COMMERCE DEPARTMENT
ENERGY RESOURCES

Energy Savings Opportunities in New and Renovated Minnesota Homes

Characteristics, Energy & Code and Beyond-Prescriptive-Code Opportunities

08/21/2020
Contract 156093

Conservation Applied Research and Development (CARD) FINAL Report

Prepared for: Minnesota Department of Commerce, Division of Energy Resources
Prepared by: Slipstream

slipstream

Prepared by:
Scott Pigg
Melanie Lord
Karen Koski

Slipstream
431 Charmany Drive
Madison, WI 53719
Phone: (800) 969-9322
website: www.slipstreaminc.org

Contract Number: 156093

Prepared for Minnesota Department of Commerce, Division of Energy Resources:
Grace Arnold, Commissioner, Department of Commerce
Aditya Ranade, Deputy Commissioner, Department of Commerce, Division of Energy Resources

Lindsay Anderson, Project Manager, Department of Commerce, Division of Energy Resources
Phone: (651) 539-1771
Email: Lindsay.anderson@state.mn.us

ACKNOWLEGEMENTS

This project was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources, through the Conservation Applied Research and Development (CARD) program, which is funded by Minnesota ratepayers.

The authors would also like to acknowledge Leede Research and Aaron Riendeau of St. Croix Energy Solutions for their essential contributions to this study. Without Leede's perseverance in recruiting participants for the study and St. Croix Energy Solutions' help in completing site visits, this project would not have met its goals. We'd also like to acknowledge all the homeowners who agreed to let our technicians come into their homes and collect data on energy characteristics. Many thanks also to Slipstream staff who got pulled into this project, including Leith Nye, Quinn Koenig, Jasmine Robertson, Info Center staff (Dawneen Steinhauer, Carlyn Pruess, Dorothy Johnson, Charlene Needham, and Judy Minter), and Cherie Williams. We also acknowledge the many helpful comments on the draft final report provided by Nick Minderman (Xcel Energy) and Rebecca Olson (Center for Energy and Environment): any remaining errors or omissions are of course ours alone. Finally, a huge thank you to both Aaron Riendeau and Greg Nahn with Slipstream, for their site visit work.

Table of Contents

List of Figures

List of Tables

Executive Summary

This report examines the characteristics and energy savings opportunities associated with new and renovated homes in Minnesota that are subject to residential energy code, which includes single-family homes and multifamily properties that are three stories or less in height.

The four objectives of the study were to: (1) characterize construction practices for new and renovated homes in Minnesota; (2) assess the lost energy savings associated with construction practices relative to prescriptive code; (3) estimate the potential energy savings for beyond-prescriptive-code practices and measures; and, (4) provide guidance for Minnesota utilities in their program efforts related to residential new construction and renovation. Note that that a formal assessment of energy code compliance is not an objective of the study: instead, the study seeks to benchmark energy performance and savings potential relative to prescriptive energy code, which is only one of the possible compliance paths that builders can take. Further, an analysis of construction and renovation first costs relative to beyond prescriptive code measures was outside of the scope of work of this project.

The study gathered data for a statistically representative sample 100 Minnesota single-family homes and leveraged similar data from a separate Department of Energy study of 25 low-rise multifamily properties in the state. The study relied on energy modeling to estimate energy consumption and energy costs for homes in the study, using REM/Rate a well-known residential modeling software tool.

Key findings from the study are as follows:

- New single-family homes in Minnesota are currently being built *above* prescriptive energy code in terms of air-leakage and windows. At about $2,160 per year, energy costs for the average new home are modeled to be about 4 percent less than they would be if all homes were built exactly to prescriptive energy code.
- Many homes in the study had at least one item that was not up to prescriptive energy code. However, these generally have minor implications for energy use and cost. Correcting below-energy code items would save the average homeowner only about $30 per year.
- There is considerable remaining potential for beyond-prescriptive-code energy savings. If all homes were built with all of the most efficient characteristics found in different homes in the study sample, energy bills would be reduced by about 25 percent and the average home would use 2,400 fewer kWh of electricity and 370 fewer therms of natural gas annually.
- The study found little difference in modeled energy performance between homes located in jurisdictions that have formally adopted the state building code—and can therefore issue permits and conduct inspections—and those in areas that have not done so.
- The study also found little difference in modeled energy performance between homes that were certified under a utility whole-home new construction program and those that were not. This does not necessarily mean that utility programs have been ineffective: with about 40 percent statewide participation, it is possible that the programs have had a spillover effect into the broader market, a possibility that was beyond the scope of the current study.
- The estimated 20 percent of new homes that lack natural gas service employ a wider variety of space-heating strategies—including electric resistance heat—and are also more likely to slab-on-grade or have a crawlspace foundation. These homes are overwhelmingly served by cooperative electric utilities.

- Widespread issues were found with the balanced mechanical ventilation systems that are required by energy code in Minnesota. Correcting mechanical ventilation issues would likely improve indoor air quality in new homes, but also increase energy consumption somewhat.
- In comparison to the statewide new-construction market (which has ranged between about 11,000 and 14,000 single family housing units per year in recent years), renovation appears to offer less energy savings potential. About 1 in 1,000 single-family households undertakes an addition or major remodel in a given year, which adds up to a few thousand homes per year. As with new-construction, lost savings for renovation that is below prescriptive energy code appears to be small on average—though one of the 13 renovation-project homes in the study sample showed substantial lost savings from an attic that was left completely uninsulated. Beyond-prescriptive-code savings are certainly possible for renovation projects, but the potential appears to be much more limited because only part of the home is typically affected by renovation.
- Lost-savings potential for low-rise multifamily new construction may be somewhat higher than that for the single-family segment. There may also be more opportunities to displace electric-resistance heat with air-source heat pumps, as Census data indicate 40 percent saturation of electric heat in this segment. Field data on these properties are lacking, however.

Key recommendations from the study include:

- Utilities may need to recalibrate their baselines for calculating savings from new-construction programs in order to move the market beyond current practice. Policymakers and utilities should work together to reach a common understanding regarding the market-transformational role of residential new-construction programs.
- More research is needed on the installation and operation of balanced mechanical ventilation systems in new homes. The State and the utilities should step up training and education efforts related to these systems. Utilities could incentivize systems that do not require concurrent air-handler operation.
- Electric utilities that are outside natural gas service areas (primarily cooperatives but also some investor-owned utilities) could create a joint new-construction program specifically targeted at the disparate and unique subpopulation of new homes that lack natural gas service.

Introduction and Objectives

Energy Codes in Minnesota

Like many states, building code provisions in Minnesota that address energy consumption date to the Energy Crises of the 1970s. In contrast to other aspects of building codes, which tend to be focused on life, safety and building durability, energy codes seek to minimize wasted energy from poor construction practices.

Minnesota's energy codes have been revised at least 10 times as construction practices and knowledge of how energy is used in buildings have evolved. Minnesota's current residential energy code has been in effect since 2015. Minnesota code is based on the International Code Council's 2012 International Energy Conservation Code (IECC), which spells out in detail insulation levels and many other requirements for various climate zones. Like many other states, Minnesota adopted the model 2012 IECC with amendments, meaning that certain aspects of the IECC code are changed for the statutory language that formalizes adoption of the code in the state. For example—and notably—Minnesota's implementation of the IECC 2012 code requires *balanced* mechanical ventilation involving simultaneous exhaust of stale air and introduction of fresh air in residential structures (the model IECC code also requires mechanical ventilation but does not require it to be balanced).

Energy codes are split between residential and commercial buildings. This study is concerned with buildings that are subject to the residential code, which includes single-family homes, townhomes, duplexes and multifamily properties that are three stories or less in height.[1] Manufactured homes are excluded from this study because they are subject to federal HUD code, but modular homes, which are subject to local code are within the scope of the study.[2]

While the code applies statewide, in order for local jurisdictions such as counties, cities or townships to enforce the code, they must formally adopt it—and not all have done so. As we will show shortly, we estimate that about 80 percent of new homes are built in what we will refer to throughout this report as *enforcement* jurisdictions and 20 percent are built in *non-enforcement* jurisdictions. Note that being in an enforcement jurisdiction does not necessarily mean that all aspects of the code are actually reviewed and enforced by local officials, but simply that there is a local mechanism for doing so.

