and designers were not able to quantify specific costs of labor, materials, and equipment in ways that were useful for this research.
- *Update:* The research team updated this objective to focus on energy costs and usage by homeowners, through analysis of energy bills and energy data from a Bridger View home that has an energy use monitor installed.

Objective 3 – Barrier and update:

- *Barrier:* Due to the construction delays, homeowner move-ins were also delayed, making the goal of comparing perceptions at move-in relative to perceptions after 6-12 months unfeasible within the project timeline.
- *Update:* The research team engaged with participating homeowners one time and updated the interview guide to ask about homeowners learning curve with technologies between their move-in date and the time of the interview.

Objectives 2 and 4 were able to be examined in accordance with the original research design. Technical details about the specific size and brand of DHPs are included in the Appendix.

1.3 Research Design

There were a total of three research phases, associated with three groups of stakeholders, as outlined in
Table 1. This report is organized according to these phases, with each section focusing on an individual phase, and subsections that will discuss each technology. Additionally, there is a section that discusses energy and cost analyses for selected residences that was conducted by the research team.

[3] Please see Appendix Section 7.2 for details on the original scope of work and timeline.

Table 1.Research phases and report layout

Research phase	Stakeholders	Section focuses
Phase 1: Planning Bridger View and technology decisions	*Consultants and designers:*	• *Decision making that went into choosing the technology to be included.* • *Perceptions of technology.* • *Concerns or expectations about performance, particularly in cold weather.*
Phase 2: Building process and technology installation	*Installers and sub-contractors:*	• *Perceptions of technology.* • *Concerns or expectations about performance, particularly in cold weather.* • *Challenges related to installation.*
Phase 3: Use of technology – Homeowner perspectives	*Homeowners:*	• *Perceptions and experiences with technologies.* • *Concerns, experiences, or expectations about performance, particularly in cold weather.* • *Challenges with the use of technology.*

1.4 Data Collection and Analysis Methods

1.4.1 Interview Participants

Interviews across all three research phases were conducted with several types of individuals who had important and complementary perspectives on the technologies of interest for this study at Bridger View. Table 2 outlines all completed interviews by participant type:

Table 2. Information on interview participants

Participant type	Interview location	Number of participants
Project manager	*Video conference*	*1*
Project lead – Ownership representative	*Video conference*	*1*
Sustainable building and site design	*Video conference*	*2*

City of Bozeman	*Video conference*	*2*
Architect	*Video conference*	*2*
Sustainable building design	*Video conference*	*3*
Sustainable building and site design	*Video conference*	*1*
HVAC and plumbing subcontractor	*Phone call*	*1*
Insulation subcontractor	*Phone call*	*1*
General ontractor/site manager	*Video conference*	*2*
Homeowners	*Video conference/Phone call*	*14 residences*
Total		*30*

The research team conducted four site visits to observe technology installations and engage with installers, as well as a group site visit with members of the consultant and design team to observe the creation of a promotional video being completed on the Bridger View development that highlighted the use of energy efficient technologies included in this study. During the on-site visits, the research team observed technologies being installed, viewed completed installations of study technologies, and asked of installation teams about their experiences and challenges with the installation of each technology. During the group site visit in the spring of 2022, the research team observed completed installations of the study technologies, and engaged with members of the consultant and design team by inquiring about their experiences and the challenges encountered through the planning and building processes. Table 3 outlines the completed on-site visits and technologies observed during each visit.

Table 3. On-site visits and technologies observed

Visit	***Visit date (2023)***	***Mini split heat pump***	***Heat pump water heater***	***Triple pane windows***	***Insulation and building envelope***
Group site visit – Promotional video	*June 22*	*X*	*X*	*X*	*X*
Site visit 1	*July 13*			*X*	*X*
Site visit 2	*July 18*			*X*	
Site visit 3	*August 12*	*X*		*X*	*X*
Site visit 4	*September 9*		*X*		

1.4.2 Interview Structure

The background research conducted during the literature review stage of this project in 2022 informed the overall structure and individual questions included in the interview instruments for installers and homeowners as well as the beginning of the on-site observation checklists. Checklists were finalized after the interviews with project consultants, subcontractor/supervisors, and installers to ensure that on-site data collection aligned with concerns identified in both the literature review and interviews. Detailed interview guides and a literature review are included in the Appendix.

The interview guides were designed with similar but different sets of questions created for each type of interview, depending on the background of the interviewee.

All interviews were recorded and transcribed via Rev, an online service that transcribes audio recordings. Detailed notes were taken for on-site visits and summarized by a member of the research team upon completion of the visit. After all interviews were completed, a standardized coding scheme was created to organize quotes into common themes and analyze trends that appeared across interviews. Exemplary quotes that demonstrate the themes which inform the research findings presented in this report are presented in Appendix B.

Project consultant interviews

Purpose: Development of Bridger View began in 2012 when the Trust for Public Land purchased 70 acres on the northeast side of Bozeman with the goal of creating a regional park and adjoining mixed-income neighborhood. Through this process, a broad set of consultants and stakeholders shaped the development of the residences, and their decisions and commitments greatly informed the adoption and use of technologies that are the focus of this study. Interviews with project consultants focused on identification of how the homes were designed, how individual technologies were selected, and their perspectives on the supply chains for each study technology.

Subcontractor/supervisors interviews

Purpose: Owners or supervisors within subcontracting firms had a significant amount of responsibility for the correct installation of technologies under examination in this study. Interviews with subcontractors/supervisors provided background and context for the installer interviews and supported the research team gaining access for on-site observations. One other key element of these interviews was to understand how the leadership of subcontracting firms viewed the technologies, gauge their understanding of whole-house design processes, and ascertain their motivations for bidding on the Bridger View project.

Installer interviews and on-site observations

Purpose: The perspectives of installers on each study technology will support efforts by NEEA to integrate energy-efficient technologies in homes throughout their service area. Installers have the opportunity to support or decry specific technologies. In these interviews and on-site visits, the research team aimed to further our understanding about installer perspectives on both the technology they install, and the broader energy efficiency goals embedded in the Bridger View project.

Homeowner interviews

Purpose: Homeowners are the end users of each technology, and the way in which they utilize the technology substantially impacts energy efficiency, costs, and their experience living within the home. These interviews focused on understanding homeowners' overall experience using each technology, their perceptions, and challenges in use. The research team utilized these interviews to understand how their challenges were addressed and to what degree energy efficiency motivated their decision to purchase a Bridger View home.

2 Project Phase 1: Planning Bridger View and Technology Decisions

Bridger View is a values-driven housing development, which highly influenced the planning process and technology to be included within the homes. Four specific goals were shared by study interview participants as having informed the project's decision-making: 1) meaningfully addressing the housing needs in Bozeman; 2) complementing the design of Story Mill Community Park; 3) incorporating sustainable design; and 4) creating a model that is replicable and elevates understanding in communities about affordable housing. Memoranda of Understanding were signed during the initial project planning phase about these goals, ensuring commitment from organizational partners and providing continuity across transitions in ownership of the site. These value-based commitments informed the types of consultants who were engaged and how the site owners approached budgets, code restrictions, certifications for the buildings and neighborhood (LEED), and the process for envisioning both the site and the residences.

Many unique aspects of this project shaped the project planning process. Study participants shared that this project involved both more consultants, and more types of consultants, than a normal housing development. The expanded utilization of consultants was attributed to the unique neighborhood goals and intentional sustainable design elements of both the residences and the neighborhood. The presence of a large team with sometimes varied opinions on design decisions during the planning period created a longer time period for the initial planning period. Resolution of these challenges was achieved through more communication between each type of specialty than normal during a building project. Architects were asked to work closely with sustainability consultants and the general contractor to balance the design aspects and technology necessary to achieve the efficiency goals. All interview participants shared that they valued this process, even while noting that it was at times challenging and time consuming.

Because the primary goals of Bridger View were to fill a gap in the local housing market and create a sustainable and energy efficient development, the budget was a secondary concern, particularly because of the presence of outside funding that supplemented planning and management costs for Bridger View. Unlike most developments, consultants and designers were told to prioritize the design, livability, and sustainable technology first, and budget and tradeoffs would be determined secondarily.

A key theme identified by study participants in phase 1 of the Bridger View project was related to tradeoffs, which were noted as being necessary to keep the project moving forward. Initially, project aspirations met potential barriers, most notably addressing code restrictions and the contracting processes. Each of these challenges prompted ownership to add consultants with expertise in site planning and sustainable design to mitigate these barriers. The need to balance aspirations and make tradeoffs with practical challenges structured the contractor hiring process and informed contracting procedures.

A majority of the tradeoffs made were a result of having to strike a balance between technologies and cost limitations, despite the substantial amount of funding for the project. Technology and design decisions were made to fulfill two primary goals: staying within budget and achieving energy efficiency targets. Participants often described collective decision-making and acceptance of tradeoffs to balance efficiency goals against costs, such as using electric resistance heat as a backup to heat pumps and DHP systems rather than installing DHP's on each level of the residence; and avoiding spray foam insulation by using packed cellulose instead. Home designs sought to incorporate efficiencies with layout, as exemplified by one example of placing heat pump clothes dryers in proximity to the heat pump water heater.

The research team discussed potential future challenges with project consultants, designers, and subcontractors, asking about the areas where they anticipated challenges, resistance, or confusion with the technologies or whole-house designs. While the consultants in charge of making the technology and design decisions understood the potential benefits of the Bridger View design, it was less clear to them if the people who must understand the technology down the line (e.g., subcontractors, installers, and homeowners) would be able to effectively install or use it.

Several interview participants expressed concerns about the proper installation and utilization of technologies. The consultants understood the benefits and were confident that the technologies would perform in accordance with expectations, but also noted that effective performance relies heavily on proper installation by the contractors and proper understanding and use of the systems by the eventual homeowners. Several interviewees pointed out specific examples, such as homeowners potentially not understanding how to use heat pump clothes dryers, misunderstanding the energy recovery ventilation system (which is used to recover heat and energy and serves in place of a vent fan in bathrooms, which may lead to confusion), and not properly setting the thermostat to optimize efficiency. They planned to address the homeowners' challenges with comprehensive homeowner manuals explaining how to use the home's technological system and a supportive Homeowners Association (HOA) to help homeowners with questions and problems.

Section 2.1 focuses on perspectives of each of the study technologies individually as shared during interviews with the planning team and consultants. Each technology subsection presents the decision-making processes that went into the inclusion of the technology in the homes, the perceptions and anticipated challenges with the technology from the perspective of the planning and consulting team, and expectations of how each technology will perform in the Bozeman climate.

2.1 Building Envelope and Insulation

2.1.1 Decision Making

Project consultants conducting an on-site visit.

During the planning process, considerations regarding how the technologies of the home worked together as a system, rather than individually, proved to be essential. In order to ensure the project met its efficiency goals, the building envelope and insulation became integral parts of the design process. Although each technology can be thought of individually, the design and sustainability consultants emphasized how the building envelope and each technology could work in combination to maximize the overall benefits of the energy efficient design. For example, DHP units will maximize energy efficiency most optimally if the air seal of the house is tight. Consequently, the triple pane windows are an important aspect of the air seal and heat retention. To ensure that heat is cycling and recycling efficiently in the house, the energy recovery ventilation (ERV) system is equally as important. Finally, the HPWH relies on a steady and conditioned environment to run efficiently, which is related to the temperature in the house. Through the interviews, it became clear that the homes were designed with the conceit technologies function most efficiently when they work together within a properly insulated and tight building envelope.

Interview participants were asked to share how they used the building envelope and whole-house design to meet efficiency goals and the most important aspects of the envelope and insulation in achieving those goals. Collaboration between stakeholders primarily drove the planning process, as most interviewees noted that communication between the architects, sustainability consultants, and contractors ensured energy efficiency goals were met while staying within budget and achieving buildable designs. Stakeholders generally worked to compromise on necessary challenges and tradeoffs in the design and technology selection process.

In relation to insulation specifically, packed cellulose is used as the insulation material in the Bridger View homes, as opposed to the spray foam typically used in construction. The use of packed cellulose was motivated primarily by its low carbon footprint, as well as its contributions to efficiency. The architect noted the insulation is "seen by the green building community as a really positive material from a number of standpoints if it's installed correctly and protected from moisture correctly." Additionally, the sustainability consultants pushed for the use of packed cellulose for the same reasons, stating to the project manager that spray foam is something that "the industry needs to be moving away from." The insulation decision represented a technology that seemed to be a straightforward choice for the designers and consultants.

2.1.2 Perceptions and Anticipated Challenges

The decision to use packed cellulose was straightforward, overall, with the perception that it was energy efficient and had a low carbon footprint relative to spray foam. The process for deciding on packed cellulose took some convincing for the general contractor, as they had more experience with spray foam and a perception that packed cellulose would settle and, therefore, leave gaps in insulation. Ultimately, through discussion with the design team and sustainability consultants, the general contractor became comfortable with the process. To ensure that settling over time did not occur, the project manager stated that they "talked through it with the insulator and talked through the tradeoffs, and it's really a QC (quality control). Someone needs to monitor the pressure, how packed the stud cavities get. So, we got them comfortable with that."

2.1.3 Concerns and Expectations for Cold Weather Performance

There were no specific challenges or resistance noted by interview participants about cold weather performance of the building envelope or insulation. One consultant noted that they considered panelized framing early in the project, but delivery costs became too expensive. It was unclear if the increased costs were due to Bozeman's location, the pandemic, supply disruptions, or if costs simply did not fit into the overall budget of the project.

Outdoor foam board insulation

A majority of the challenges anticipated by the project consultants and designers related to installation were not with the installation of the technology but rather the knowledge and perceptions of the technology. Additionally, the costs, lack of consistent suppliers, and lack of information and education in the market has further limited uptake of the technology. Because installers had little experience with the technology, many expressed concerns related to risk aversion, noting how installing a costly product they were unsure would work and could then reflect poorly on them.

2.2 Triple Pane Windows

2.2.1 Decision Making

The decision to include triple pane windows appeared to occur naturally and fall in line with the overall strategy of using a tight building envelope to reach the efficiency goals outlined at the beginning of the Bridger View project plans. As mentioned in the discussion of the whole-house design in the previous section, there was significant emphasis on the building envelope to maximize the benefits of the technology in the house and achieve the desired energy efficiency goals. The triple pane windows were a part of creating the desired building envelope, making sure that there was a proper air seal, and that energy was not escaping through the windows. Overall, very few interviewees had anything to say regarding the window choice, and it appeared easy to justify including it in the home design.