There are multiple paths for complying with Minnesota's residential energy code. The easiest to understand—and the one that appears to be taken by most builders—is the prescriptive path, which simply spells out required insulation levels for various spaces as well as other prescriptive requirements such as air-leakage and duct leakage. Alternatively, there are also U-factor and Total-UA compliance

---

[1] By "multifamily" we refer here primarily to apartment buildings and condominiums with three or more living units that are meant for permanent residency. Residential properties (ie. buildings intended for sleeping) with transient occupancy, such as motels, are governed by commercial code. Less common group quarters such as dormitories, convents and smaller assisted living facilities are also be subject to residential code (if they are three stories or less in height)—though these were not included in the scope of this study. We also note here that there appears to be some ambiguity about how to treat mixed-used apartment buildings and condominiums buildings that have both commercial and residential space in them. We discuss this issue later in this report.

[2] While both manufactured and modular homes are largely built off-site in a manufacturing facility, the former is built with in integral steel undercarriage for transport, while the latter is not.

paths that specify the maximum allowable heat flow across entire assemblies, such as ceilings and foundation walls. In addition, there is a whole-building performance path that can be used to satisfy the energy code requirements if overall modeled energy performance is less than or equal to that of a standard reference building.

Because of these complexities, it is important to recognize that this study is not an energy code compliance study in the sense of formally deciding whether homes in the study complied with the code or not. Rather, it is a study of energy use relative to prescriptive code. For example, if we find a home with R-38 ceiling insulation, we cannot definitively say whether the home is in compliance with the code, because it could have used a performance path that allowed for less than the prescriptive-code requirement of R-49. However, we can model the energy use of the home with its actual R-38 ceiling compared to what its energy use would be if it had been insulated to R-49.

We chose prescriptive code for our code baseline because it is the easiest to understand and because it is likely that most builders follow this path (the data that we gathered suggest as much). However, there are some important differences in assumptions between the paths, and some choices that need to be made regarding how to model prescriptive code requirements. (Appendix E: Prescriptive-Code Modeling Details provides more detail for Prescriptive-Code Modeling Details.)

Past studies of codes and new homes, including in Minnesota, tended to focus on compliance rates, meaning the percent of homes that comply with a checklist of code-required items, not all of which have energy impacts. Therefore, it is difficult to use a measured compliance rate to quantify energy savings opportunities because some items have little or no energy consequences and others can have substantial energy impacts. Nonetheless, the most recent study in Minnesota (Hernick and Sivigny 2013), showed 80 percent compliance relative to 2009 IECC code among residential new construction, 72 percent compliance for residential additions and 73 percent compliance for renovations. That study was conducted under a prior version of the energy code, however.

Study Objectives

The study was funded by the State's Conservation Applied Research and Development (CARD) Grant Program, which is intended to help improve the effectiveness of utility energy conservation programs.

Specific objectives of this study were to:

1. characterize current residential new-construction and renovation practices;
2. measure the lost savings associated with homes being built (or renovated) relative to prescriptive code and identify any key savings opportunities that could potentially be addressed by utility programs;
3. similarly identify and quantify beyond-prescriptive-code savings opportunities for utility programs; and,
4. provide general guidance to Minnesota utilities for their new-construction and renovation program offerings.

Note: an analysis of construction and renovation first costs relative to beyond prescriptive code measures was outside of the scope of work of this project.

Approach

The study is divided into three parts representing different segments of the market that are subject to residential energy code:

- a field study and analysis of single-family new construction, which comprises the majority of the energy-related new-construction and renovation activity;
- a smaller field study of single-family homes that had recently been renovated with an addition or major remodel; and,
- analysis of field data for low-rise multifamily new construction projects gathered as part of a separate DOE-funded effort

For all three of the above, we characterize key energy-related construction aspects and use energy modeling to assess the potential savings from various measures intended to address construction relative to below-prescriptive-code levels or to go beyond current code.

The design of the study was informed by stakeholder feedback at a project kick-off meeting in June 2018 that was attended by about 25 individuals. Key outcomes from that meeting include: (a) a desire for the study to oversample single-family homes in code non-enforcement areas so that more can be learned about this sub-population; (b) home renovation is of secondary interest, so should make up a smaller fraction of the fieldwork and should be limited to major renovation activities such as heated additions and whole-home remodels; and, (c) the fieldwork should pay close attention to mechanical ventilation due to Minnesota's code requirement for balanced ventilation and a lack of statistically-representative data on installation practices.

Sampling and Data Collection

Sampling and data collection for the three parts of the study proceeded somewhat differently and are discussed separately below.

Single-family New Construction Sample

The goal of the sampling and recruiting effort for the single-family, new-construction sample was to gather data on a representative sample of new homes in the state. An early study-design decision in this respect was to target the study at recently built *occupied* homes. This stands somewhat in contrast with a methodology developed by the Department of Energy and Pacific Northwest National Laboratory that calls for using building permit data to sample and visit homes that are at various stages of construction (Bartlett et al., 2018).

The advantages of targeting occupied homes (which has also been employed in similar baseline studies in New England) are that it avoids potential builder bias that might otherwise skew the study towards builders that use above-average construction practices. It also avoids issues with obtaining permit lists in non-enforcement areas that were of particular interest to the study. On the other hand, visiting completed, occupied homes carries its own set of challenges for gathering certain kinds of data, such as the installation quality of wall insulation and changes that may have been made to homes post construction. We call out these areas of uncertainty later in this report where they are relevant.

It is also possible that the recruiting homeowners instead of builders could introduce other kinds of response bias, such as homeowners who are dissatisfied in some way with their new home and seeking third party input. However, homeowner response bias could cut both ways and perhaps lean toward homeowners who were promised an efficient home and are seeking validation of that claim. On balance, we felt that potential recruiting bias for a homeowner-based approach was less of a concern that that for a builder-based approach.

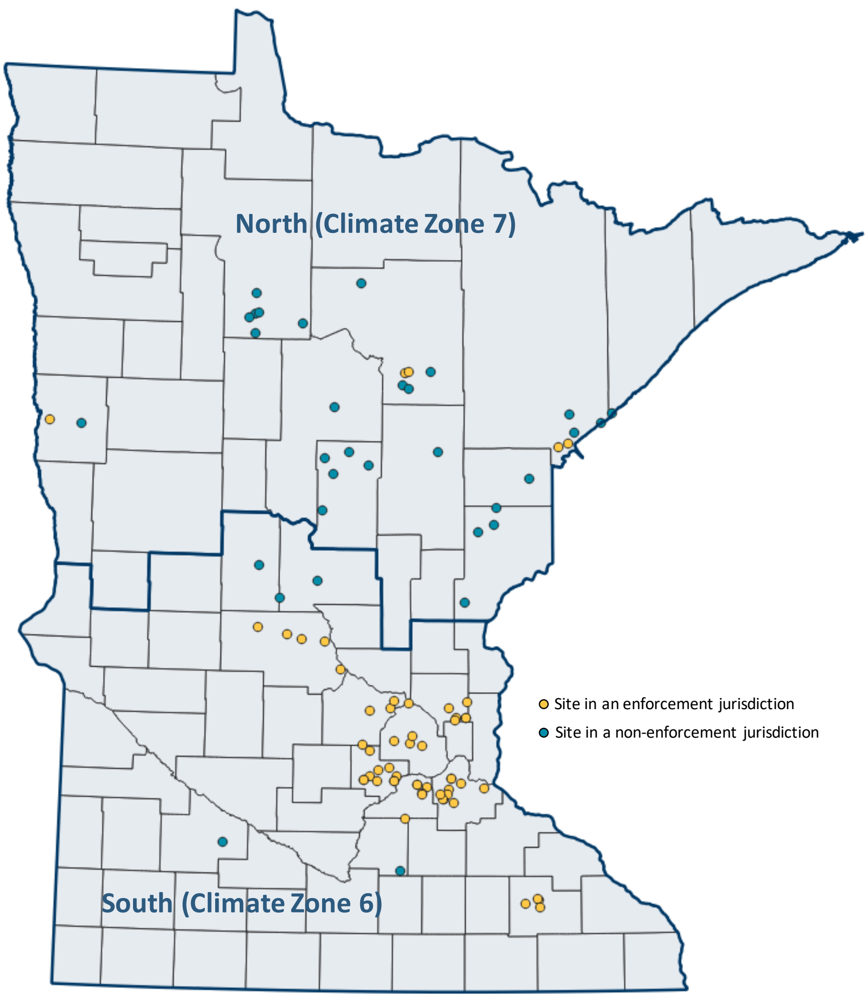
We used a two-stage approach for identifying new homes for the study: first we sampled counties within the state, then we obtained property-tax listings for new homes in those counties and recruited households for the study itself. The process is described in more detail in Appendix A: Single-Family New-Construction Sampling Details. Suffice to say here that it did not go precisely as planned, and a supplementary sample of counties was needed in order to meet the recruitment goals of the study. In the end, we contacted 30 of Minnesota's 87 counties and ultimately recruited participants from 20 counties, using a combination of telephone and postcard recruitment.

Part of what complicated the recruiting for the study was that stakeholder feedback at a project kickoff meeting indicated a high level of interest in assessing construction practices and savings opportunities in non-enforcement jurisdictions in the state. We therefore designed the study to deliberately sample new homes in non-enforcement jurisdictions at a higher incidence rate than they naturally occur in the population (20%). We sought to evenly divide the new-construction sample between homes in enforcement and non-enforcement jurisdictions: difficulty achieving this goal is what led to the need to add more counties to the original sample, and in the end we were only partly successful in that 32 of the 87 homes in the sample (37%) came from non-enforcement areas.

This also means that the study sample is not self-weighting in the sense that taking a simple average of a given characteristic across the sample would yield a result that is skewed toward homes in non-enforcement areas and, if not adjusted, could give a misleading notion of the statewide average for the full population of new homes. We therefore used case weights to true up the sample to the estimated population proportions of homes in enforcement and non-enforcement jurisdictions as well as the proportion of homes in Minnesota's northern and southern climate zones. Appendix A: Single-Family New-Construction Sampling Details provides more details.

The final study sample (Figure 1) comprises 87 homes, all built between 2016 and 2019 under current residential code. Among the sample are one modular home, two seasonal homes and one duplex home. With regard to seasonal housing, the study probably under-represents the fraction of northern seasonal housing because we screened out property-tax listings for cases where the tax bill was sent to an address other than that of the property—and we required the homeowner to be present for the site visit. The duplex was not identified as such until the time of the site visit: we retained it in the study as Census data show that a small percentage of new housing is two- to four-unit multifamily. Notably, the study sample did not include any single-family attached homes (townhomes), though Census data indicate that these make up about 1/7th of new single-family, site-built homes built in the last 10 years.

Figure 1. Single-family new construction sites.



Single-family Renovation Sample

By necessity, the single-family renovation sample was limited to enforcement jurisdictions, because the sample frame for this part of the study was renovation permits, of which we obtained about 34,000 from nine jurisdictions within the original new-construction sample. We winnowed the large list of projects down to those involving an addition and/or substantial remodel of a home and recruited 13 participants for site visits by postcard, almost all of which were in Minneapolis or the greater Twin Cities area. Additional details about the renovation sampling are provided in the relevant Results section.

Low-Rise Multifamily Sample

The low-rise multifamily sample leveraged a parallel effort by DOE that was a four-state study of low-rise multifamily new construction (Davis et al. 2020). As part of that effort the Center for Energy and Environment collected on-site data for 25 Minnesota properties and conducted air leakage tests on another 10 properties. We used those data and the results of energy modeling undertaken as part of the study to characterize and assess the low-rise multifamily market that is subject to Residential code.

(Mid- and high-rise multifamily construction is subject to Commercial code and is included in a parallel CARD project covering commercial new construction.)

Data Collection

The single-family new construction and renovation parts of the study relied on site visits using a common data collection protocol for gathering detailed information about each home and its energy-related characteristics. An experienced home-performance rater visited each home to gather information about building geometry, insulation levels, equipment model numbers and other information needed for assessing and developing an energy model for each home. The effort was supported by a tablet-based instrument (Appendix C: Data Collection Instruments) for many data items and that also provided for linking on-site photos to various data elements.

In addition to gathering observational data for each home, a number of tests were conducted in at least some of the homes:

- blower-door based measurement of air leakage (all homes)
- duct pressurization testing (all homes with exterior ductwork and a sample of homes with no exterior ductwork)
- infrared scans for insulation coverage issues (subject to adequate indoor-outdoor temperature difference)
- mechanical ventilation flow (most bath fans and balanced systems with test ports)

Participating homeowners were asked to sign a release so that the project team could obtain information about participation in utility programs including both whole-home new construction programs and rebate programs for heating, cooling, and water heating equipment. All but four homeowners provided this release, but eight smaller utilities (affecting 16 participants) still refused to provide rebate information to the team.

Analysis and Reporting

In addition to characterizing various aspects of each home, analysis of the data primarily consisted of running various versions of as-built, at-code and beyond-prescriptive-code energy models for homes in the study using the REM/Rate (Version 16.0.1) energy modeling software, which is widely used for modeling the energy performance of homes in new-construction programs. The modeling analysis began with an as-built model for each home that was fully customized to the home. These models were then individually adjusted as appropriate to bring below-code items up to prescriptive code or—for the beyond-prescriptive-code scenario—to specified beyond-prescriptive-code levels. Individual items, such as ceiling insulation and air leakage, were evaluated both individually (i.e. with only that measure adjusted) and collectively so that that interactive effects across measures could be captured. We refer to results from the individual runs as “non-interacted” and to the latter as “interacted” results. In most cases the differences are small.

Not all items could be directly observed for all homes. When analyzing and reporting characteristics, we generally confined the analysis to homes with reliable knowledge of the characteristic of interest, drawing on the following hierarchy of reliability: (1) visual verification; (2) code-compliance certificate;

(3) building plans; (4) homeowner self-report; and, (5) site-visit technician estimate.[3] Which homes were included and which were excluded is noted in the reporting for each item.

Similarly, we asked owners of new homes about changes that might have been made to the home after construction. The most frequently encountered changes involved households finishing and insulating basement spaces and changes to hard-wired lighting. We took these changes into account in our assessment of lost savings and beyond-code savings estimates.

The energy models required an input for all characteristics regardless of whether it was observed or not. We used several imputation methods to backfill unobserved items in a way that attempted to capture the distribution of that item for known cases. For example, duct leakage was only measured for a sample of homes that lacked exterior ductwork. For each home with *unmeasured* duct leakage, we randomly selected a home with *measured* leakage that lacked exterior ducts and used that value for the unmeasured home. A similar procedure was used for window properties: we inferred the energy characteristics for many windows by imputing these within categories of window properties (number of panes and low-e coatings) obtained from a special tool used to determine these properties for all homes. Above-grade walls required a separate procedure because installation quality was generally unobservable for the occupied homes in the sample: infrared scans suggested that few homes had substantial installation quality issues (Grade 3), so we randomly divided homes between Grade 1 and Grade 2 and modeled them as such. Additional information about the nature and extent of imputation is provided in the detailed findings for single-family homes later in this report.

The modeling used utility rates and fuel costs that were customized for Minnesota and (for electricity) by type of utility. Appendix D: Utility Rates provides the details for these.

All homes were modeled at the average self-reported heating setpoint of 69F and cooling-season setpoint of 73F.

As noted above, we developed case weights to correct for the fact that the study was designed to oversample homes in non-enforcement areas and to true the sample up to population proportions of new homes in the two climate zones. Results that reflect these corrected population estimates are labeled as “weighted population estimates.” Reported characteristics for the sample without these weights are referred to as “unweighted sample” results.

Margins of error (confidence intervals) are reported for certain results and many detailed tables flag cases where there is a statistically significant difference between subgroups. These reflect uncertainty owing to variation across the study sample (taking into account the multi-stage nature of the sampling process): they do not account for potential recruitment bias, modeling error or other non-random factors that could affect the accuracy and ability to generalize the results from the study sample to the larger population of homes. All error margins and significance tests are at a 95 percent confidence level. This means that in theory, if we repeated the study 100 times with different samples, the confidence intervals for 95 of the 100 sets of results would contain the correct population average.

[3] Code-compliance certificates were found for 26 of the 87 homes in the new-construction sample. Building plans were available for 51 homes, though not all contained useful information for some items of interest.

Results

Results presented here are divided into three broad sections:

- single-family new construction
- single-family renovation
- low-rise multifamily new construction

For each, we provide some statistics about the population, report on observed characteristics, estimate lost-savings relative to prescriptive energy code and estimate the potential for beyond-prescriptive-code energy savings.