Installed window with zip tape

2.2.2 Perceptions

The perceptions of the technology were positive from our time on site and in interviews. Most interviewees did not have information to share on the windows or strong opinions on them.

2.2.3 Cold Weather Expectations

Interviewees did not comment specifically on cold weather expectations for the windows. The triple pane windows will likely complement other technologies and have secondary impacts on performance, such as allowing other technologies to perform better in cold weather.

2.3 Ductless Heat Pumps

2.3.1 Decision Making

Indoor DHP unit

Indoor Ductless heat pump (DHP) units are found in the main living spaces of all the homes and are supplemented with electric resistance backup heat for times of extreme temperatures. Other areas of the homes, such as bedrooms and upstairs spaces, are solely heated using electric resistance heating, one of the biggest technological tradeoffs made in the project. The original intent was to include DHP units in all rooms. There were two main reasons for this tradeoff: cost and concerns over performance in the extreme cold temperatures that frequently occur in the winter.

Although tradeoffs related to overall costs were identified by participants as necessary regarding the DHP system, it appeared that the decision to include DHPs as part of the technological system of Bridger View was an obvious choice, consistent with the all-electric goals agreed upon by designers, consultants, and contractors. The other benefit of the DHP was its ability to provide both heating for the winter season and cooling in the summer. One consultant noted that the decision to include the DHP was primarily driven by its ability to provide cooling and efficiency, stating that, "there was a desire to have both heating for winter season but also cooling for the summer season," which they went on to say "points to a heat pump … which is vastly superior to standard electric resistance heating."

The cooling features of the heat pump were one of the key reasons both the consultants and contractors justified including it, even though the costs of the DHP units were substantially higher than the initial cost of installing only electrical resistance heaters. One of the subcontractors noted in relation to the heat pump that it was "easier to justify that extra expense when you're getting both summer and winter duty from it."

The DHP units' cooling features were another benefit as wildfire smoke can be prevalent in the summertime in Bozeman. There may be up to two months of the summer when smoke is present. Typically, nights are cool enough in Bozeman for many people to cool their homes by opening their windows, but people are less likely to open their windows when smoke is present. The heat pump units solve this problem, as noted by one of the project consultants who stated, "Cooling. The idea is that when you have really smoky air, people want to close their windows. They have no way to cool their house when it's 90, 100 degrees out there. That was the idea."

Despite the relatively straightforward decision to have DHP's, cost and overall project budget were a concern, and the number of DHP units in the house were one of the primary areas that cost saving cuts were made. The original intent was to include DHP units in all bedrooms. However, as noted by one of the subcontractors, full home coverage by DHPs did not end up being feasible as the design progressed due to budgetary issues, leading to the decision for DHP's to only be included in the primary living area, and cove heat in the bedrooms. This decision can be partially attributed to the fact that the building envelope and whole-house design still allowed the energy efficiency goals to be met. The consultants and designers felt that the passive approach to the design was a better way to keep the energy efficiency goals while staying within budget and minimizing the impacts of individual homeowner choices, for example, how residents set their thermostats. One of the subcontractors involved in the decision-making process for the DHP units noted that the tight building envelope will "help minimize the energy impact" from choices made by homeowners and how they use the technology systems.

2.3.2 Perceptions

Overall, the perceptions of the heat pump technology were positive in the context of how they would be used at Bridger View. However, there were some doubts about DHPs, primarily attributable to their cold weather performance. These doubts were evident in the decision to that it to include a back-up electric resistance heating unit for times when outdoor temperatures could impact heat pump performance. There was consensus among all consultants, designers, and subcontractors that backup heat was necessary, as it was possible that temperatures could fall below the rated temperature for the heat pump units. The sustainability consultants noted that "the mini-split (DHP) will block out at about minus 13 degrees, but the design temperature is minus 20. There has to be electric resistance backup in that main living space, which otherwise is served by the mini-split (DHP)." The primary reasons for the backup were to ensure homeowner comfort and minimize the risks to the subcontractors and designers whose reputation and work depend on their products reliably working.

Despite these doubts, the overall perceptions of the heat pump technology were positive across the planning and design team, and each of the interviewees anticipated that the heat pumps would perform well. A majority of the concerns were not directly related to the technology itself but were rather based on how contractors and installers would perceive the technology, and how homeowners would use it.

2.3.3 Concerns and Expectations for Cold Weather Performance

Installed Heat Pump

As mentioned above, one of the greatest anticipated challenges of the heat pump units was the perception by some consultants that they may not perform well in extreme cold weather. With the addition of electric resistance heat in Bridger View, the possibility of homeowner discomfort is low. There is, however, a relevant challenge in the market more broadly, as not all homes installed in the region are designed with the Bridger View homes' particular focus on a tight building envelope and substantial insulation.

One of the primary challenges for designers related to the cold weather environment at Bridger View was the location of the outdoor heat pump unit, which could be susceptible to issues related to ice and snow buildup throughout the winter. There was a disconnect between the decision to include the technology and implementing it in the design. The architect for the project noted, in detail, that this was an expected issue and that additional design considerations for the outdoor unit location were necessary.

Navigating the complexities of the potential of placement issues posed a significant challenge because of the critical importance of determining the location of the outdoor unit. The designers did their best to draw the unit location into the plans. However, the location of the wall mount often had to be made on site based on aspect, wind, and shade from neighboring homes. Solutions included features such as drain pans to divert water drainage away from the unit, wind baffles to help control airflow around the unit, and installing them on south facing aspects that receive the most sunlight through the winter. Additionally, the units required wall mounts to avoid ice buildup. Under normal circumstances, the units would typically be installed on or near the ground.

2.4 Heat Pump Water Heaters

2.4.1 Decision Making

Heat Pump Water Heater in basement

The suggestion to include heat pump water heaters (HPWH) in the homes at Bridger View was made by the sustainability consulting team, who made many of the suggestions on which energy efficient technologies to include in the homes. Like most of the decisions made in the design of the systems for the homes, the inclusion of HPWHs was made to maximize energy efficiency and to align with the project goal of having an all-electric home. The HPWHs in the Bridger View home are a hybrid unit, meaning that backup resistance heat may kick in if there is a large hot water draw in a relatively short period of time.

There were several considerations made in the water heater decision including the costs, size of the tank to match the size and number of people living in the home, and conditioning of the space to optimize the heat pump performance. The cost savings over time were the largest justification for including the HPWH despite the higher unit costs relative to a traditional water heater. One of the sustainability consultants noted, “it was actually extremely easy to justify the pretty nominal added cost to do water heating as opposed to electric tank. It was a five- or six-year symbol payback even with pretty low electricity costs [in Montana].”

To realize those cost savings, and maximize efficiency, the sustainability team had many discussions regarding the tank size and ensuring that it had the right sizing and capacity for the home sizes and number of people expected to live in them.

Finally, the placement of the HPWH is important, as the conditioning of the space impacts the performance. The subcontractor and mechanical team were concerned the water heater may not work properly because the water heater is located in an unconditioned basement that may become cooler than the rest of the house. The sustainability team was not overly concerned about this, as the temperature of the basement is not expected to fall below the level necessary for the heat pump to function properly. Additionally, the heat pump clothes dryers are in the basement and will, from the perspective of the sustainability consultants, "help heat up the space." As stated by a member of the sustainability team, there is "at least a slight synergy between the closed dryer adding heat to the space and then keeping up dry heat."

2.4.2 Perceptions of Technology

While few interviewees commented directly on their perceptions of the heat pump water heater, it seemed that among the design and consultant teams, that the water heaters were viewed as a positive addition to the houses. In general, the overall view of the energy efficient home design and system (of which the heat pump water heater was a part) was favorable, particularly among the consultant and design teams. This is not unexpected, as the push for energy efficiency came from the designers, project planners, and sustainability consultants.

2.4.3 Concerns and Expectations for Cold Weather Performance

In one on-site visit, the research team engaged a few of the subcontractors and project planning and design team who were filming a promotional video about the energy efficient design and technology for the housing trust in charge of the home sales. On this visit, the team engaged with both the subcontractor in charge of the HPWH and one of the sustainability consultants who helped make the decision to have HPWH's in the homes, which allowed the research team to understand additional details about their expected performance and to learn if there were any installation challenges or unique aspects to installing the HPWH's relative to conventional water heaters.

HPWH control panel

The research team learned from the sustainability consultant that the performance of HPWH's will not decrease in an unconditioned basement. It would not be possible for the basement to reach temperatures cold enough to cause the water heater's performance to decrease during normal use of the residence.

The biggest challenge with the HPWH will most likely come from individual homeowner water use. The sustainability consulting team noted that "reducing water usage can improve the efficiency of the hot water heater if it's a heat pump water heater for exactly that reason, because if you have lower flow rates at the shower heads or faucets, then you're going to deplete the tanks more slowly." Although the HPWH was not specifically mentioned, most of the project planners and consultants emphasized the importance of having an owner's manual for the technology systems in the house and a supportive HOA to help with problems and proper use of the technologies.

3 Project Phase 2: Building Process and Technology Installation

The second phase of the Bridger View project was the construction of the homes, which included the installation of energy efficient technologies. In accordance with the site project phase, the research team completed research study phase 2 by engaging with several subcontractors through one-on-one interviews, and many members of installation teams during on-site visits to observe technologies being installed.

Some of the challenges occurred during the initial period of planning and construction that were related to issues with supply chains, labor force, and navigation of local code restrictions. Several subcontractors indicated that hiring and workforce turnover was an issue, and simply having enough team members to staff and complete projects had been a challenge. At times, supply chain issues with products or materials delayed timelines and compounded staffing challenges. For example, a crew may be scheduled to be on-site for installation, but if the materials were delayed, the overall timeline of the project was delayed. Some subcontractors mitigated against unpredictability in supply chains by bulk ordering products ahead of time and storing them in warehouses, which is what was done with HPWHs. There were some areas where planning ahead was not possible of feasible, and unpredictable arrival times for materials due to supply chain disruptions led to logistical challenges on site, particularly with the small site size. Specifically, there was not a lot of on-site storage, so if materials arrived at unplanned times, subcontractors lacked the space to store them. The small site size also made planning difficult because certain trades could not work onsite simultaneously without significant inefficiencies. The research team worked within these constraints and maintained a flexible schedule to complete on-site visits throughout the project to align with the construction management schedule.

3.1 Building Envelope and Insulation

3.1.1 Perceptions

Insulation being sprayed in

One of the most prominent aspects of the building envelope and construction phase referenced in the interviews were the utilization of blower door tests to check the air seal of the homes throughout the construction process. For each home, three blower door tests were completed during the build phase, in contrast to the industry standard of one test at the completion of the building envelope. Nearly every study participant viewed the multiple blower door tests as a huge success for a variety of reasons. First, they allowed the designers and consultants to track progress and ensure that the design of the home remained consistent with the energy efficiency goals. Secondly, and perhaps most importantly, by providing targets to meet and allowing the construction team to view the outcome of their work, the blower door tests incentivized attention to detail, boosted morale, and improved on-site efficiency. Many of the consultants noted that it was gratifying for the crew who had been working on the homes to see their progress and success. Even when the blower door tests showed substandard results, they gave the crews an early opportunity to fix mistakes before they became more difficult to fix later in the process.

Members of subcontractor teams viewed the blower door tests as a success because they allowed them to track their progress and make fixes throughout the building process rather than going back at the end to fix things, which is more costly. However, other contractors noted that the air seal process and having to complete blower door tests added logistical challenges and made for a longer and more detailed construction process than is typical. The strict air seal requirements, for example, made the plumbing and electrical subcontractors' job more time consuming, as holes drilled for wires and piping needed to be resealed. Although the air seal requirements were unique, they did not present challenges to the construction crews from a knowledge standpoint, as they possessed the skill set for meeting the strict requirements. The largest challenges were the coordination and planning processes, to ensure that the attention to detail was high and that corners were not being cut by any members of the construction and installation crews.

The insulation subcontractor described positive perceptions of the quality of the insulation material and ease of working with it. He noted that when he does cellulose packed houses, homeowners seem to notice a difference between houses that are insulated with typical insulation materials such as fiberglass or spray foam. The differences he noted were primarily with sound and how tight the house feels. Overall, perceptions of the advanced insulation were generally positive or neutral.

3.1.2 Challenges and Installation Experience

Example of installation fabric and blow-in hole

From the perspective of subcontractor/installers, teams did not face challenges in expertise or knowledge regarding technologies or the processes required for installation in the context of an energy efficient building envelope. According to study participants, the building processes were fairly standard and consistent with a typical home construction, in that specialized expertise was not necessary. In areas where more expertise was required, training or video instruction sufficed to get installation teams up to speed on processes. It was also stated that a lot of skills and efficiency in installation were gained through trial and error while performing tasks. Overall, installation and the tight envelope design did not seem to pose a challenge across any of the technologies examined in this study.

The processes and sequences required to implement the different technologies in the context of a whole-house design and building process, however, presented a greater challenge. The main concern was sequencing, which was more time consuming than traditional residential home construction. For example, the tight building envelope required a greater level of oversight and review of the installers' work by the general contractor site manager, consuming more time overall. From the project management perspective, it took some time to learn the new processes and importance of sequencing compared to a typical house. As the project progressed, it appeared as though the construction team successfully bought in to the process, and the teams reached their goals. Participants noted that success was heavily informed by top-end oversight, learning, and support to make sure the construction teams understood the reasons for why they had to pay attention to the details. Additionally, the project managers stated that some of the processes and requirements they learned from working on this development will make the process on future developments with high energy efficiency requirements easier and more efficient for them.

There were no challenges that any interviewees identified in installing the cellulose insulation materials. According to the insulation subcontractor, the process was “all pretty straightforward. Like I said, the only hiccup was getting the material that we were using, just because I’ve never had to order it or anything like that. My installers love the way it blows.” In fact, according to the subcontractor and his crew, the material is a less dusty product and did not cost much more than the typical insulation material used.

The primary challenges with the insulation on this particular project were related to supply chain and labor force issues. The insulation subcontractor was located out of state, so workdays were determined by the number of crew members that could travel to Bozeman and the amount of material in a truckload. A truckload is typically equivalent to the amount of work a crew can complete in a day. The challenge was related to whether the material was available on scheduled workdays because pandemic related supply chain issues occasionally caused delays. According to the subcontractor, they experienced several project delays because they were running out of material and had to wait several weeks before new shipments came in.

3.1.3 Cold Weather Concerns

There were no cold weather concerns noted in relation to the building envelope or insulation.

3.2 Triple Pane Windows

3.2.1 Perceptions

The perceptions of the triple pane windows generally seemed positive from our time on site and in interviews. Most interviewees did not have information to share on the windows or strong opinions on them.

Triple pane window from interior

3.2.2 Challenges and installation experience

There were no anticipated challenges related to the windows or their installation. The project manager stated that there were no differences in the way a triple pane window is installed compared to a normal window. The only difference that added challenges were how the windows fit in with the exterior insulation panels of the home and the air sealing required for the building envelope. The project manager stated that the process for the windows is “not too bad, it's mostly just related to the air sealing requirements that seal the window units themselves to the air barrier.” In addition to the air seal, the project manager mentioned that window boxes had to be built so that the exterior insulation would fit around the windows.

Overall, the windows did not present a challenge, but the requirements for how they fit with the insulation and building envelope required extra time and work. On-site visits to observe the installation process of the triple pane windows confirmed that installation did not present any challenges to crews. The primary challenge with the triple pane windows comes from the tape used to seal the windows once they were installed, which is consistent with the statement from the project manager that the air seal and insulation requirements were the main issue. The installers mentioned that when temperatures rose above about 90 degrees the tape became overly stretchy, making it difficult to manipulate properly. If the tape sticks to itself, it usually has to be thrown away as they are rarely able to unstick it from itself. To remedy this, they tried to get their work done in the morning and worked in the shaded areas during the hotter times of day if the project permits. They also noted that the liquid flash used as a sealant is very difficult to get off if you get it on yourself but does not pose challenges to the actual installation process. Other than these minor issues, the installation process was rather standard and no different than the installation process for typical windows.

3.2.3 Cold Weather Concerns

There were no cold weather concerns related to the windows.

3.3 Ductless Heat Pumps

3.3.1 Perceptions

In general, installers and subcontractors' perceptions of the heat pump technology were positive in the context of how they would be used at Bridger View. However, there are still some doubts about DHPs, attributable to particular subcontractors' perceptions of their cold weather performance. These doubts are evident by the fact that it was decided to include a back-up electric resistance heating unit for times when outdoor temperatures could impact heat pump performance. The primary reasons for the backup were to ensure homeowner comfort and minimize the risks to the subcontractors and designers whose reputation and work depend on their products reliably working. One of the subcontractors noted the lack of published data on DHP performance below temperatures of minus 13, which was a concern, as temperatures in Montana can "get to minus 18… and oftentimes even lower than that" in the winter. If the technology cannot perform in these temperatures, even though these temperatures are rare, the burden of the technology failing at low temperature was perceived to fall on subcontractors.

Doubt concerning the reliability of DHPs in cold weather may be a significant limiting factor in uptake or perceptions of DHPs in the broader market. When the subcontractor was asked for more detail on their limitations, he noted that the concern over cold temperature performance will always be a limiting factor for him, and that he will always recommend backup electric heat, which is not viewed ideally, as it adds "redundancy in your system, which adds cost."

Part of this perception may be due to this particular subcontractor's previous negative experiences with heat pump units. He said, "I have seen numerous projects where the unique climate to Montana tends to cause heat pumps... (DHP) mini-split heat pump-style units to fail." It appears that prior biases and experiences could impact future use of certain products, particularly when that experience is negative.

Another interesting, and relatively positive, perception of the technology was that they were seen as a tool to solve specific problems that cannot be addressed with a normal HVAC system. According to one contractor, "When I have a situation where I don't have sufficient space for a more conventional system, I can use a mini-split (DHP) to solve that problem. When I'm dealing with a renovation where I have limited access to install components, they're a way to solve that problem."

3.3.2 Challenges and Installation Experiences

Another interesting point made about the heat pumps was not necessarily related to their performance but their availability in the market and what that means for their use and uptake from contractors and installers, which could be a potential challenge in Montana. The installation subcontractor said that there were several heat pump manufacturers who are represented in the market, but the manufacturers who provided the best support played a large role in which heat pump model was chosen, as the manufacturers can provide support to subcontractors to ensure they are installed properly.

Finally, the subcontractor anticipates the homeowner's experience with the DHP unit, particularly in the summer when it will be used for cooling, will be another challenge. Because the living room where it is located is the only room directly cooled by the DHP, the homeowners may become confused as to why there will be no cooling in the bedrooms. Based on his personal experiences living in Montana, the subcontractor thinks that bedroom DHP units should have been a feature. He noted that "cooling was needed most in the bedrooms, not the living area, and I fear that that's going to be the case for a lot of people that own these homes, and I think some of them… are going to start to wonder, 'Why did they put that thing downstairs? Why isn't it upstairs where all the heat is?'"

The DHP's appeared to be a relatively straightforward installation process from the research team's on-site visits. The installers noted they have had previous experience with this type of installation though they typically installed these in commercial developments rather than home developments. However, it was an easy transition to installing them in a residential setting. This is consistent with statements from the on-site project manager, who noted that there were "no major challenges. I can speak to the design end of it. As far as installation, [it] hasn't presented any un-sizeable challenges… It's probably quite a bit easier than a traditional ducted system."

The only issue that arose during the installations were associated with the copper pipes that connect the outside heat pump to the inside unit. When kinked, these copper lines must be completely replaced. The installers noticed that some of the workers not involved with the heat pump installation would bend the copper wires without thinking about it to move them out of the way of their work. The damage was unintentional and likely a product of having multiple crews on site at the same time, as well as working in a relatively small work site. The problem was easily remedied by simply telling everyone on site not to bend these copper wires and putting signs around them.

Example of copper pipes that were sometimes damaged at heat pump location

3.3.3 Cold Weather Concerns

One of the primary challenges for designers related to the cold weather environment at Bridger View was the location of the outdoor heat pump unit, which can be susceptible to issues related to ice and snow buildup throughout the winter. There was a disconnect between the decision to include the technology and implementing it in the design. The architect for the project noted that this was a challenge. Additionally, the subcontractor in charge of the DHP installation also noted the consideration for how they are installed and that there are potential issues with ice buildup when water drains off the unit and freezes.

The considerations that had to be made for these potential issues seemed to be the largest challenge because the location of the unit was highly important. The designers did their best to draw the unit location into the plans, but some onsite changes were necessary to mitigate some of these issues.

3.4 Heat Pump Water Heaters

3.4.1 Perceptions

The most skepticism of the HPWH's came from the subcontractor and mechanical team tasked with ordering and installing the water heaters. One thing that was initially pointed out was the lack of literature on residential heat pump water heater products, particularly related to understanding how much energy it is taking out of the surrounding atmosphere and how much it will cool the room. This was concerning for the subcontractor, as they had experience installing HPWHs in large commercial projects, where they noted that information is typically readily available.

Another key perception of the HPWH was linked to the potential cost, both the high cost of the unit and the potentially large energy savings over time from its efficiency. The design team and sustainability consultants had a positive perception of the units based on the understanding that the energy efficiency benefits would be realized within 5 to 6 years, which justified its inclusion despite the initial cost.

From the perspective of the subcontractor and mechanical team, however, there were concerns on whether cost savings would be realized, stemming from a lack of literature and concerns about how they would operate in the unheated basement. In particular, the subcontractor was worried that the HPWH may create a colder environment in the basement by pulling heat from the air which could also potentially create condensation issues, stating that "It's just a bit of an unknown" and that he would have "felt more comfortable having electric heat" in the basement to ensure proper functioning of the HPWH.

The other issue related to the skepticism about performance was if the high costs of the units were worth it. Although the budget was a secondary issue of the Bridger View project due to the supplemental private funding, there were still areas where finding ways to save were necessary. Because of the uncertainty about performance, the subcontractor felt that the heat pump water heaters were a technology that could be cut to limit overall costs, while retaining other aspects of the energy efficient design elements.

3.4.2 Challenges and Installation Experiences

One of the anticipated challenges and resistance to HPWHs was directly related to the skeptical perceptions of their performance. As mentioned, some participants were concerned that they would not perform well in the unconditioned basement and that the energy saving costs would not be realized. It is important to point out that these perceptions from the subcontractor were from an interview relatively early in the research for this project. In subsequent interactions with this participant, it appeared that there was increasing confidence in the performance of the heat pump water heaters. This attitudinal shift was likely due to continued education, interactions with members from the sustainability team, and participating in the progress of the construction.

In an on-site visit where several members from the sustainability consulting and subcontractor teams were present, the research team learned a substantial amount about technology performance, both through direct questions and demonstrations.

First, the research team learned from the sustainability consultant that the performance of the heat pump water heaters will not decrease in an unconditioned basement. It would not be possible for the basement to reach temperatures cold enough to cause the water heater's performance to decrease. Secondly, the research team asked the subcontractor about installation and if there were any challenges related specifically to installing the HPWH. His response to this question made it definitively clear that there were no challenges to installing a heat pump water heater relative to a normal one and it was nearly the same process for a conventional one. When the research team pursued this question with other on-site members and pressed further with the lead subcontractor, it was confirmed through his response that there were no challenges with installation.

As mentioned in the previous section, the heat pump water heater follows essentially the same installation process as any other water heater, leading to no complications with installation, according to installers on site. The installers mentioned that the location of the heat pump water heater varied depending on the layout of the basement in the unit where they were installing it. Across all units, it is not sealed off by a door, although in some units it is located under the stairs, and in others it is in a more open location in the basement. The particular heat pump water heater used at Bridger View comes with an electrical resistance backup to heat the water in case the HPWH cannot keep up with hot water demand. It was also noted that an expansion tank was installed to ensure that the heat pump water heater never runs dry because that could damage the heating parts of the water heater. If the city water is shut off for any reason, the expansion tank will kick in to ensure this doesn't happen.

Connected to the heat pump water heater is the heat pump water heater circulator. The circulator is located next to the heat pump water heater and is activated via a Wi-Fi/connected button in the upstairs bathroom. Most circulators run every hour, rendering them inefficient when the hot water being circulated is not used. This button dissipates this issue by only circulating hot water on demand, so no energy is wasted circulating hot water when it is not being used. The installation process of this circulator was smooth and without issue, according to installers. The installers also noted it was as simple as pairing any Bluetooth device to Wi-Fi.

3.4.3 Cold Weather Concerns

There were few concerns related to cold weather performance of the HPWH, other than those expressed by the HVAC subcontractor mentioned above in section 3.4.2. This matter arose early on in the construction phase and appeared to have been resolved in subsequent conversations with this subcontractor.

4 Project Phase 3: Use of Technology – Homeowner Perspectives

Home building and nearly complete homes

The original project goal was to complete interviews with 30 of the 62 resident units planned for Bridger View. Due to construction related timelines, there were a total of 30 resident occupied units at the time of the completion of homeowner interviews. The interviews with homeowners focused on understanding and documenting how the end users of study technologies learned about each technology, the expectations they had for the technology, the experience of interacting with the technology, and their confidence in being able to access services and maintenance as needed for the given technology. The research team was able to complete interviews with nearly 50% of homeowners of units occupied during the study period.

4.1 Building Envelope and Insulation

Homeowners had little awareness about the building processes that created their homes and this lack of awareness that extended to the building envelope and insulation. The majority of homeowner participants shared that they could feel the tightness of the home, and appreciated the insulation, but had few specific insights about the technical elements of these systems.

4.1.1 Process of Learning About the Homes

Multiple participants noted that they received some description of the building envelope and insulation during the home purchasing process. As an element of the built environment that does not require regular maintenance, participants shared relatively little information about learning specific details about either the envelope or the insulation. One detail which homeowners noted that real estate agents consistently mentioned during the home sale process was how the cellulose-based insulation contained lower levels of toxicity than traditional fiberglass insulation. This detail interested home purchasers who anticipated having children in the home and had desires to limit exposure to toxins, even if they also shared an awareness about their own limit understanding of toxicity levels across different types of insulation.

The research team inferred that the Bridger View residences were designed in an integrated way, with the idea that all the technologies would work together, and that the performance of each technology would be impacted by the building envelope as well as how the other technologies are used and perform. It is evident that many homeowners have a general understanding of this concept, but there were others who were not aware of this fact or do not yet understand it. One homeowner who has lived in the home through the cold temperatures experienced in February mentioned that their home "did great, using only the heat pump" during that time. Due to that, when asked about the backup heat, they stated that they are "not aware if we have backup systems" but that their "partner is whispering to me that we do have a backup system. I don't have any details about that. So I think something does exist that someone hasn't told us about." While this was indicative of strong performance by their heat pump during cold weather, it also demonstrates that not all homeowners may be fully aware of how their full systems function.

4.1.2 Expectations of Home Performance

A number of participants purchased condos in Bridger View that are either a basement unit or share a wall with an adjoining unit. In these interviews, study participants shared how they had some apprehension about the sound carryover from adjacent units, but how they have been consistently surprised and impressed by the ways in which the insulation mitigates sound-travel.

One participant went on to share how she had very limited experience with hearing the neighbor, minus a few occasions with exceptionally loud music or home repair projects that required the use of power tools. When asked directly, homeowner participants had little to share about their expectations of insulation quality of the building envelope other than that they expected it "to be solid."

4.1.3 Experience With Home Performance and Cold Weather

The expectation of homeowners about the "solid" feel of the homes has been consistent with their experiences of residing in the homes. Across all unit types, homeowners shared how the sound barrier was notable, especially when recognizing that they are all still residing in an active construction site, with phase 3 homes still under construction. When the windows are closed, all resident participants echoed the sentiments of this participant who shared, "Once you close all the windows, it's pretty quiet." Another resident who had lived in a similar living setting also noted that relative to their previous place, they "feel like they don't hear their neighbors here."

Another aspect of the homes that homeowners have attributed to the insulation and building envelope is the ability of the homes to maintain a consistent temperature, regardless of season or outside air temperature. One participant noted that "it stays very cool in this house. So, in the winter, I feel like it's kind of like a thermos in a good way, where it's like if you keep it at 67 degrees in the winter, it will be at 67 degrees. And if you don't have anything going on in the summer, you don't have the cooling on and you don't have the heat on, it's doing its own thing, so far this summer it's quite cool."

A different homeowner stated that they "haven't spent a full winter here yet, but we did spend some of the coldest winter days here somehow and definitely have noticed a more consistent temperature throughout the home, even upstairs. And same in the summer." They went on to share that they had previously lived in a three-floor condo in town, and how the Bridger View homes were substantially more consistent in temperature relative to their previous condo.