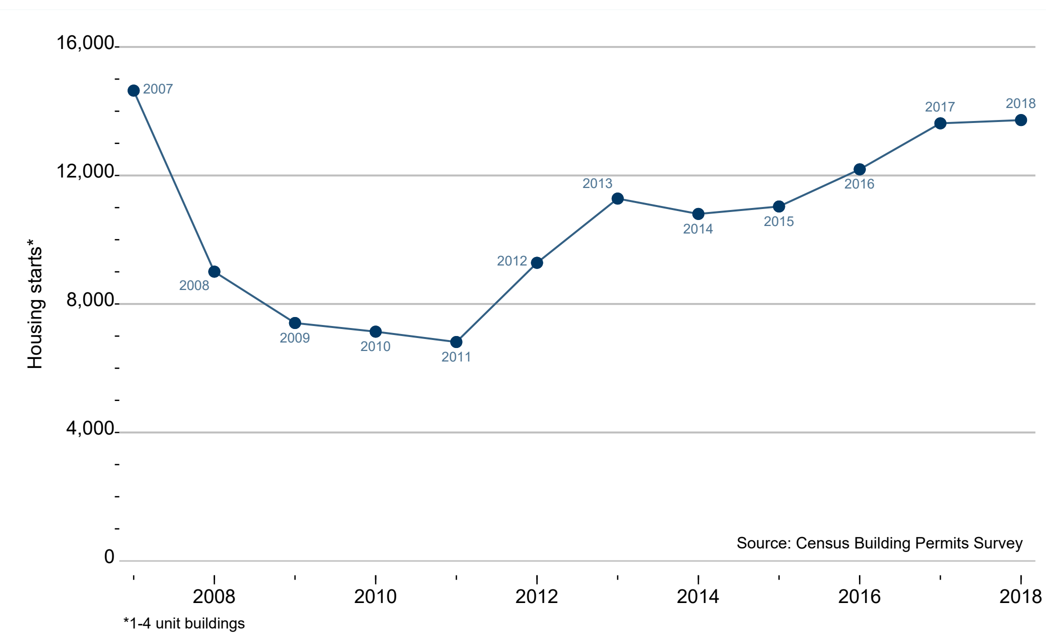
Single family New Construction

We begin with an overview of the single-family new-construction market in Minnesota, followed by a brief description of utility new construction programs in the state. We then provide a big-picture overview of the main findings from the energy modeling. The bulk of the section is then devoted to a detailed review of individual building components and equipment.

Overview of the Single-Family New Construction Population

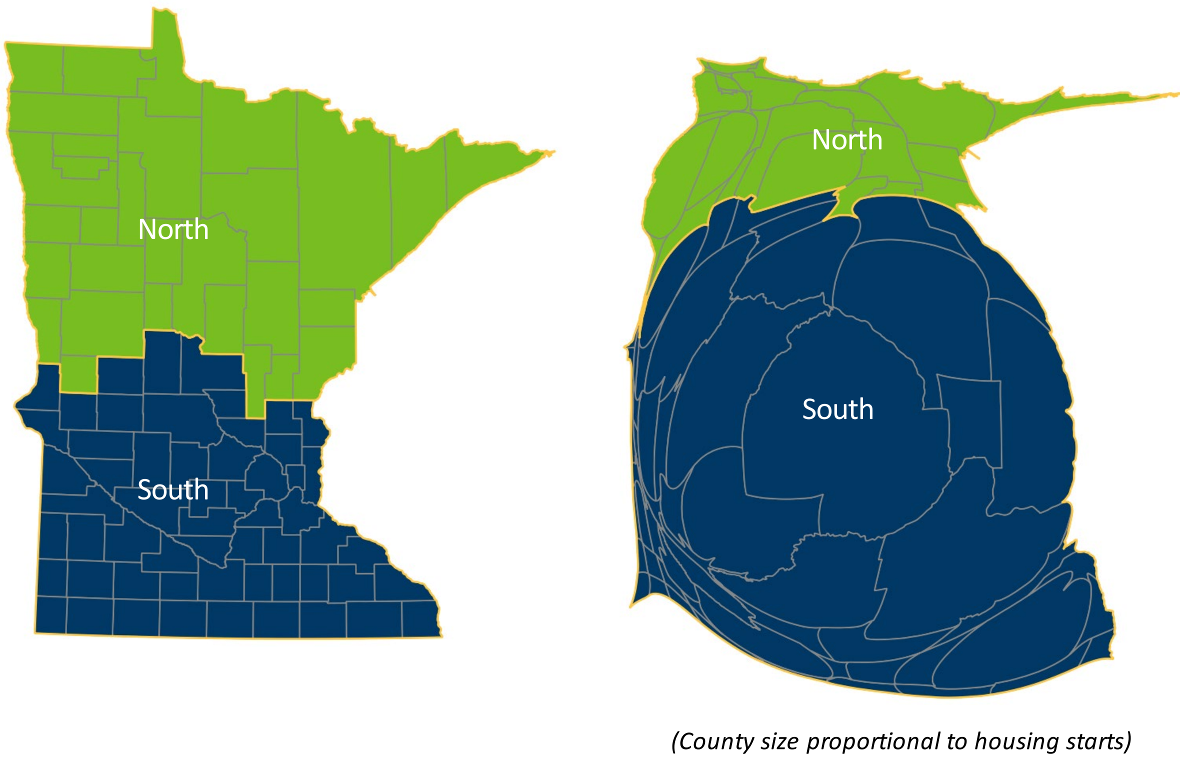
Over the last 12 years, the annual number of new single-family homes built in Minnesota has varied from about 7,000 to more than 14,000, with construction on the upswing since the depths of the Great Recession in 2011 (Figure 2).

Figure 2. Minnesota housing starts, 2007-2018.



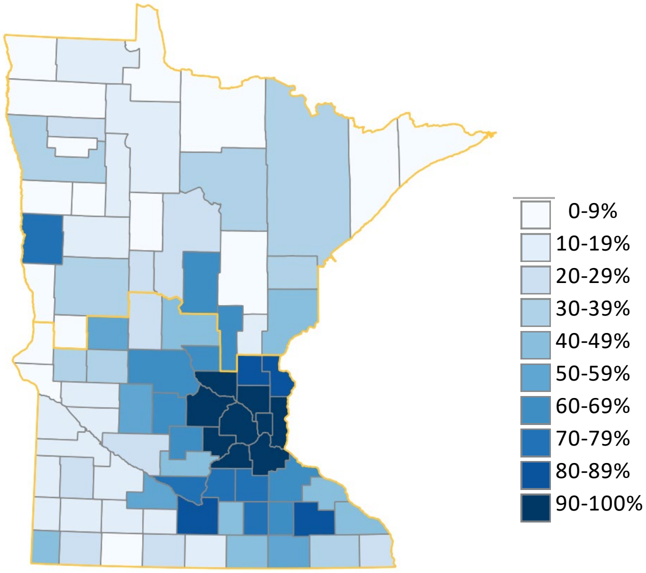
A statistical profile of new Minnesota homes that combines Census data on housing permits at the city and township level, information about utility service territories and information about local code enforcement and non-enforcement jurisdictions confirms that most new construction occurs in the southern part of the state, particularly around the Twin Cities (Figure 3), where the proportion of homes using natural-gas is high (Figure 4) and code is enforced county-wide (Figure 5).[4] Outside the Twin Cities and a few other metropolitan new-construction-growth areas, such as Rochester and Fargo ND, natural gas is much less prevalent, the local jurisdiction is less likely to have a formal code-enforcement mechanism and the home is much more likely to be served by an electric cooperative (Figure 7) or municipal utility (Figure 8). As we will show later, homes in these outlying areas are also more likely to be slab-on-grade construction and have a wider variety of space-heating equipment than their more urban counterparts.

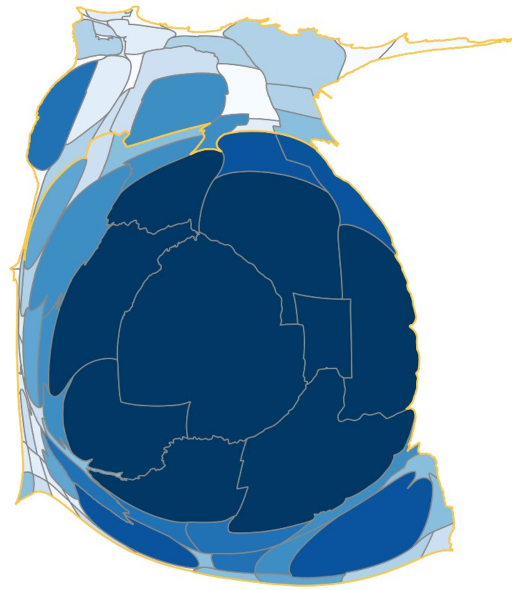
Figure 3. Climate zones. The southern zone corresponds with IECC Climate Zone 6; the northern zone is IECC Climate Zone 7.



[4] Census data are from the Census Building Permits Survey at the Place level. Utility service territories are based on publicly available GIS shape files for electric utilities and tariff-book listings of communities served for gas utilities. Code enforcement is based on a database of code jurisdictions maintained by the Minnesota Department of Labor and Industry.