The cold weather performance has clearly been something that homeowners who have lived in the homes during the winter have found to be a strength. Another homeowner noted that during the "cold months that we have spent here, our electricity bill has been insanely low because we felt very comfortable and warm without feeling like we were spending a ton of money on electricity. And then same in the summer, we have these really awesome fans that I think are in all the homes actually that have been really, really great for keeping the whole house cool." Overall, homeowners have found the insulation and the ability of the homes to maintain a consistent temperature to be a huge plus, as it has allowed them to live in comfort and save on energy bills due to the heating and cooling units having a lower load.

4.2 Triple Pane Windows

4.2.1 Process of Learning About the Technology

Participants noted that realtors and consultants described the windows as a key part of the insulation and tight envelope of the homes. Similar to the insulation and overall building envelope, participants did not have a substantial amount to share about learning about the technology, beyond that the windows were a contributor to the energy efficiency of the homes and that those things "are the key points I remembered when we came to tour (the homes)." In general, the triple pane windows intrigued the participants, with one participant noting that "I like the idea of the triple pane. I loved that idea, but that was also really related to noise too, I think."

4.2.2 Expectations of Performance

Participants shared very little on their expectations of the performance of the windows, as most would "assume that they're good quality in terms of being gas filled and multiple panes and everything, so that's nice." In general, they expected strong performance and a contribution to energy efficiency based on information given on tours and upon moving into the homes.

4.2.3 Experience of the Technology Performance

Homeowner experiences with the windows have varied, with some participants noting that they have performed in alignment with expectations and that they are pleased with the performance, while several others have noted issues with the windows having some drafts or issues with alignment and latching. In general, the homeowners who have had positive experiences with the windows had little to share, as the windows have met their expectations and have not generated strong attitudes. One participant shared that "the windows seem to hold a lot of heat in" and that they have not experienced any condensation or issues with the windows becoming cold like they have in previous places they lived. Another participant stated that they "think the windows are amazing" in comparison to their previous residence.

While the windows perform well when fully latched and closed, multiple homeowners have experienced challenges with the mechanical components of the windows and difficulties latching and locking them after they have been opened. One participant stated that "mechanically, they've been a disappointment." Another participant also noted, in relation to the windows, that they are "pretty concerned about that because windows are a big deal to have problems on."

In order to deal with the window latching and mechanical issues, builders were asked to adjust or fix some of the windows. Although this fixed some of the issues, some of the homeowners who expressed this difficulty still had concerns over their functionality even after the builders came in. Another homeowner mentioned that the builders said that "the whole frame needs to come out and be redone." While this homeowner went on to say that it was a warranty issue, they were concerned about it being replaced with the same brand since it "didn't last several months before it was broken."

Homeowners had positive experiences overall regarding the windows' performance and contribution to the building envelope of the home when they close and latch properly. However, a few homeowners did have challenges in closing the windows properly. This appears partially due to a complex or faulty latching system, and possibly is related to improper window framing. If the performance issues were caused by improper framing, there may need to be additional training for crews installing triple pane windows, which need to be framed differently than standard windows.

An additional need may be for training or additional instruction among installers about the micro-adjustments that are possible with this model of triple pane window.

4.3 Ductless Heat Pumps

4.3.1 Process of Learning About the Technology

The process of learning about the ductless heat pumps appeared to unfold slightly differently for each homeowner, mostly as a result of a lack of familiarity with heat pump technology itself and exactly how it will work. Upon move-in, homeowners were given manuals on how to use the technology and have received resources through the HOA and newsletters available to them. Despite this, much of the learning appears to have come through trial and error to figure out which settings work best and how to use the heat pump most efficiently with other HVAC components, such as the back-up heat, ceiling fans, and ERV system.

One new homeowner approached the learning process with indifference and cited the resources they have available to help them through the process. Other homeowners, in general, seemed prepared to use the technology while acknowledging that there were still some kinks to work through in understanding how the whole system works. One homeowner noted they feel "pretty prepared to use it," although they still have a couple of questions about air circulation and how the unit works with colder air. Another homeowner referenced how they just recently turned their heat on as it has gotten colder, and they were slightly uncertain initially about how to use the smart thermostat to program the DHP and backup heat, and particularly "if there was a separate thermostat for the heat, electric heat, versus the DHP thermostat in the living room." They went on to state that they had found the answer to their question and that the system "seems fairly easy to use once you get the hang of the smart thermostat."

Uncertainty on how the systems function has been expressed by other homeowners as well. Another homeowner mentioned, in relation to the settings for the DHP, that "as far as programming, programming it to turn off, turn down at night, whatever, that sort of thing, probably not as high (as turning the unit on or off)." There was also some confusion on how other components were supposed to function to maximize the benefits of the DHP system, such as the ceiling fans. One homeowner mentioned, "I don't know if I'm supposed to have the ceiling fans on or not. I think I am, but I don't know. That's another thing. I don't know what I'm supposed to do."

Despite some of the uncertainty, many homeowners have demonstrated how the learning process has been eased, either through self-teaching or through HOA newsletters. One homeowner discussed utilizing YouTube videos on how to use the heating system during the winter, which was something he was confused about.

It was also mentioned that in a recent HOA newsletter there was a topic on how to set the heaters, which one homeowner stated was "a really, really cool feature. They made it clear in our last newsletter… suggesting that the most energy efficient behavior is setting your AC really warm, then using your ceiling fan, which makes the room feel so many degrees cooler. Big supporter of that."

Overall, the learning process for the technologies appears to have varied by homeowner and how much they engage in the learning process, as well as how they learn about it. It is clear that a substantial portion of learning comes through manuals and HOA engagement. However, more consistent training or standardized messaging from Bridger View HOA and consultants may streamline the learning process of how to use the DHP technology most effectively for homeowners.

4.3.2 Expectations of Performance

The variation in the learning process among homeowners impacted the amount of information gleaned during interviews about their expectations of performance. The majority of study participants expressed that they had general confidence in the potential performance of the system prior to utilization. A few individuals expressed some uncertainty about how the units would perform in extreme cold temperatures. This concern resonated with those of the designers, who added supplemental electric cove heaters to manage this potential limitation. The sentiment about the role of the cove heaters in expectations related to extreme cold were expressed succinctly by one study participant who shared, "We didn't really think we would get through a winter with the heat pump. I'm familiar with the technology and like that there are supplemental on the wall because I know they're not terribly effective in the cold, cold."

4.3.3 Experience of the Technology Performance

Generally, homeowners have been pleased with the performance of the DHP system itself and have found that when the settings are set properly their home maintains a comfortable temperature and energy efficiency is maximized. Homeowners that live in smaller one-bedroom units found the heat pump to be highly effective, as the heat was able to effectively disperse through the whole space without the need to utilize the backup heat. Several participants also noted that the ceiling fans, which can be set to rotate to maximize the dispersion of warm or cold air, were very good for maximizing the benefits of the DHP unit.

One of the main frustrations that people had was that there was only one DHP unit in the homes, which is located in the main living area. Many homeowners were confused as to why there were no units in the bedrooms. One homeowner mentioned that this aspect was something they "felt tricked on," as they were given the impression that it would service the whole house.

Despite this feeling, this homeowner did go on to say that the DHP unit "did work well" in the living room, so the frustration was based on the absence of additional units, not DHP performance. Similarly, another homeowner stated they would prefer the DHP to be able to service "the whole house, but we figured out how to make it work. It hasn't been that hot this summer, so I think that's just been really helpful. I just like not being really hot when I sleep."

The cooling aspect was one of the main reasons homeowners would have preferred units in their bedrooms. Another homeowner mentioned that "it would be nice to have a dual unit or dual head heat pump so that you're able to get air conditioning upstairs. The heat obviously works great going upstairs, but I guess I don't know what it's going to be like in the summer when it's smoky and it's bothering us and we're also hot." They went on to say, "We had a rough summer last year because we didn't have any air conditioning." Another homeowner also felt additional units would have been better, stating, "We use the air, but the hard part is you have the air on down here, but you're in the bedroom, so you have your windows open and the fan going. It just seems silly to be running air or heat with windows open."

Multiple homes in phase 1 experienced poor performance initially due to incorrect settings with ERV component to the heating systems. While this problem has since been mitigated, several homeowners mentioned these issues, which were causing the units to operate highly inefficiently in the first winter that homeowners inhabited the homes. These were primarily due to the settings on the backup cove heat causing the heating to kick on substantially more than it should have relative to the DHP, and the ERV system functioning improperly.

Members of the sustainability and installation teams were able to quickly identify this issue and correct it in all of the homes. One homeowner mentioned that they appreciated these things being fixed, stating, "When we first moved in, they did say like, 'Hey, we recognize we set things incorrectly. We will send somebody to come fix it,' without us having mentioned it. That was nice having that fixed." One of the consultants mentioned that this upcoming winter is "going to be a good test because now we've worked out all those kinks and are eager to see where people's bills are coming in."

The one other area where some owners had frustrations was the location and size of the outdoor unit. One homeowner thought "the heat pump should have been put somewhere other than the walkway to the back stairs," as it sticks right out into the walkway. Another homeowner wished there was a larger unit that they could tap into, as they wanted to add a unit to the basement they eventually want to finish. They mentioned, "I think a couple of us wish that they put bigger units on our homes. Because when we plan on finishing our basement, the idea is to tap in, but you can't because the capacity of our unit basically would be at max capacity."

Aside from some of the frustrations with units only being in the living room, and some of the initial challenges with the systems having improper settings, the DHP units were viewed favorably and working well from an energy efficiency standpoint. Many preferred it over normal heating systems, mentioning things such as *"the way it pumps is really cool too, because, in the other rooms, it's silent, which is awesome."* Homeowners certainly face a learning curve in how to maximize the benefits of the technology, but with experience, the technology functions well.

4.4 Heat Pump Water Heaters

4.4.1 Process of Learning About the Technology

Homeowner participants shared very little about the learning process associated with the heat pump water heaters (HPWH). Many of them mentioned that both the HPWH and the Bluetooth-based on-demand hot water pump controller was identified as a useful feature by the realtors. In addition, interview participants shared that the HOA and Headwater Land Trust staff provided documentation associated with these systems. Those that have engaged in self-learning about these systems shared that they tended to utilize the internet and YouTube more than the documentation offered directly to them as home purchasers in Bridger View. Homeowners felt adequately informed about how to make adjustments to the HPWH, but they reported feeling under informed about how to manage or adjust the hot water pump controller.

4.4.2 Expectations of Performance

Home purchasers had few expectations of HPWH because it was a new technology, and they simply trusted the designers and builders. Those with expectations shared that they appreciated the flexibility of the heating standards built within the units, allowing them to *"toggle from what heat source, efficiency, vacation mode, just as options for us as we travel just reflect on our heating costs."* A few participants shared that they expected to need to make adjustments from the efficiency setting to a higher-heat output setting to account for additional household members as they added new children or shared the living space with a roommate.

4.4.3 Experience of the Technology Performance

All homeowners were pleased with the performance of the HPWH. Very few of them reported having to adjust the efficiency setting to meet their desired needs for hot water. One or two shared that they noticed how on high volume water use days (multiple loads of laundry, dishwasher, and multiple showers and/or baths) they reached the limits of the HPWH capacity. Of these participants, all of them noted that this did not lead them to make changes to the default settings but reflect on their own daily utilization and accept that heavy utilization days may simply result in lower hot water availability.

In contrast to the attitudes about the HPWH, resident participants universally have struggled with the on-demand hot water pump controller. All participants shared that they have not been using this functionality, instead allowing the water in the bathroom to run before it becomes hot. Those individuals and households who tended toward problem-solving of other home systems also expressed frustration about this particular functionality. No one interviewed for this study reported the ability to effectively link the system to generate on-demand hot water in their bathroom.

4.4.4 Perspectives on Servicing and Maintenance

As with a few of the other technologies of focus for this study, homeowners felt underprepared for servicing their HPWH if the need was to arise. At the time of the study, they shared how they would continue to rely on the construction company for support as they have been the entity with primary responsibility for addressing warranty related issues within the homes. During the interview process, in May of 2023, the research team was informed that warranty issues for all homes would be transitioning from construction company staff to the staff of Headwaters Community Land Trust. This was knowledge that had not been fully understood by homeowners, who continued to express uncertainty about how they would go about receiving support for any service needs regarding their HPWH.

There were some concerns among homeowners that they will have difficulty in being able to identify organizations with the appropriate expertise in HPWH to service their units. Although, it is important to note that this concern was in the minority, with the majority perspective being one of uncertain confidence in being able to find a firm or individual to maintain the unit over time.

5 Energy Efficiency and Costs – Analysis of Energy Use in Bridger View

5.1 Estimated and Actual Energy Use – Energy Models and Homeowner Energy Bills

This section focuses first on pre-construction energy modeling, which was conducted by the sustainability consultants on the project to understand estimated energy usage for each home. The second focus of this section is on homeowner energy bills and, when possible, comparisons of actual homeowner energy bills to the estimated energy use and costs from the energy modeling.

The research team did not conduct any cost estimates or analyses for the unit or installation costs of the technologies themselves, as those costs were highly variable and dependent on timing of the purchase of units and labor costs, which were subject to pandemic and market driven uncertainty. For example, the heat pump water heaters were purchased in bulk prior to construction and then stored in the HVAC contractor warehouse until installation. This helped minimize costs and logistics but makes determining unit costs difficult. Other examples mentioned by the project manager included change orders to windows and insulation that impacted costs, as well as the large increase in labor costs that may have occurred over the time span of the project. They mentioned that the general contractor was "able to get the subs to lock their labor, I mean at the value to the ownership because, in theory, those subcontractors likely had to pay their guys two years later significantly more. So that was a big win for them to get the subs to commit to their original price." For these reasons, only energy costs were analyzed.

5.1.1 Estimated Energy Use and Cost Savings

As the Bridger View homes were being built, energy usage models were applied to each home type by the energy consulting team in order to estimate the energy usage and annual cost savings relative to normal homes[4]. These estimates were shared with the research team and are presented here. There are several important things to note prior to presenting the estimates:

- Cost estimates are based on energy rates at the time when modeling was done, which occurred from late 2022 through the first half of 2023, so may not reflect current energy rates.
- The modeling software only allowed for one heating type to be chosen and heating estimates assume that the DHP system is the only heating source for the homes and does not account for backup electric cove heat. Due to this, heating estimates presented may be lower than actual heating energy use, particularly in multi-bedroom homes where the heat generated from the DHP unit may not spread to the bedrooms.
- The modeling also does not account for electric duct heaters connected to the ERV system. The sustainability consultant noted that those may account for additional KWH per month during the winter, depending on the air temperature and how well the units end up functioning.