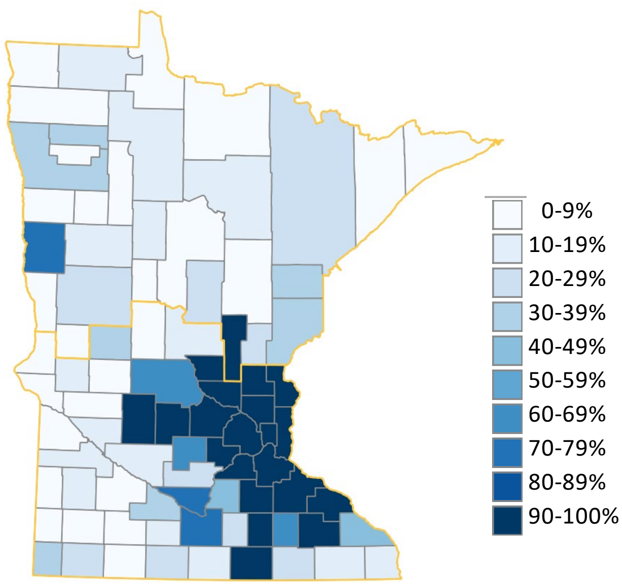
Figure 4. Estimated percent of new homes with natural gas service.

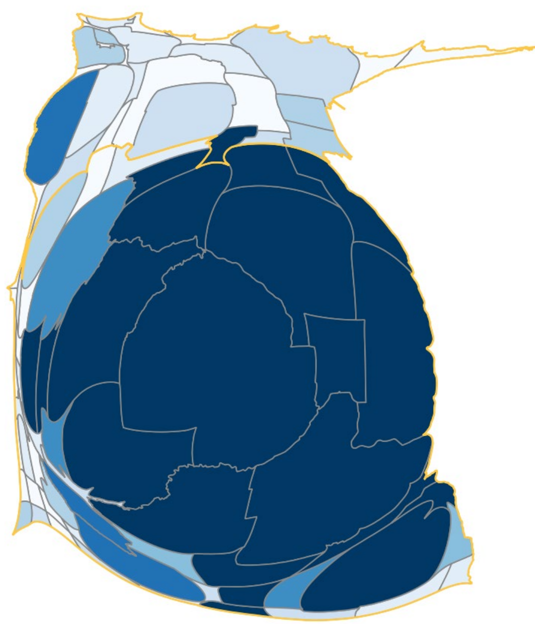




(County size proportional to housing starts)

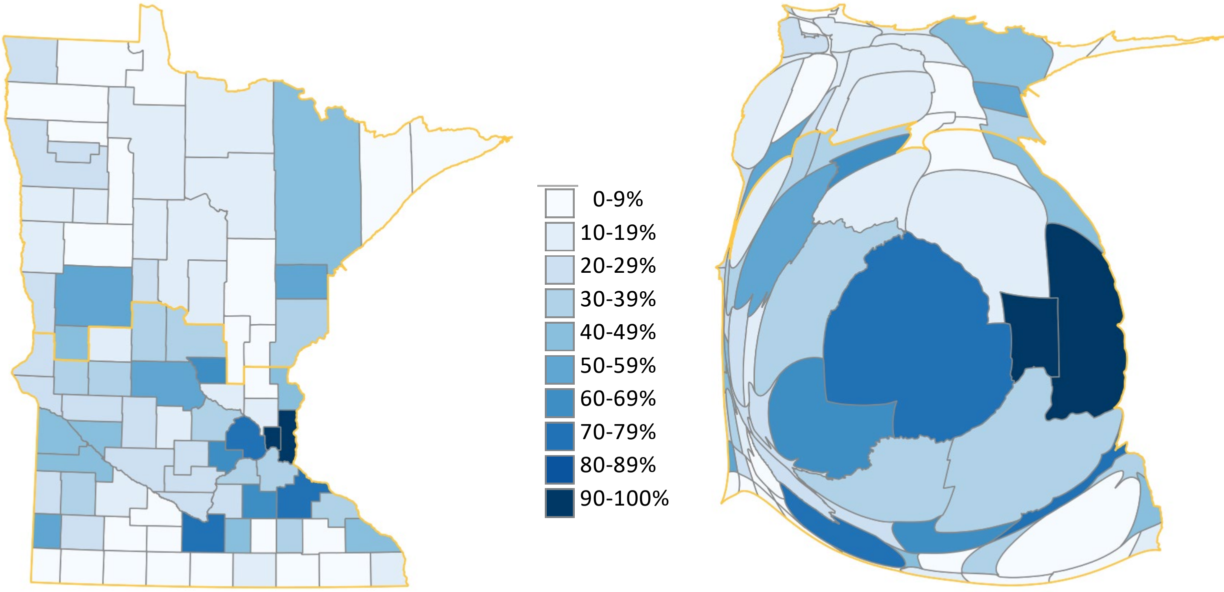
Figure 5. Percent of new homes in a code-enforcement jurisdiction.





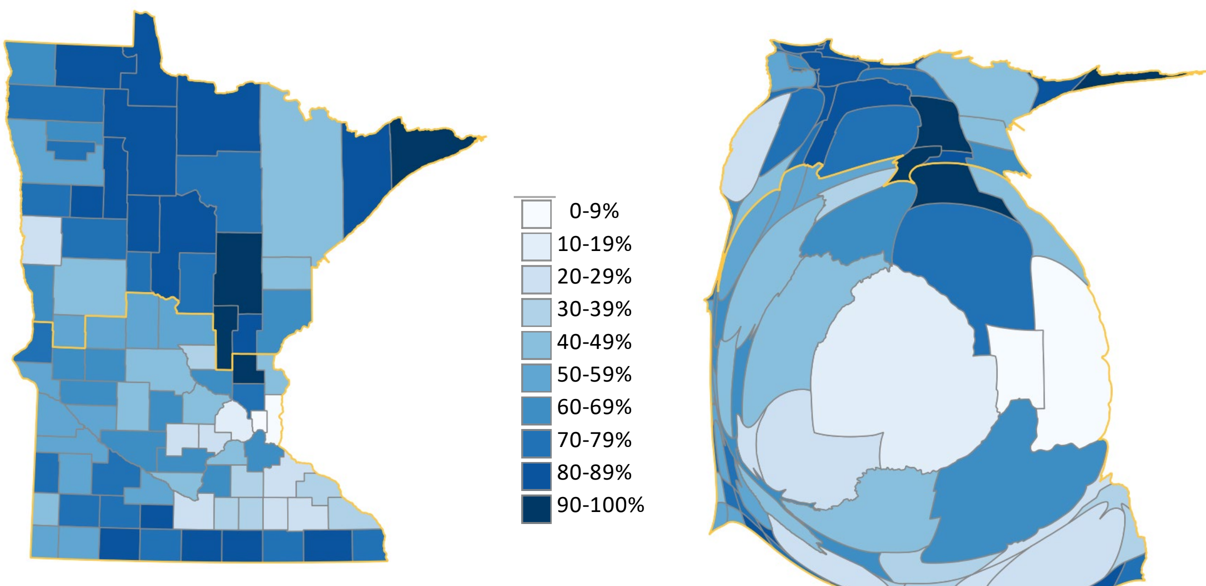
(County size proportional to housing starts)

Figure 6. Estimated percent of new homes served by an investor-owned electric utility.



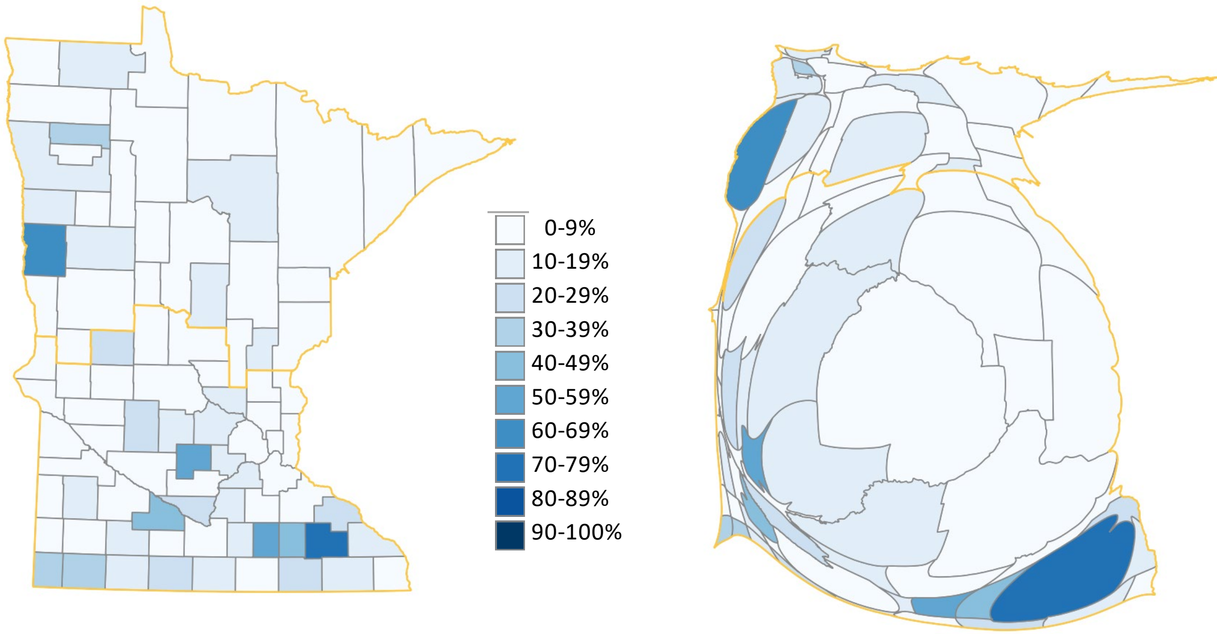
(County size proportional to housing starts)

Figure 7. Estimated percent of new homes served by a cooperative electric utility.



(County size proportional to housing starts)

Figure 8. Estimated percent of new homes served by a municipal electric utility.



(County size proportional to housing starts)

Throughout this report, we provide statistics in terms of some key population subgroups, such as climate zone, code-enforcement, and presence of natural gas service. It is important to recognize that there is a great deal of overlap for some of these dimensions (Table 1). For example, reading the table row-wise shows that 91 percent of homes built in the southern climate zone are also in jurisdictions with a code enforcement mechanism but only 28 percent of homes in the northern zone are in enforcement jurisdictions. Climate zone is thus highly correlated with code enforcement and vice versa.

Table 1. Estimated sub-population splits for new single-family homes.

Group	Natural gas service? (Yes/No)	Enforcement Jurisdiction (Enf/Non)	Climate Zone (South/North)	Electric Utility Type (IOU/Coop/Muni)
Statewide	**80/20**	**80/20**	**83/17**	**41/46/13**
Has natural gas service	100/0	95/5	92/8	49/36/15
No natural gas service	0/100	26/74	47/53	13/85/2
Enforcement jurisdiction	94/6	100/0	94/6	48/37/15
Non-enforcement jurisdiction	21/79	0/100	64/36	15/82/3
Southern climate zone	88/12	91/9	100/0	46/42/12
Northern climate zone	38/62	28/72	0/100	21/65/14

Group	Natural gas service? (Yes/No)	Enforcement Jurisdiction (Enf/Non)	Climate Zone (South/North)	Electric Utility Type (IOU/Coop/Muni)
IOU electric utility	93/7	93/7	91/9	100/0/0
Coop electric utility	62/38	65/35	76/24	0/100/0
Municipal electric utility	98/2	95/5	81/19	0/0/100

Note: the table should be read row-wise; e.g. 94% of new homes in enforcement jurisdictions have natural-gas service and 6% do not.

Single-Family New Construction Programs

Five Minnesota investor-owned utilities offer whole-home new construction programs, meaning that the program is oriented around overall energy performance and typically involves on-site testing and certification:

- Xcel (gas & electric)
- CenterPoint (gas)
- Minnesota Energy Resources (gas)
- Minnesota Power (electric)
- Greater Minnesota Gas (gas)

In addition, many utilities offer rebates for specific high efficiency equipment, such as air conditioners, for which new construction participation is also allowed.

Throughout this report, we provide breakout statistics for utility program participants and non-participants. For the most part, this means homes that were certified under one of the above whole-home programs (there were 24 in the study sample) versus those that were not. However, in the case of heating, cooling and water heating equipment, we also include a small number of homes that received an incentive for equipment outside one of the whole-home programs.[5]

Overview of Energy Modeling Results

We begin with a high-level summary of the key modeling results in terms of energy consumption, costs and savings. Figure 9 illustrates the main concepts in terms of annual energy costs. The modeling suggests that the average new home has annual energy costs of $2,160. Owing to the fact that homes are currently being built beyond prescriptive energy code in some respects, this is $85 *less* than would be the case if the home was built exactly to prescriptive energy code. Nonetheless, many homes have at least some prescriptive energy code items that are below code, though on average the "lost savings" associated with these is only $30 per year. Going beyond prescriptive energy code, if we model all homes as being as efficient as the most efficient homes in all respects—and using the most efficient

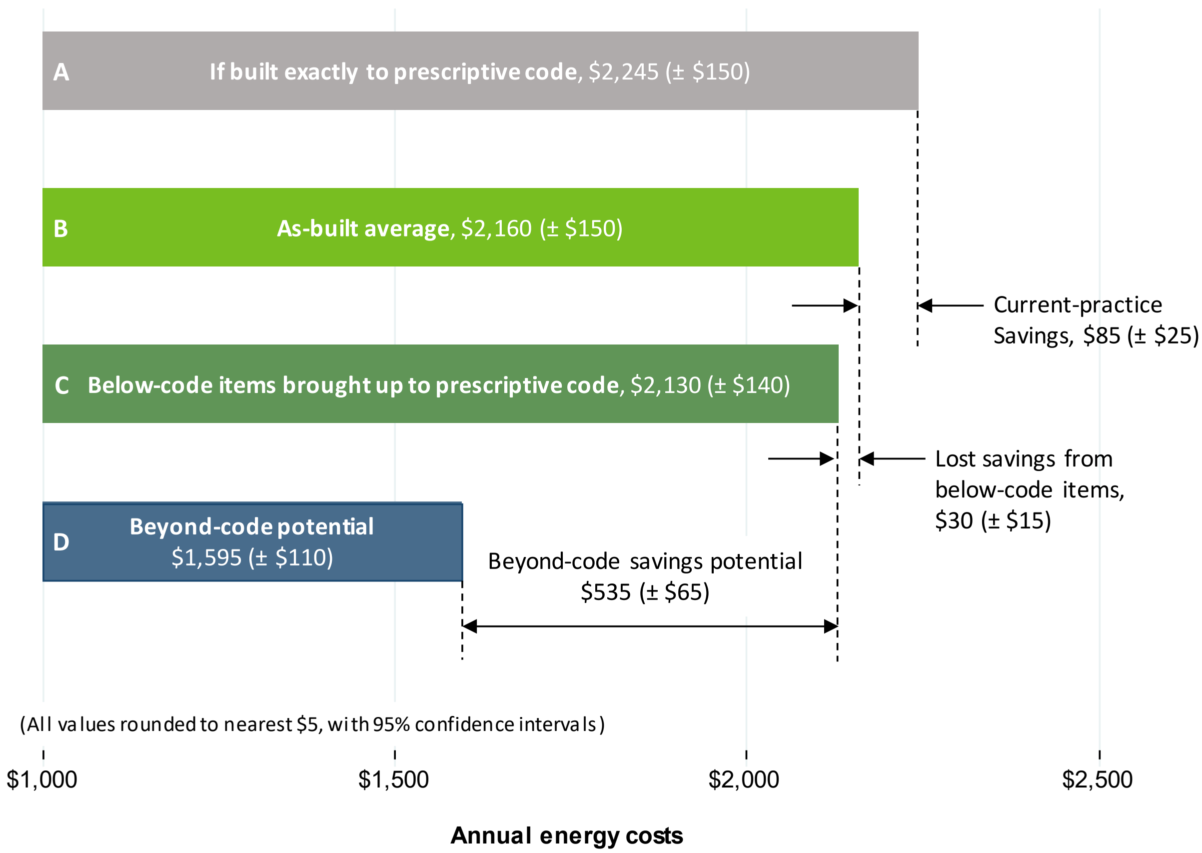
[5] Note also that three households in the new-construction sample refused to sign a release authorizing us to obtain information about program participation from their utility, and some smaller utilities refused to provide this information even when we had such a release. There are thus some cases where we do not know the status of the site with regard to utility program participation: these are omitted from the program participation breakout statistics.

available equipment—there is potential for a further reduction in energy costs of more than $500 per home, or about 25 percent lower energy costs compared to homes that are currently being constructed.

Table 2 provides these same high-level statistics but expressed in terms of electricity and natural gas consumption. Note that margins of error in this table are considerably wider for the estimated average level of consumption (first four rows) than for the estimated differences between scenarios (last three rows): this is because the former must account for the fact that homes in the sample have widely varying overall modeled consumption levels, which tend to disappear when we focus on within-home differences between scenarios.

In subsequent subsections, we break these high-level results into more detail.

Figure 9. Statewide average energy costs and savings under various scenarios (weighted population estimates).



<u>**Scenarios**</u>

A – home modeled with all components (insulation levels, etc.) set to prescriptive-code minimums
B – home modeled as-built
C – home modeled as-built, but with all below-prescriptive-code items set to prescriptive-code minimums
D – home modeled with all components set to defined beyond-prescriptive-code-potential levels (e.g. R-30 above-grade wall insulation, triple-pane windows, etc.)