Table 4 below displays the average HERS rating, cost savings, and energy use estimates by home type. The HERS rating is based on a reference home, which has a score of 100, and a zero-energy

[4] Normal homes were not well defined in the energy modeling, but we assume they are homes not built to strict energy efficiency requirements.

home, which has a score of 0. The lower the HERS rating is, the more energy efficient the home is. The annual cost savings are estimated in relation to an average U.S. home.

Table 4. Estimated annual energy use and savings by home type

Home type	***# of bedrooms***	***Avg. HERS rating***	***Avg. annual savings ($)***	***Avg. total electric use (KWH)***	***Avg. DHP heating (KWH)***	***Avg. HPWH (KWH)***
2 bedroom farmhouse	*2.00*	*47.78*	*$2,214.22*	*11,048.62*	*6,000.93*	*641.47*
3 bedroom farmhouse	*3.00*	*45.43*	*$2,777.00*	*12,986.04*	*7,414.10*	*752.00*
Bungalow 1	*1.00*	*47.83*	*$1,668.33*	*8,521.88*	*4,431.75*	*517.62*
Bungalow 1	*2.00*	*46.00*	*$871.50*	*8,763.45*	*4,480.75*	*551.45*
Bungalow 2	*2.00*	*46.38*	*$2,277.50*	*10,971.02*	*5,941.70*	*600.65*

Sources: Pre-construction energy use estimates from construction energy consultants. Energy models were received for 32 of the 62 units in the development. The HERS index is based on a scale where the reference home is a score of 100, and a zero energy home is a score of 0. The lower the HERS score, the more energy efficient the home is. The annual savings are estimated relative to an average U.S. home.

All homes show substantial estimated cost savings relative to average U.S. homes, with the most savings coming from two- and three-bedroom homes.

5.1.2 Homeowner Energy Bills and Usage

Eleven homeowners were willing to share their energy bill data, however, data was severely limited due to the fact that many of these homeowners had only recently moved into their homes and most homeowners did not provide information on their unit size or address. Additionally, energy usage across the different homeowners was highly variable, likely due to differences in how they used electricity, unit size, and family sizes. Without being able to control for these things comparisons of energy use are difficult. Despite this, we were able to compare relative energy use by month for three units where we had monthly data from April to October.

In Table 5 below, we breakout each unit's percentage of energy usage by month within the range of April to October, and then average this percentage across the three available units to understand how energy usage changes by homeowner by month. For example, Homeowner 1 had their highest energy usage in April, using 20.6% of their total energy usage from April through October in April. On average, April had the highest energy usage, and therefore the highest energy bills. This makes sense as April is the coldest month in this range of time.

Table 5. Homeowner Energy Bills - Relative Percentages

Month	Homeowner 1 - % Basement Condo Unit	Homeowner 2 - % Full Condo Unit	Homeowner 3 - % 3 Bed Farmhouse	Average %
April	20.6	30.0	31.7	27.4
May	17.4	18.9	16.1	17.5
June	13.0	9.4	10.5	10.9
July	12.2	9.0	10.2	10.5
August	12.1	10.6	9.9	10.9
September	13.6	11.3	11.1	12.0
October	11.2	10.8	10.5	10.8

Homeowner 3 had lived in their home the longest of any homeowner who provided us energy usage data, which allowed us to see their usage for January, February, and March. Unsurprisingly, their energy usage was highest in January, and got progressively lower each month through February, March, and into April.

5.2 Home Specific Energy Use Detail – Bridger View Lot 28

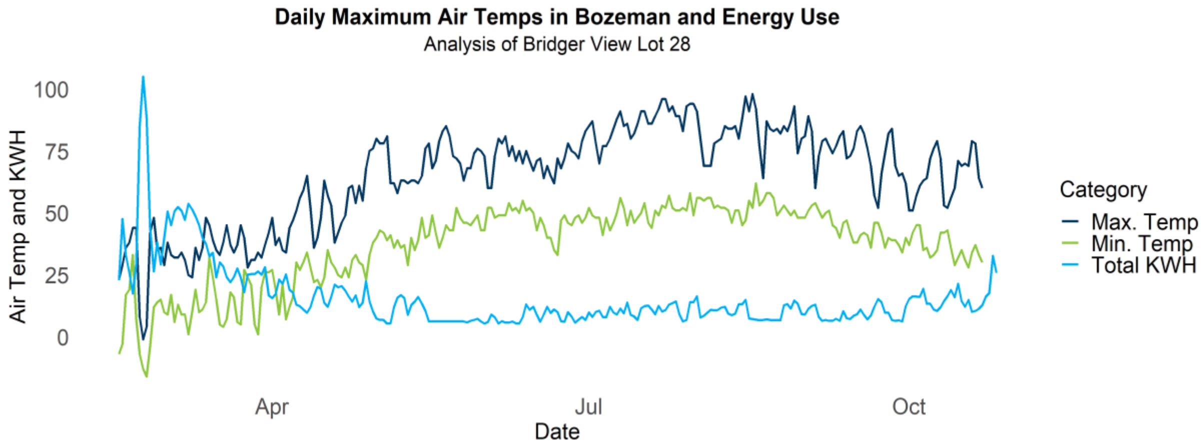
Although not part of the original scope of this project, the research team was able to access detailed energy use data from a single home within Bridger View (Bridger View Lot 28), which allows for a supplemental analysis of total energy use and energy use by technology for this home. Early in 2023, new homeowners were experiencing unusually high energy bills and consumption, which prompted the sustainability consulting team to place a monitor on the Lot 28 home to identify which technology within the homes was causing the high energy usage.[5] This monitor has remained installed on this home since mid-February, allowing the research team to view daily energy usage through October.

In this section, energy usage is compared to daily maximum and minimum air temperatures, which provides some insight into how the technologies perform through all temperature extremes that occur in Bozeman. Throughout the time that the monitor was installed, the lowest temperature recorded was -16°F, on February 24, and the highest temperature recorded was 98°F, on August 17. Additionally, there was one day in February where the maximum temperature was -1°F with a low of -13°F. From February 16 through February 25, the temperature fell below 0°F six days, thus providing substantial insight into energy usage and performance by technology at the extreme low end of the temperature range. Analysis of energy usage is presented below by total energy usage, heat pump water heater, ductless heat pump, backup baseboard heat, and ERV system.

[5] The contributor to the high energy usage was identified quickly and was due primarily to improper functioning of the inside air duct of the ERV system, as well as some improper usage of the DHP by some homeowners. There have been no further issues once these were solved. The ERV system is the Energy Recovery Ventilation system, which cycles fresh air into the home and helps the air in the home retain heat.

5.2.1 Total Energy Usage

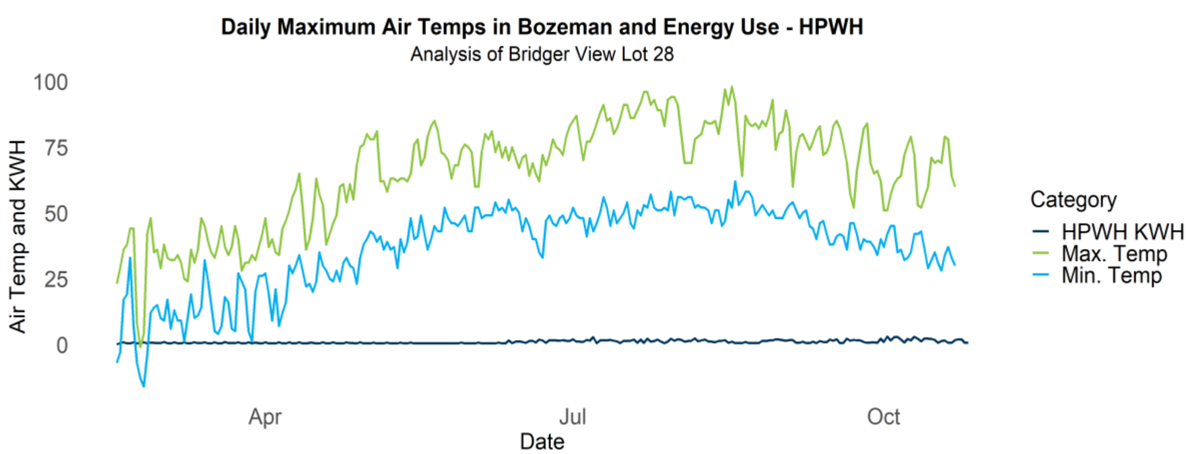
Figure 1. Daily Maximum Air Temperature and Energy Use



In Figure 1, total energy usage fluctuations throughout the year correlate with air temperature, with usage generally increasing as temperatures get colder, which is expected. Of note is the extremely high energy usage day in early February, which was around 100 KWH. This occurred shortly after the energy monitor was installed, which also coincided with one of the coldest weeks and day of the year. The high usage can be attributed to the ERV system inside duct functioning improperly, as well as significant load on the heating systems. While energy use is still high after this initial spike, it remained lower than previously due to the problem with the ERV being resolved, thus making the high energy usage attributable primarily to heating. The load and usage from the heating system will be further discussed in subsection 5.2.3.

5.2.2 Heat Pump Water Heater Energy Use

Figure 2. HPWH energy usage



Early on, there were some concerns from a subcontractor that the HPWH would not function effectively or efficiently with its location in an unconditioned basement. These concerns decreased as this subcontractor learned more about how the HPWH functions. Figure 2 confirms that the HPWH works well, even in extreme cold temperatures. Over the year, energy use is minimal, with very little fluctuation.

5.2.3 Heating System Energy Usage – DHP and Base Heat

Figure 3. DHP energy usage

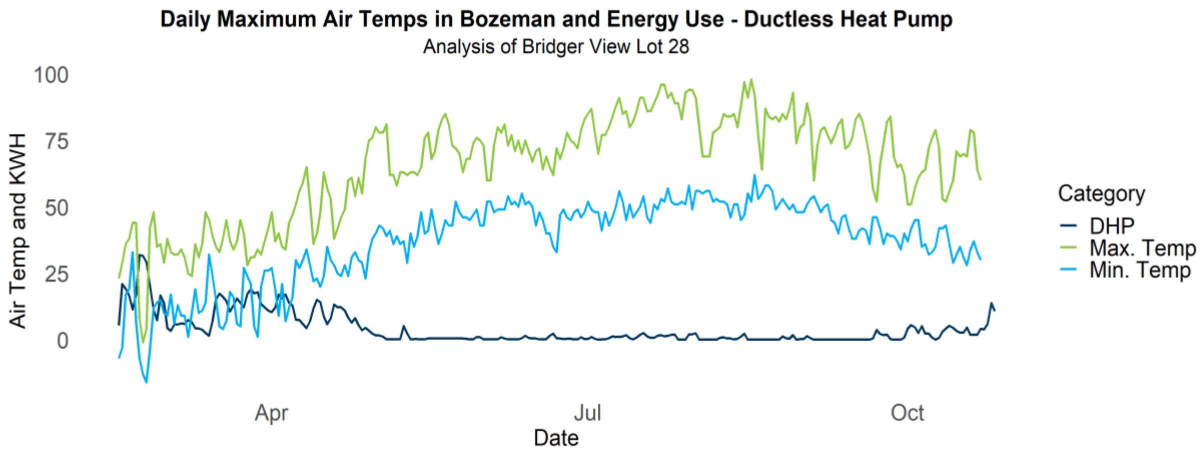
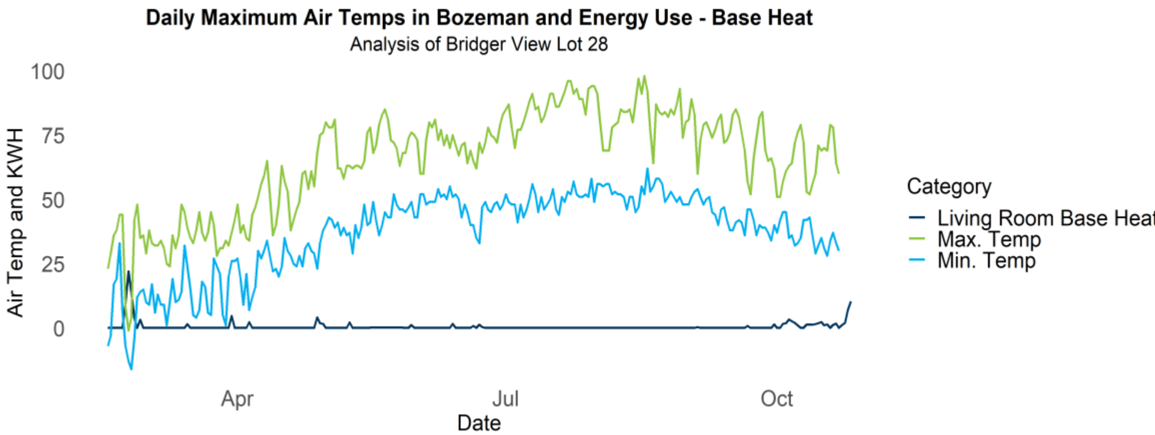


Figure 3 shows that the energy use of the DHP system is highly correlated with air temperature, which is to be expected, as there is higher heating demand in times of cold temperature. The most energy usage occurred during the week of February when temperatures frequently fell below zero degrees. The energy usage fluctuated through the remainder of winter and into spring, as temperatures in Bozeman frequently remain around the freezing mark through late April and into May. Through the summer and early fall months, energy usage was low, with some uptick in usage occurring through the second half of October as temperatures get colder. There did appear to be some usage throughout the summer for cooling. However, usage was minimal compared to times of colder weather.