Table 2. Statewide average electricity and natural gas consumption and savings under various scenarios (weighted population estimates).

Scenario	Electricity (kWh/yr)	Electricity 95% confidence interval	Natural gas (therms/yr)	Natural gas 95% confidence interval
Built exactly to energy code (1)	11,300	± 900	890	± 90
As-built (2)	11,000	± 1,000	830	± 80
As-built, w/o below-code items (3)	10,900	± 900	810	± 70
Beyond-prescriptive-code potential (4)	8,500	± 600	440	± 40
Current-practice savings (1-2)	+300	± 200	+60	± 20
Lost savings for below-code items (2-3)	+100	± 100	+20	± 130
Beyond-prescriptive-code savings potential (3-4)	+2,400	± 600	+370	± 30

Electricity values rounded to nearest 100.

Natural gas values are for homes with natural gas service and are rounded to nearest 10.

Modeled As-Built Energy Consumption and Costs

Modeled as-built consumption for individual fuels (Table 3) and combined annual energy costs (Figure 10) show that energy costs vary regionally within the state, as homes in the northern climate zone—and elsewhere where natural gas service is unavailable—rely more heavily on propane or electricity (Figure 11), both of which are more expensive space- and water-heating fuels than natural gas. However, as we will show shortly, northern homes are also almost 25 percent smaller than southern homes on average. Note also that the apparent difference in energy costs between utility-program and non-program homes here is mostly a reflection of geography: the program homes in the sample all have natural gas service and thus tend to be less expensive to heat than non-program homes on that basis alone.

Table 3. Modeled as-built energy consumption (weighted population estimates).

Group	Mean electricity use (kWh/yr)	% of homes using natural gas	Mean natural gas use[a] (therms/yr)	% of homes using propane	Mean propane use[a] (gallons/yr)
Statewide	**11,390**	**85%**	**861**	**15%**	**617**
Has natural gas service	10,860*	100%	861	<1%	(no data)
No natural gas service	14,310*	0%	—	99%	617
Enforcement jurisdictions	11,410	92%*	860	8%*	642
Non-enforcement jurisdictions	11,330	53%*	865	45%*	512

Group	Mean electricity use (kWh/yr)	% of homes using natural gas	Mean natural gas use[a] (therms/yr)	% of homes using propane	Mean propane use[a] (gallons/yr)
Southern climate zone	11,090	93%*	857	7%*	591
Northern climate zone	13,220	35%*	881	64%*	774
Utility program non-participants	12,060	73%	825	26%	617
Utility program participants	10,500	>99%	887	<1%	(no data)

[a]for homes that use this fuel

*Subgroup differences are statistically significant at a 95% confidence level.

Figure 10. Average modeled energy costs for new homes, as-built (weighted population estimates).

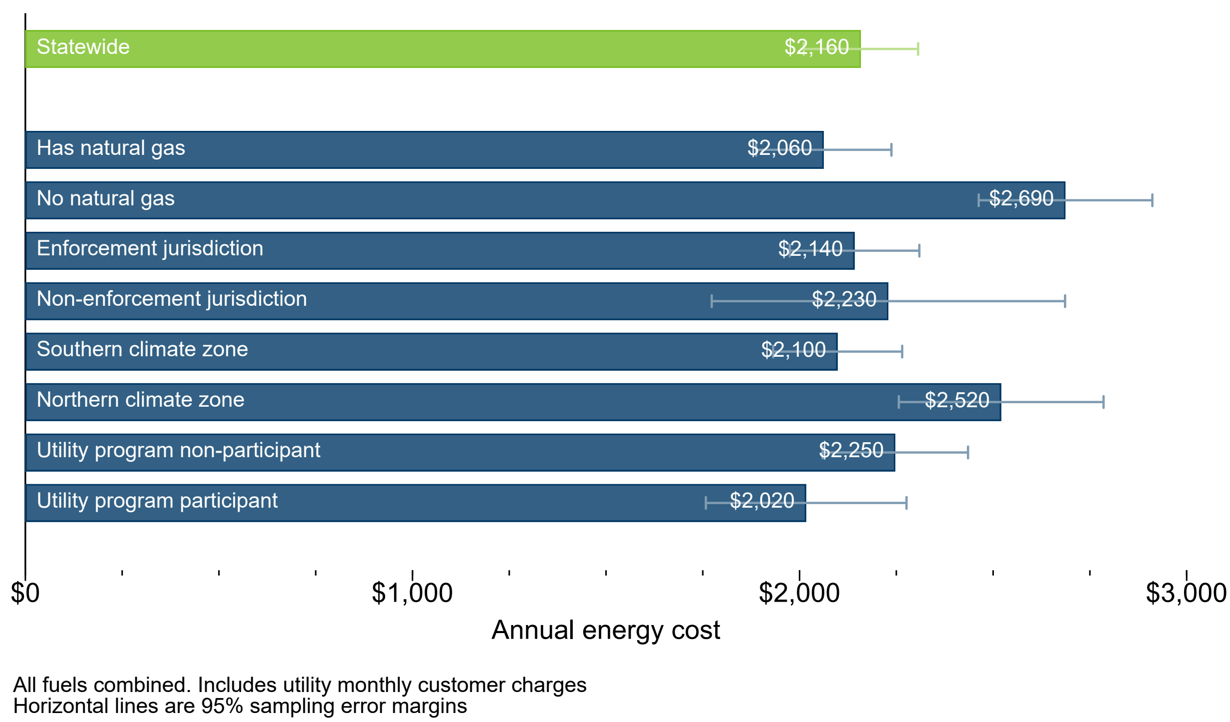
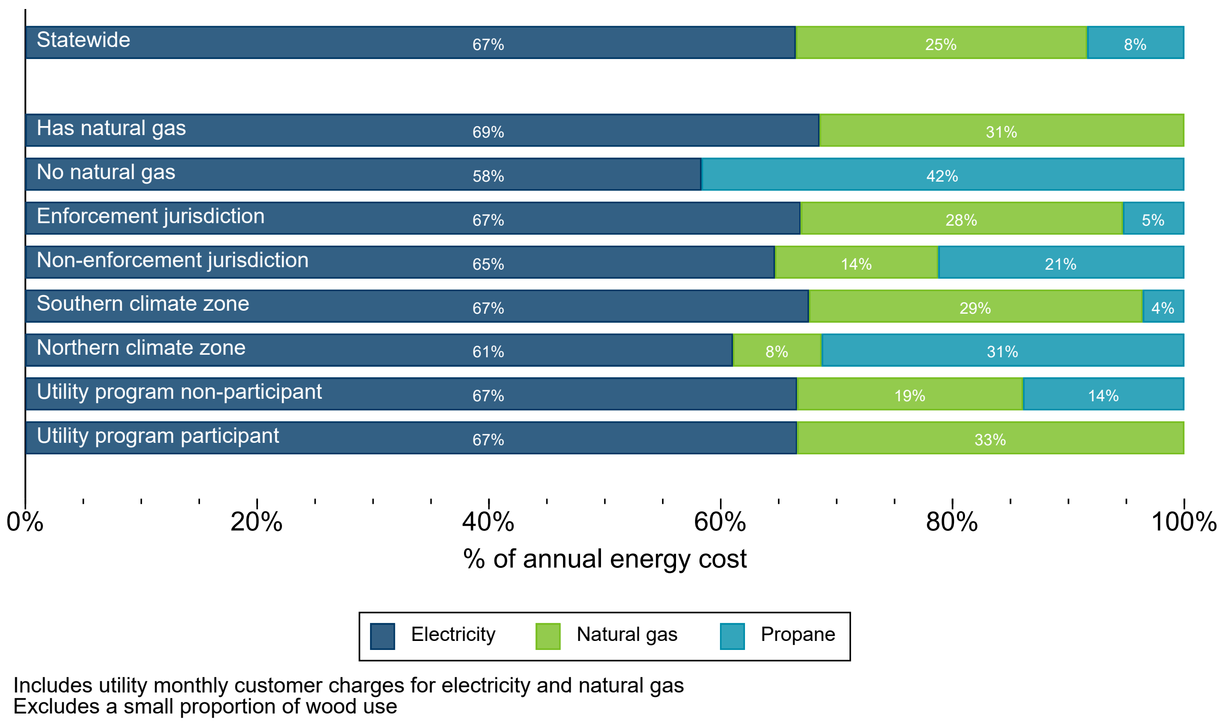
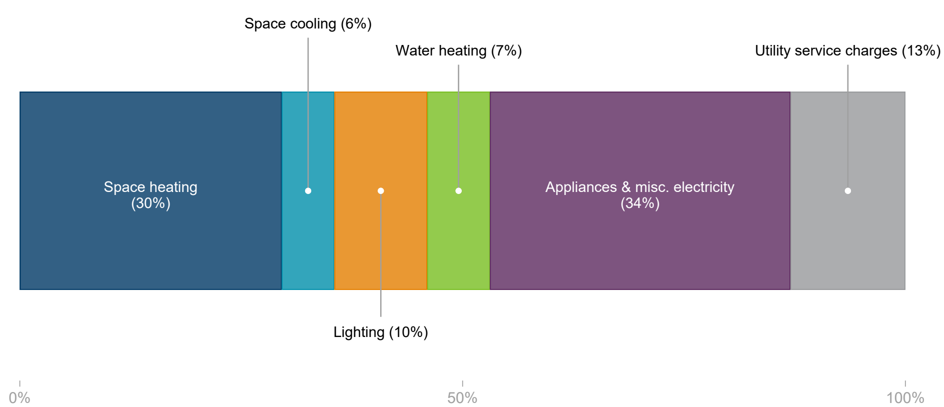


Figure 11. Aggregate average fuel contributions to energy costs (weighted population estimates).