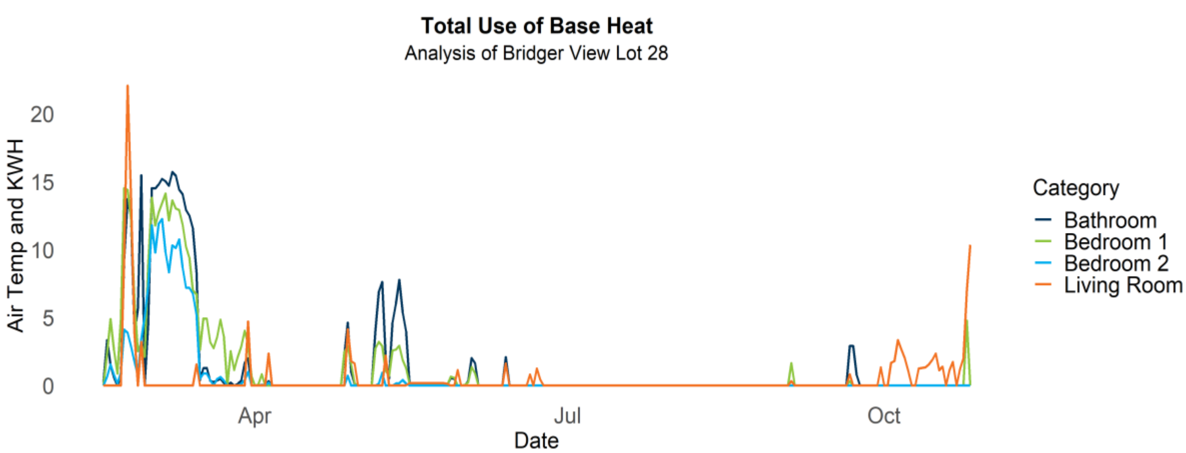
While it is expected that the DHP's energy usage is correlated with temperature, the more relevant measure of energy usage in cold temperatures is how frequently the backup heating unit in the living room is used, as that is indicative that the DHP may not be meeting the heating demand. Overall, it appears that there was relatively infrequent utilization of the backup heat, with the most energy use occurring on the coldest day of the year, as shown in Figure 4. This suggests that in all but the extreme coldest temperatures, the DHP appears to meet most of the heating demand. This also confirms some of the concerns of the design, sustainability, and contracting teams, who were all concerned that the DHP may not function as well in extreme cold, thus necessitating backup heat. The occasional use of the backup heat shows that it is necessary to meet the heating demand on the coldest days, which occur each winter in climates such as Bozeman.

Figure 4. Living room base heat energy usage



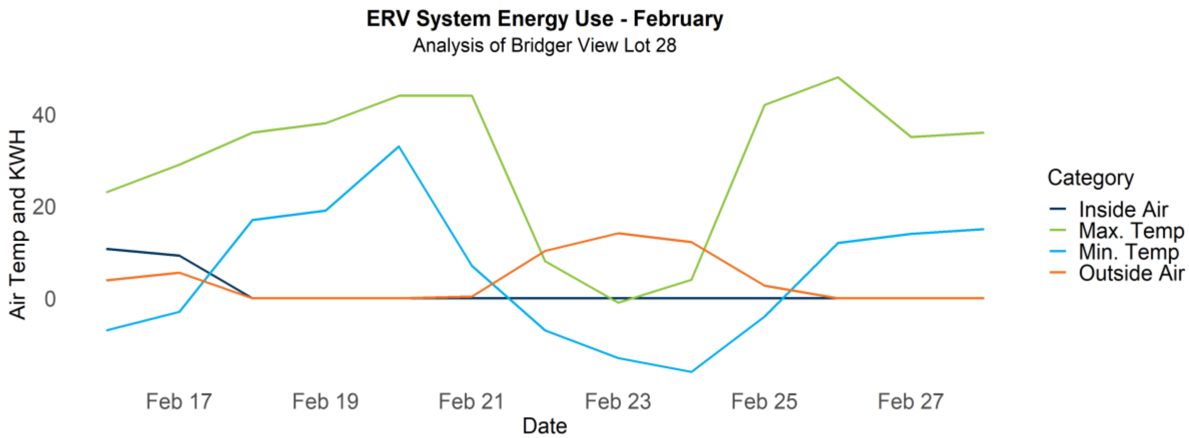
In addition to the living room, there is also backup heat in each of the bedrooms and the bathroom, as the only DHP mini-split unit is in the main living area. Utilization of these other units occurs slightly more frequently than the living room unit, particularly in the coldest months, as shown in Figure 5.

Figure 5. Total base heat energy usage



5.2.4 Energy Recovery Ventilator System Energy Usage

Figure 6. ERV system energy usage - February



While the ERV system was not one of the technologies of focus in this study, it is an important component of the HVAC system and plays a large role in controlling the climate within the house and thus the energy efficiency of the homes. The inside air duct of the ERV was identified by the sustainability team as the primary driver of the high energy usage in the homes and, as can be seen in Figure 6, was utilizing fairly substantial amounts of energy shortly after the energy monitor was installed in the home and prior to the issue being fixed. This problem was quickly fixed, and the energy usage of this inside duct remained at zero, even through the coldest day of the year around a week later. Interestingly, the outside duct also contributed to some energy usage on the coldest days, with zero usage on what could be considered more seasonable temperatures for Bozeman in February. It is likely that the higher energy usage on cold days is due to the fact that the outside duct is pulling in extremely cold air and must use more energy to handle the colder air.

5.2.5 Bridger View Lot 28: Actual Energy Usage vs. Estimated Energy Usage

With the availability of both the energy use models and actual daily energy consumption for Bridger View Lot 28, the research team was able to compare actual energy use and estimated energy use to see how Lot 28 performed relative to modeled expectations.

As discussed, the energy use monitor on Lot 28 was installed in mid-February, so the research team only had actual usage data from mid-February through the end of October (despite the unit having been occupied since December 2022), the time at which this report was written. To compare to the annual estimated energy use, the research team modeled energy usage in January, early February, November, and December as a function of daily air temperature and season, which are highly correlated with energy use and can therefore be used to predict daily energy use to fill in data gaps. The research team created a regression forecasting model, using daily weather data to predict daily energy use for Lot 28 where gaps existed due to when the monitor had been installed.

Table 6 displays the total actual estimated energy use compared to the pre-construction energy models for Lot 28. Across each category, there is substantially lower actual use compared to the energy modeling, indicating that the energy efficient technology has been operating at more efficient levels than expected. This is particularly important in relation to heating, as the backup cove heat and ERV systems were expected to add a substantial amount of additional KWH in the winter months. It is clear that these concerns did not materialize except for on the most extreme cold days, as demonstrated through these results and the subsections above.

Table 6. Energy Use - Estimated vs. Actual Use - Lot 28

Energy Estimate	Total Energy Use (KWH)	HPWH Energy Use (KWH)	DHP Energy Use
Post-Construction - Actual Est. Annual Energy Use	8,358.30	295.38	2,607.34
Pre-Construction - Model Estimated Energy Use	11,080.80	610.90	6,200.60
Sources: Bridger View Lot 28 energy use data and pre-construction energy use estimates from construction energy consultants.			

6 Conclusion and Recommendations

6.1 Conclusion

This market research project covered the full building phase of the Bridger View housing development from planning and design through homeownership, providing key insight into perceptions, challenges, and performance of energy efficient technologies in a cold weather climate. The research team engaged with designers and project planning consultants, installers and subcontractors, and homeowners to learn about experiences with study technologies, including the insulation and triple pane windows, and energy efficient technologies such as the DHP and HPWH. Throughout this process, the research team identified several key research findings, which are outlined below.

6.1.1 Key Findings

Key Finding 1: Designers and Consultants understand the benefits and performance of energy efficient technology and design in cold climates but have concerns about installation and homeowner understanding and use.

Designers and consultants were one of the primary reasons that the Bridger View development included energy efficient technologies and design components, as they have a strong understanding of the performance potential and benefits, even in the cold climate. Despite this, it became evident that they all had concerns about whether installers and homeowners had the knowledge to properly install and then efficiently use the technologies to maximize energy efficiency benefits.

Key Finding 2: Supply chain issues were a barrier for subcontractors.

Several subcontractors referenced supply chain issues were a challenge, particularly early in the project, when COVID-19 was still a significant disruption to the economy. While COVID-19 certainly contributed to many of the delays, some of the technologies appear to be more challenging to acquire in markets such as Bozeman. While some subcontractors planned ahead for this, like the HVAC subcontractor did by ordering HPWHs ahead of time and storing them in a warehouse, there were still disruptions that delayed the construction timeline.

Key Finding 3: Market availability and manufacturer support may be a barrier to large-scale uptake of DHPs in the market.

Some of the supply chain issues may be partially due to a lack of support in the local market, as many large scale manufacturers of energy efficient technologies do not appear to be well represented, according to some subcontractors. One of the HVAC subcontractors noted that having market support and representation is a strong driver for which technologies are chosen, as the subcontractors want to ensure they have support if they need help understanding installation requirements or run into issues during the installation process.

Key Finding 4: Homeowners like energy efficiency technology, but do not understand how to use it in an optimal way.

Homeowners were excited about the energy efficient technology in their homes, and the efficiency aspect was one of the motivating factors for purchasing a home for many homeowners. Despite the interest in energy efficiency, it became clear that many of the homeowners did not fully understand how to optimize their technology settings to maximize energy efficiency. In addition to lack of understanding, there were issues with the technology settings, particularly the HVAC system, that needed to be addressed by the housing trust and subcontractors. Early on in our research, designers and consultants noted that their main concerns about the technologies were that they would be improperly installed and used. It became clear that these concerns were valid, as they emerged as actual issues for installers and homeowners in particular.

6.2 Recommendations

Based on the findings from each phase of this project, the research team has several recommendations to NEEA for increasing market uptake of energy efficient technologies in colder climates. The evidence from this research suggests that these technologies have the potential to be highly effective and efficient when used and installed properly, even in times of cold weather. Primary barriers to widespread uptake appear to be costs, perceptions, risk aversion about their performance in low temperature extremes, and awareness of their existence in the market.

Recommendation 1: Create connections with suppliers to increase market presence.

Several subcontractors referenced the lack of suppliers and market presence of many manufacturers for technologies such as HPWHs and DHPs, which appears to be an important component of uptake of technologies for many contractors, as the contractors want to make sure there is support and connections from the manufacturer side to be able to deal with supply side issues that may arise. Subcontractors appear to tend to go with brands that are well represented in the market. Therefore, the research team recommends NEEA to work directly with suppliers and learn about their current presence, plans, or ability to expand their representation of energy efficient technologies in cold weather climates. Increased presence in cold weather climates may also help to decrease unit costs in the long term, another barrier to widespread uptake.

Recommendation 2: Provide literature on cold weather performance to installers and sustainability consultants.

During each phase of the project period, this study learned that there is a continued lack of knowledge or expertise about the performance of the focus technologies. Outreach and literature that is designed to be received by installers could aid in addressing these misunderstandings. One key finding of the cost modeling undertaken in this study was higher performance of the units than anticipated in the design process. Dissemination of real-world electricity utilization and monitoring to key constituencies could aid in additional adoption of the study technologies.

Recommendation 3: Provide trainings on installation and use of Ductless Heat Pump systems.

One of the valuable components of this study design was the ability to engage in repeated interviews with installers across the project phases. It was clear that there was a slight learning curve within the Phase 1 homes, largely reflected in the error associated with the setting of the intake system. Throughout the study period, the learning experienced among installers proved to address any of these installation barriers.

Recommendation 4: Develop utilization videos for key technologies and post them to popular websites (YouTube) to ensure that homeowners who have these systems are gaining access to precise and accurate advice.

Bridger View residents have access to a very high degree of educational materials, due to the nesting of market rate homes within a land trust with staff who are creating handbooks, summary reports, and training materials for the homeowners. Even with this level of support, residents reported that they tended to rely on their own self-directed learning, primarily on YouTube. The creation of NEEA branded or associated branding could ensure that self-learning is occurring with the best resource

7 Appendices

7.1 Appendix 1. Literature Summary

A complete literature review served as the foundation for the research design and the development of data collection instruments and was completed at the outset of the project. A brief summary has been included in this report, reviewing key research foundations for this project. The summary is centered on three overarching categories: Energy-Efficient Homeownership; Installer and Homeowners' Perceptions; and Technology Details. The primary purpose of this review was to inform development of interview protocols for four constituencies: subcontractor owners/supervisors, installers, homeowners/residents, and project consultants.

To ensure the relevance and accuracy of the literature review, JG staff requested the construction drawings from the construction manager (Berring Construction Management). In the set of bid drawings, the project manual provides key details about the selection of models for each target technology and revision processes if alternative models are needed due to supply change challenges or the identification of problems with a given model on site. The manual also provides details about audit processes to ensure appropriate installation, site reviews, and energy-efficiency standards being pursued in the development of the site and individual homes. JG staff also collected and reviewed each installation guide (by technology), as identified from the project manual and construction drawings.

The literature review was based on a key word search in Web of Science, a citation database for accessing peer-reviewed publications, and in Google Scholar, to access the gray literature and internet-based resource guides. JG staff set advanced filters and search parameters based on topical relevance and refined the search criteria as key articles were identified. Relevant articles provided additional keywords to further expand the search until we reached saturation with the following search terms: low carbon, stakeholder motivation, installer, heating, energy demand, control systems, socio-technical, heating installers, communities of practice, energy efficient policy, energy retrofit, repair-maintain-improve practitioner, energy efficiency, renewable energy technologies, technicians, heat pump, advanced framing, advanced insulation, training, skills, technology performance, residential, energy efficiency, Energy Star, affordable housing, climate change, and household energy use.

7.1.1 Energy-efficient homeownership

National policy context

In 1976, the US federal government instituted its earliest and most well-known energy efficiency program: the Department of Energy's (DOE) Weatherization Assistance Program, which sought to improve insulation in current homes (DOE, 2016). Ensuing federal programs targeted efficiency in new homes, emphasizing building design and construction while calculating the expected program benefits (Taylor et al., 2014). The Residential Energy Services Network (RESNET) developed the Home Energy Rating System (HERS) and the US Environmental Protection Agency (EPA) ENERGY STAR® certification program. The US Federal Housing Administration (FHA) rolled out its national Energy Efficient Mortgage (EEM) program to help homebuyers save money on their utility bills, which also enabled future homebuyers to qualify for larger loan amounts on an EEM (HUD, 2012). These programs spurred "electrification" within new and retrofitted homes: switching homes from combustion-based fuels to cold-climate heat pumps, heat pump water heaters, and induction ranges (Brasch, 2021).

Today, ENERGY STAR® Qualified New Homes and the DOE's Building America and Builder's Challenge programs set energy savings goals in homes through a diagnostic test and RESNET-accredited energy modeling software to generate a HERS Index. US taxpayers and builders are eligible for energy tax credits on solar electric and solar hot water systems, and builders are eligible for a $2,000 tax credit for energy-efficient homes built by the end of 2021 (Zero Energy Project, 2021). The US government sets aside millions of dollars every year to complete new single-family homes, multifamily apartments, and commercial buildings that meet the aforementioned energy efficiency standards (ACEEE, 2020).

In 1998, the U.S. Green Building Council (USGBC) initiated the Leadership in Energy and Environmental Design (LEED) Green Building Rating System ('LEED rating') v1.0. The LEED rating system provides standards for sustainable design, construction and operation of individual private residences, commercial buildings, and neighborhoods. The most recent LEED standards are in v4.1, which includes a new option to achieve LEED certification with points through performance monitoring on an ongoing basis.

More recently, the DOE has developed the Zero-Energy Ready Home Program (DOE-ZERH), which builds on ENERGY STAR® and Building America requirements and utilizes the HERS Index for verification (a typical HERS Index score for a ZERH home is in the low to mid 50s). The focus of the ZERH program is on "increasing energy efficiency, improving indoor air quality, and making homes zero energy ready." ZERH homes can qualify through a prescriptive path (following all DOE requirements) or a performance path (utilizing RESNET-qualified software to characterize a specific home has a ZERH). Achieving ZERH status contributes credits and prerequisites to the LEEDv4.1 scorecard.

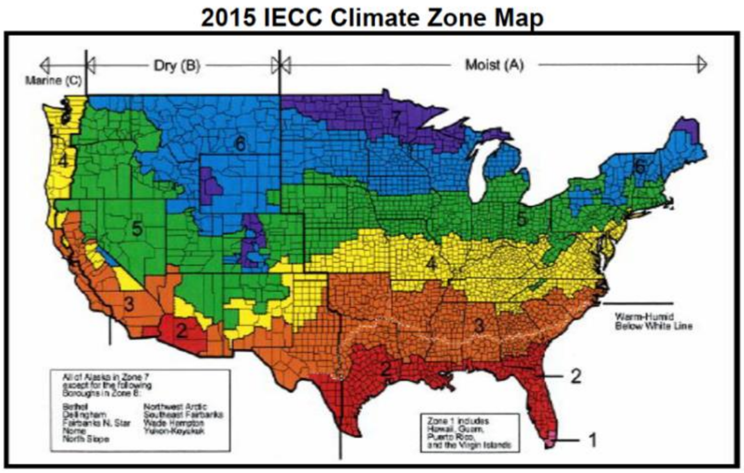
State policy context

States have also implemented electrification programs and resources for homeowners and builders. In Montana, the Department of Environmental Quality (MDEQ) provides a checklist for builders to "help ensure your new home is comfortable, healthy, and energy code compliant" (MDEQ, 2021a). In 2021, the MDEQ updated their energy efficiency requirements and now requires builders to certify that new homes meet minimum code standards for insulation, windows, doors, ventilation, and air tightness (MDEQ, 2021b).

Site context

The Bridger View development is pursuing LEED certification for both the housing development and individual homes, with the specific goal of achieving the DOE Zero-Energy Ready Home (DOE-ZERH) label with corresponding HERS targets. Scorecards to determine alignment with LEED v4.1 categories of performance are planned to occur throughout the project process. In addition to efforts to pursue national certification requirements, all building efforts will need to align with relevant Bozeman building codes. Standards developed by LEED and DOE are unable to supersede local code requirements and vary to correspond to the IECC Climate Zones.

Figure 7. IECC climate zone map



7.1.2 Perceptions of installers and homeowners

Installers

Residential heating installers and technicians often perform invisible work for homeowners, designers, and scientists because this work is often wedged between the bottom level (e.g. residential heating system design) and broader social, economic, and environmental systems (e.g. policy incentives and requirements) (Corbin and Strauss, 1993; Janda and Parag, 2013; Star and Strauss, 1999; Strauss, 1985 & 1989; Pallensen and Jacobsen, 2018). These laborers form an occupational community whose work, including what they do on the job and how they do it, is impacted by decisions made both upstream and downstream of actual installation (Janda and Parag, 2013; Wade et al., 2016). The formal training workers receive affects their ability to "do a good job" (Murtagh, 2021; Wade et al., 2016), as do their personal attitudes and preferences.

Some installers and technicians express a lack of confidence in energy-efficient technology and view it as costly to install, maintain, or use (Murtagh, 2021), while others prefer fossil fuel-based technologies because they are easier to install (Freyre et al., 2021). In the US, where continuing education or ongoing training is common and even required by some companies (IGSHPA, 2021), efforts to frame energy-efficient technology as high-quality workmanship and associate poor energy efficiency with low-quality workmanship may better align with the attitudes of installers than policy or design arguments or requirements to increase energy efficiency and reduce carbon emissions (Gleeson, 2016; Murtagh, 2021).

Installers and technicians often interact with homeowners, influencing the heating system choices homeowners make (Pallensen and Jacobsen, 2018) and the ways in which homeowners interact with these heating systems (Parrish et al., 2021; Wade et al., 2007). When installers make decisions about what controls to install and where to install them and express opinions about use patterns that are more or less efficient, they have the potential to "script" how users interact with technology (de Wilde, 2021). When installers and technicians script or simplify complicated instructions to ensure that users possess a cursory knowledge about their heating systems, they may inadvertently contribute to higher energy consumption (Janda and Parag, 2013; Pallensen and Jacobsen, 2018;

Parrish et al., 2021). In fact, some research shows that variation in user behavior may lead to three times as much energy consumption in identical houses when comparing appropriate and inappropriate technology use patterns (Gram-Hannsen, 2010).

Homeowners

Parrish et al. (2021) posit that policies targeting carbon reduction from domestic energy use must consider the ways in which users interact with and use technology in their everyday lives. Sometimes, as in the case of Bridger View, homeowners cannot choose their heating system type because this decision is made by the project developer and the system cannot easily be changed (Michelson and Madlener, 2012). Some research reveals that users forced to use heat pumps may face a technological learning curve (Michelsen and Madlener, 2016).

Homeowners are often more concerned with the annual cost of heating systems than with the upfront investment cost when considering a heating system installation or retrofit (Mahapatra and Gustavsson, 2008). The higher concern for annual cost might stem from homeowner subsidies that enable households with low incomes to recoup some of the upfront installation costs, while wealthier users upgrade to a new system for its operational convenience (Hecher et al., 2017).

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7.2 Appendix 2. Technical specifications

DOE-ZERH goals influenced decision making on each of the energy efficiency technologies and building practices ("measures") included in the Bridger View project plan and this study. Possible measures related to the building envelope, windows, insulation, water heaters, and HVAC systems. Advanced framing is not a specific content area of the DOE review criteria, but the air barriers and reduction of thermal bridging inherent in advanced framing techniques inform the achievement of insulation goals. Table 1 provides a summary of detailed information about each technology under examination in this study, including the planned unit/model, key standards against which post-installation will be measured, and additional notes that informed the research process and draft interview guides.

As whole-house design influenced the conceptual approach to the design of the homes, analysis about installation and homeowner use aimed to integrate understanding about individual technologies, as well as their interoperability. Whole-house design is a "holistic approach" to energy-efficient, single-family home design that considers the interoperability or impacts of the systems among one another (for example, redirecting/using heat generated by a HPWH elsewhere in the home with double pane windows [DOE, 2021d]). The dynamic nature of the interactions of these systems required interview protocols that aim to identify perceptions of how the systems engage with each other, as well as questions about each individual item.

Table 7. Technology details featured in Bridger View residential units

Energy efficiency technologies and building practices	***Planned unit/Model***	***Relevant standards (will inform on-site checklists)***	***Additional notes***
Heat Pump Water Heaters (HPWH)	*Lochinvar HPA052KD*	*Energy Star*	*Requires wireless internet connectivity*
Ductless Heat Pumps (DHP)	*Multi-split fan coil: Daikin FTX15NMJVU or FTX09NMVJU* *Split heat pump: Daikin RXL15QMJVUA or RXL09QMJVU* *Heat Recovery ventilation: Aldes H190TQG*	*American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)* *ES HVAC design report* *DOE HVAC system checklist* *ANSI/RESNET/ACCA St.310* *National HVAC commissioning checklist*	*Homes have electric heaters in all rooms and electric duct heaters*
Triple Pane Windows	*Alpen High Performance products – Zenith series ZR-7.*	*AAMA rating requirements.* *NFRC U-factor rating.* *SHGC values by window type.*	
Advanced Framing	*No specifics on technology or methods were provided.*		
Advanced Insulation	*SIPS and ZIP systems, Cellulose insulation in walls and attic, mineral fiber insulation for basement walls. Dense pack insulation*	*HERS rating for density of installation.* *Grade 1 installation per ANSI/RESNET/ICC Std. 301.* *2015 IECC.* *Reviewed by HERS rater at framing, post-insulation, and post completion.*	*Plan is to install interior air and vapor retarders*

Below are the technical specifications for the HPWH and DHP system.

1 - HEAT PUMP WATER HEATER SCHEDULE

MARK	MFGR.	MODEL #	DESCRIPTION	STORAGE VOLUME (GAL)	1ST HR RATING	HEATING ELEMENT CAPACITY (W)	HEIGHT (IN)	DIAMETER (IN)	SHIPPING WEIGHT	ELECTRICAL DATA		REMARKS
										VOLTAGE	PHASE	
HPWH-1	LOCHINVAR	HPA052KD	HYBRID HEAT PUMP WATER HEATER	50	68	4,500	63	22	196	208/240	1	SEE NOTES

NOTES: PROVIDE WITH SEISMIC STRAPPING, HONEYWELL MODEL AMX101-US-1LF THERMOSTATIC MIXING VALVE AND WATTS PLT-12 EXPANSION TANK.

1 - SPLIT HEAT PUMP SCHEDULE (R-410a)

MARK	MFGR	MODEL NUMBER	DESCRIPTION	COOLING DATA		HEATING DATA		VOLTAGE	PHASE	MCA	REMARKS
				TOTAL CAPACITY (BHU/HR)	EER	TOTAL CAPACITY (BTU/HR)	C.O.P.				
HP-1	DAIKIN	RXL15QMVJUA	AIR SOURCE HEAT PUMP	12,470	13	18,300	4.0	208/230	1	13 A	SEE NOTES

NOTES:
1.) COOLING CAPACITY IS BASED ON 80F BD / 67F WB INDOOR AND 95F DB / 75F WB OUTDOOR.
2.) HEATING CAPACITY IS BASED ON 70F BD / 60F WB AND 5F DB / 5F WB.
3.) UNIT SHALL HAVE AN OPERATING RANGE FROM 115F TO -13F WITH NO LOSS OF HEATING OR COOLING CAPACITY....

1 - MULTI-SPLIT FAN COIL SCHEDULE (R-410a)

MARK	MFGR	MODEL NUMBER	UNIT TYPE	AREA SERVED	SUPPLY FAN		COOLING CAPACITY (BTU/HR)	HEATING CAPACITY (BTU/HR)	ELECTRICAL DATA		REMARKS
					CFM	ESP (in W.C.)			VOLTAGE	PHASE	
FC-1	DAIKIN	FTX15NMVJU	WALL MOUNT	LEVEL 1	595	N/A	12,470	18,300	208/230	1	SEE NOTES 1 & 2

NOTES:
1.) COOLING CAPACITIES ARE BASED ON 75F BD / 55F WB ENTERING CONDITIONS AND 95F DB / 75F WB OUTDOOR CONDITIONS. HEATING CAPACITIES ARE BASED ON 70F BD ENTERING CONDITION.
2.) PROVIDE WITH CORROSION RESISTENT DRAIN PAN.

7.3 Appendix 3. Key Quotes by Research Phase

Table 8. Research Phase 1 - Key Quotes from Consultants and Designers

Topic	Quote
DHP Benefits	*So, there was a desire to have both heating for winter season but also cooling for the summer season, which meant that we were going to be trying to maximize the... I guess I'm trying to figure out how to say this that immediately… points to a heat pump, I guess, as the easy way to get there. Right? I mean, a heat pump is electrically operated. It provides heating as well as cooling. And through the refrigeration cycle on the heating side, it's vastly superior to standard electric resistance heating. – Subcontractor*
Heating Tradeoffs	*Early on, there was a desire to have a ductless heating and cooling unit in the primary living space as well as each bedroom. And as the design progressed and as budgeting progressed, it was determined that that did not fit with the budget, and so they decided... It was decided that we would only do a ductless min- split in the primary living area, and so really the ductless mini-split, the heat pump system we have, is heating and cooling the main living area, and we just have heating provided by electric resistance to the bedroom. –Subcontractor*
Building Envelope and DHP	*I think it was just the team had decided that, oftentimes, a passive approach is the best way to minimize, right? I mean, we can't necessarily control the behavior of the people that are going to operate the building, right? We can't guarantee they're going to set their thermostat the way we thought they were. But if we give them a very good envelope, that will help minimize the energy impact from the choices that they make, so it's sort of a... You start with the fundamentals and then add. And I think the viewpoint of the overall design team was that a good envelope is fundamental to good energy conservation. –Subcontractor*
Perceptions and Expected Challenges - DHP	*… A mechanical designer says, "Yeah, we're going to have a heat pump." It's like, where does it go? Well, we can't put it on the ground because it's going to get covered in snow and it's going to bound up or freeze up or whatever the stupid thing is. It's like, well, it's got to be hanging on the side of the building. You're like, look at all the drawings. Zero of them have heat pumps hanging off the side of the building. So, I think we should start drawing a box on the outside that says heat pump, and how does it get connected because you put them on brackets and then that translates into the structure, and then suddenly you have this... when it's running in your units. –Project architect*
HPWH Decisions	*As a team, we've had a lot of discussions related to the sizing of those and how big the storage tank should be, because if you have a larger storage tank, you can have a bigger hot water draw in a short period of time without kicking on the backup resistance element so they're more efficient in that case. –Sustainability team member*

Table 9. Research Phase 2 - Key Quotes from Subcontractors and Installers

Topic	Quote
Supply Chain Issues - Insulation	*The last year has been very interesting, to say the least. I mean, it's been very challenging. So cellulose, for example, we get 5 semis, 5 53-footers, 1 a day, every week. They've had to ration and stuff like that to where it's just... Ration between branches and, I mean, to where it gets challenging to where we run out of material. In fact, I think this project got delayed a couple weeks on the unit or two that we had to wait for material. –Insulation subcontractor*
Heating Performance Expectations	*The other piece of that is that in HVAC design, there is an organization called ASHRAE, which is the American Association of Heating and Refrigeration and Air Conditioning Engineers. They're sort of our go-to for all of our design information. They publish all of our weather data that we use for design. So ASHRAE's published minimum outside air temperature for Montana is minus 19 degrees, and we all know that it gets to minus 18 here, and oftentimes it gets even lower than that. But statistically, ASHRAE is saying if you design for min's 18, you're going to cover 98% of the hours in any given year.* *So mini-split heat pump systems are generally only rated to a temperature. And in the case of the Daikin equipment that we decided to use, they're only rated to minus 13. So' it doesn't mean that they won't operate below an outside air temperature of minus 13. It just becomes that there is no published data, which basically means it's... You're taking a bit of a risk by counting on it operating in that condition. So, the electric cove heat is not only providing heating to the bedrooms, but it's also providing supplemental or backup heat to the primary living area, should we encounter an outside air condition. Where the heat pump can no longer meet the heating demand of the space, the electric heat is there to–ack it up. –Subcontractor*
DHP Skepticism	*That's always going to be a concern and a limiting factor with the use of heat pumps in our climate. And then on top of it… the fact that they aren't rated to run at our design condition means… that as an engineer, to protect myself from liability and to protect the owner from a non-functioning system, I always recommend having backup electric heat. So now you're talking about having redundancy in your system, which adds to cost. –Subcontractor*
DHP Market Uptake	*We oftentimes select products, not because they're the least expensive, but because they have the best support, and every heat pump, at least the style of heat pumps that we're talking about, these sort of mini-split-style heat pumps, every manufacturer is slightly different, and your experience working with the product itself is as important to the success of the project as the quality of the equipment itself, right? It doesn't matter how good it's supposed to run. If it's not installed properly, it won't run well. –Subcontractor*
HPWH Skepticism	*And what's interesting is that the literature that's available for the residential style of heat pump products, it's fairly limited. I couldn't tell you, based on the literature that I have access to from the manufacturer that we selected, what the capacity of the heat pump is in terms of the compressor that's doing that cooling. How much energy is it taking out of the atmosphere? Out of the room that it's installed in? Is it a ton of cooling? Is it 12,000 P2s an hour? Is it 18,000? Is it 15,000? I don't know. – HVAC Subcontractor*

HPWH Skepticism	*And I still have some concerns about how they're going to operate in a basement with no heat, and how cold is that basement going to become, and what kind of comfort issues is that going to cause for adjacent spaces? And are we going to start having condensation issues? I can't imagine that they are going to freeze the basement, but I mean is it going to... It's just a bit of an unknown. I would have felt more comfortable having electric heat. –Subcontractor*

Table 10. Research Phase 3 - Key Quotes from Homeowners

Topic	***Quote***
Triple Pane Window Experience	*I think the windows are amazing, especially coming from a rental property where either they should have been replaced or not. I think they play a really large role in our overall quality of life, whether it's clearly helping us maintain a cooler temperature and more consistent temperature without a lot of heat escape or coldness coming in, as well as overall natural light into our unit. And so having been explained, the tech at the high level when we moved in seemed impressive. We often remark how incredible it is that when we set our temperature to 64 or whatever, that it just stays at that temperature or cooler in spite of rising temperatures outside. –Bridger View homeowner*
Triple Pane Window Issues	*There are mechanical issues with them, the two of the larger windows on the first floor have been bowed. So unless you go outside and push on them, you can't lock them. You can't latch them tight. There's air passing through. So that's going to be an issue. In the winter they'll probably be latched all the time, but if we ever want to open them up and air the place out, so pretty concerned about that because windows are a big deal and to have problems this early on. –Bridger View homeowner*
Triple Pane Window Issues	*the seam sealed tight, and you've probably heard this, the latching mechanism is not great. It's a window that kind of tilts out like this, and there's a latch on the top and the bottom, but the mechanism to latch it and lock and shut is only on the bottom. So the top one might be misaligned, and it's catching on the bottom, but it's supposed to catch on both at the same time. So it's harder on some of the windows, I guess just depending on the way they were adjusted, to shut them and open them from the lock perspective. –Bridger View homeowner*
Triple Pane Window Issues	*I know that I asked the builder to adjust it before we moved in, because one of them actually wouldn't lock at all. You would lock it, and the window was still open. So he has somehow adjusted it and now it does lock. I mean, it's still not easy. It's kind of a cranking down on it. So there must be a way to bring the window closer with the adjustment twirler thing. –Bridger View Homeowner*
Triple Pane Window Issues	*They're really nice, but they have little issues with the way that they latch and the weather seals that you can clamp down on them. Sometimes they don't align well, and you really have to struggle to get them open or get them closed. We've actually had to have some of the crew come over and readjust them, and you notice that even if they're readjusted, sometimes they go out of alignment a little bit. That might be an ongoing maintenance thing with these windows, if eventually we're going to have to develop the skill to move these little latch mechanism pieces around to just make sure that they're still functioning really well in the long term. –Bridger View Homeowner*

DHP Learning	*I don't feel nervous, and I don't feel confident yet. I feel like I'm prepared to handle it as it becomes more real that we actually have to use these throughout the house… Yeah. I know that I will be able to reach out to Courtney if I have questions just about anything, and then I also have this tool accessible to get into and just figure out the minutia of the panels in the rooms and just making sure that everything is squared up for that. Yes, I feel like it's going to be very straightforward when we actually have to get into it. –Bridger View homeowner*
Heating Confusion	*Mainly the heater thing, because I had the idea that, in the winter, we should have our main heater lower and then maybe just the main rooms up. But they said the opposite, that you should have this higher, because it's way more energy efficient. And so, that was the main thing that stuck out to me. There wasn't really anything else. –Bridger View homeowner*
Temperature Regulation	*Here in the Bridger View home, we've felt more of that regulated temperature throughout the home. The cold months that we have spent here, our electricity bill has been insanely low because we felt very comfortable and warm without feeling like we were spending a ton of money on electricity. And then same in the summer, we have these really awesome fans that I think are in all the homes actually that have been really, really great for keeping the whole house cool. –Bridger View homeowner*
Settings Issues	*But the thing with the install was they had it set backwards. The Cove feeders in here are not supposed to come on unless the set point is your four degrees below the set point. It's like back heat when the heat pump needs help. Yeah. It was set backwards. The Cove heaters were the only thing running and the heat pump wasn't coming on, so they just flipped it. That was the first thing. Then the second thing is they have, and I don't think this is on your list, but there's a heat recovery unit and they have duct heaters in there. If the air is really cold outside coming in, it'll preheat it before it gets the heat exchanger. That was set too high, which was fine. But there's also one coming out of the heat exchanger and that one was set way too high. Even if you turned all of the heat off in here, it would still be like 75 degrees. -Bridger View Project manager*
Troubleshooting	*Being under warranty, I would get ahold of the contact at Langlas, the fellow that's been dealing with the warranty issues. But that will end soon…Once that is up, I would imagine we would find a... I usually just ask people for references for an HVAC company. Figure out who's good at that stuff. –Bridger View homeowner*

7.4 Appendix 4. Interview Guides

7.4.1 Project consultants

Background

- Tell me about your role in the Bridger View Project.
- How did you first become involved?
    - Easy transition in? Difficult for any reason?
- How similar/different was this project from projects you normally work on?
- Would you say that you often work on projects that take a whole-house design approach to achieve energy efficiency goals?
- How much collaboration and coordination have you had with other project consultants?
    - If yes, how have these collaborations, in your view, shaped the decisions made about technologies being implemented in the homes?
- And is energy efficiency important to you in your work?
    - If so, what motivates you to integrate these concerns in your work?
    - If not, how was it for you working on this project where they are a significant focus?

Energy-Efficient Technologies

- In your role, how much direct engagement did you have in decisions about each of the following:
    - Design of building envelope
    - Selection of HVAC systems – Focus on DHPs
    - Selection of Water Heater
    - Determination about advanced framing
    - Determination about insulation practices
    - Selection of windows
- Did you feel like you had a do a lot of background research to figure out what would fit best for each of these decisions? More or less than on similar projects?
- Tell me a little bit about the decisions to pursue LEED and DOE-Zero Energy Home ready certifications for the homes and site.
    - In what ways did these standards infrom decision making about the efficiency goals for the homes?
    - In what ways did these standards/other standards (Energy Star) inform selection of individual technologies?

Home purchaser perceptions

- Why do you think that individuals are interested in buying these homes?
    - Role of energy-efficient design?
- Do you anticipate that homeowners will have any difficulties with specific systems? If so, which ones?

Final questions

- Overall, would you say that you have learned things from working on this project?
  - If so, what key things? And how will this inform your other work?
- Anything that we've not discussed that is important for us to know?
- Any other individuals that you think are useful for us to talk with to better understand the decision making around the specific technologies that are the focus of this study?

7.4.2 Sub-contractors/Installers

Background

- Tell me about yourself:
  - Training?
  - Previous employment?
  - Transition to this job?

- What is the purpose of your job?
  - Detect and solve problems?
  - Examples of how you fixed problems?
  - Examples of how you anticipated problems and fixed them before they occurred?

- What are some of the things your job requires you to do?
  - Installations; Technical Troubleshooting; Sales; Transportation?
  - How do you interact with: marketing brochures?

- How do you feel about this job?

Workplace

- What can you tell me about the relationships between you and other installers/ technicians?
  - Other contractors on site?
- Who is your most experienced installer/technician?
  - How do you all utilize his experience?
  - What are your relationships like with other contractors on site?
    - You must run into the same people, yes?
    - Do any contractors (e.g. architects or builders) ever change plans that complicate your job?
      - Are you sometimes unable to perform the new plan?
    - Are there people you don't want to work with?
      - Why?
- What are the gender dynamics in consultations and marketing materials?
  - Who makes the decision about the product?
  - Are men or women more interested in the technical vs. aesthetic qualities of heat pumps?
- How do you feel about the work you complete?
  - Is it hidden?

Installer-Homeowner Relationship

- How would you describe the relationship between homeowners and technicians?
    - Do interactions differ with various user-groups/homeowners?
    - Do you tailor information to each homeowner's interest level/needs?
    - How much do homeowners understand what you're telling them?

- Do you teach homeowners how to operate and relate to their systems?
    - What do you think about the technology installed in the Bridger View homes?
        - Is this the appropriate technology for these homes?
            - What technology and/or brand do you prefer?
            - Who is the technology in the Bridger View homes designed for?
    - How do you train them to:
        - Adjust their thermostat? `
        - Heat pump settings
            - Examples?
        - Do they ever call you back for further instructions? Why?
            - What's that like?

- Do you ever perform a higher-level of service assistance (Watching kids, watching dogs, other tasks)?

Conventional Technology and Energy Efficiency

- What are your thoughts on energy efficient technology?
    - Is energy efficient:
        - Easier to install than conventional technology?
        - More time-consuming to install?
        - Require additional training or expertise to properly install?
            - Would training or education on energy efficient technology increase the likelihood of you recommending it to the consumer?
        - Do you prefer conventional or energy efficient water heaters?
        - Do updates to building code (IECC 2018) require you to install this technology?
            - Does this increase your costs?

    - How does energy efficient perform in:
        - Montana's climate?
        - New vs. a replacement in old homes?
            - How important is home design for ease/viability of installation of this technology?
            - Is installation viable/cost effective in older homes?
            - Are there other home characteristics or technologies that are required to allow this technology to work at its most efficient?

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- Does MT offer incentives for energy efficiency?
    - For consumer? For installers?
        - What are your thoughts on these incentives?
    - Are there energy tradeoffs? What's the point of energy efficiency/tradeoff?
    - Is this something you care about? (Do they really care about it, or is it a company talking point?)
        - Why? What do you know about it?
- Are there disadvantages to energy efficient technology that people may experience?
    - Who's installing this energy efficient technology? (Demographics?)
        - Can the common person afford it? (increase cost, inconvenience—i.e. longer wait times/cycles, decreased power)

7.4.3 Homeowners

Background & Bridger View

- Tell us a little about yourself.
- How long have you lived in Bridger View?
- What factors contributed to your interest in a Bridger View home?
    - What do you think of this development so far?
    - Importance of energy efficiency when considering selecting the home?
- Remote working?
- Other home ownership?
- Where were you living before this home?
- If you don't mind, can we discuss your utility expenses?
    - What are your expectations across seasons?
        - Costs?
        - Energy Use?
        - Efficiency?
        - Consent, potential for sharing these with us for the analysis?

Technological Literacy

- How much do you know about the technology installed in your new home?
    - Heat pump? Ventilation system? Water heater?
    - Where did you acquire this information?
        - Manuals, technicians, personal experience?
- What types of maintenance are you required to perform on your heat pump?
    - Where did you learn about these tasks?
- Who would you call if your heat pump malfunctioned?
- Do you ever discuss your heating system with family or friends?
    - What types of things do you discuss?
    - What do they have for systems?

Efficiency and Effectiveness

- Tell us what you know about the heating and cooling equipment in your home
- Tell us what you know about residential heating and cooling equipment efficiency
- What is your confidence level that the heating and cooling options selected for your home are appropriate/effective for Montana's climate?

    - Does anyone in your household have a different impression of this heat source?
- What are your impressions of the heat pump as a heat source?
    - Functionality, sound, temperature regulation, ask about themostat settings, preferences for warm/cool house?
    - Cost?
        - About how much is your energy bill here versus other residences? Higher/lower?
    - Does outside temperature affect your heat pump's effectiveness? If so, how?
        - How much do you know about the differences between efficiency and effectiveness?
    - Do you prefer a fossil fuel-based furnace or conventional heating system?
        - Would you consider changing to a conventional system?

<u>Homeowner-Installer/Technical assistance Relationship</u>

- What was your relationship like with the installers? Or did this happen through the land trust/HOA?
    - How did the installer instruct you on how to adjust your thermostat?
        - Have you ever needed to call them back for further instruction?
- Have you largely used the heat pump as instructed, or have you programmed it on your own?
    - Found new ways to adjust or to set it to your preferences versus how you were instructed?
    - Can you explain your controls to me?
    - How easy are they to use?
    - Who do you think they were designed for?

- Did the installers tailor the information to your interests/needs/understanding?
        - How much of what installers told you did you retain?
            - Examples of retention?

<u>Policy</u>

- What are some policy implications for using the technology in your home?
- What are your thoughts on your heat pump's environmental effects?
- Do you intend to apply for a tax credit for using your heat pump?
- Bias toward energy efficiency?