The modeling also allows for disaggregating consumption and costs by end-use and (for space heating and cooling) individual components such as ceilings, walls and windows. Statewide, costs for space-conditioning and lighting—which are the end-uses that are most strongly affected by energy codes and building practices—make up less than half of total energy costs (Figure 12). This inherently limits the extent to which state energy code—which mainly affects space-conditioning loads and hard-wired lighting—can further affect overall energy costs.

Figure 12. Aggregate statewide end-use contributions to energy costs.



It is also informative to examine component contributions to heating and cooling loads, meaning the amount of energy that must be delivered to indoor spaces to make up for losses through ceilings, walls, windows, etc. This view is agnostic to the type, fuel source and efficiency of the equipment that provides heating and cooling to the home and is solely concerned with the amount of energy that must be provided due to energy losses (or gains) through various surfaces of the home and internally-generated heat. From this perspective, the modeling suggests that codes and building-shell-oriented programs can address most of the components that make up heating loads, but only windows make up a large enough proportion of cooling loads to offer a pathway to additional savings for space cooling (Figure 13).

Figure 13. Aggregate component contributions to space heating and cooling loads (weighted population estimates).

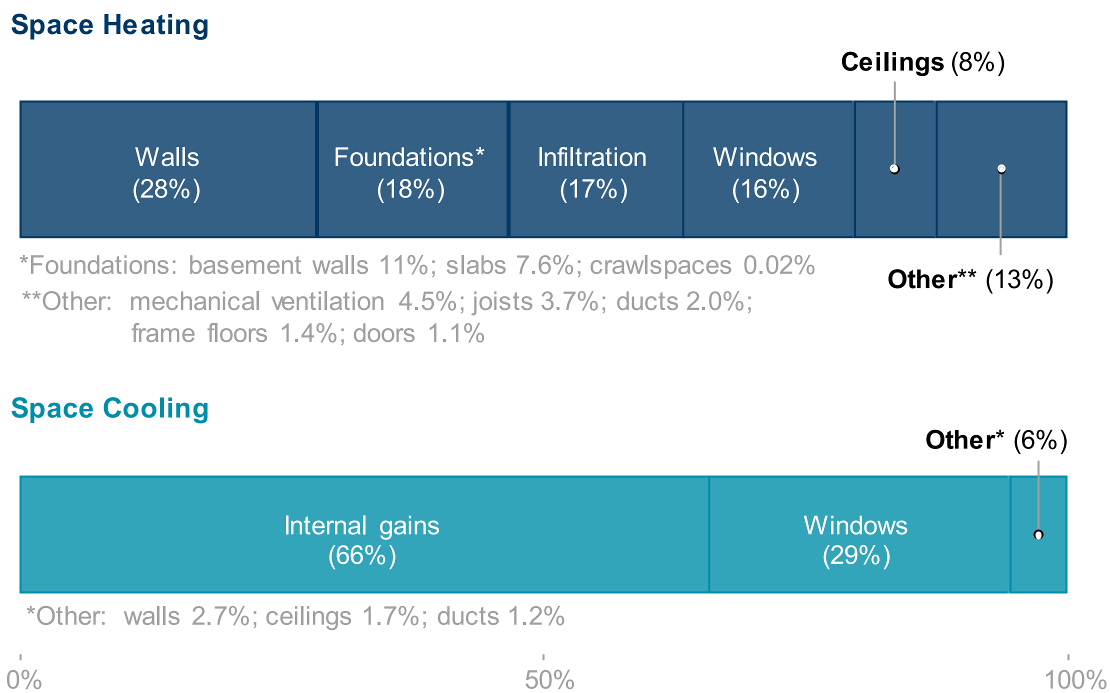
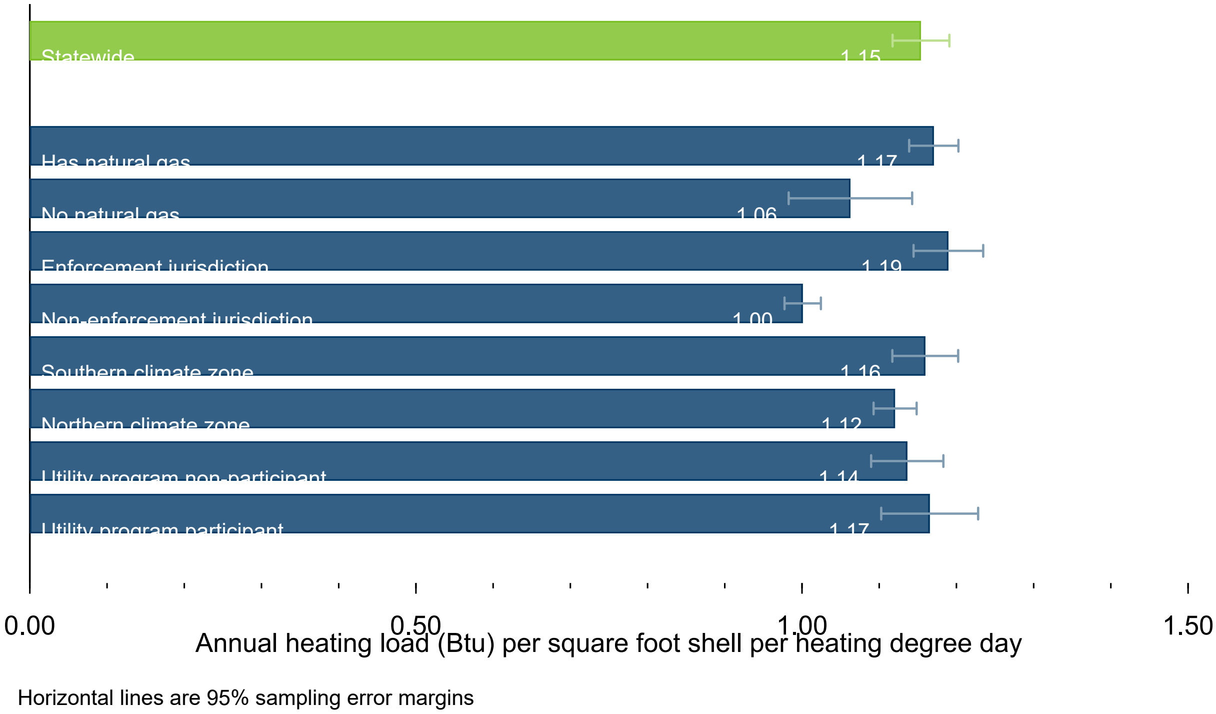


Figure 14 looks at how heating load intensity—expressed as annual Btus of heating that must be provided to the home per square foot of building shell per heating degree day—varies among the subgroups. This removes differences in equipment efficiency and climate and focuses on differences in thermal shell performance. Aside from the somewhat curious result of noticeably lower heating-load intensity for homes in non-enforcement areas, there is little difference among the subgroups. It bears noting that this includes utility program participants versus non-participants, which would seem to suggest that utility programs do not directly result in higher-performance thermal shells than standard practice among Minnesota home builders. But as we discuss later, it is also possible that these programs have had an indirect role in raising the level of standard practice throughout the state. This study was not designed to assess that possibility, however.

Figure 14. Heating load intensity (weighted population estimates).



As-Built Energy Performance Relative to Prescriptive Energy Code

We used the as-built model for each home to evaluate its energy performance relative to prescriptive energy code requirements in two ways. First, we compared as-built consumption and costs to an alternative version of each home where all values were set exactly to prescriptive code levels. Second, we compared the as-built model to results for an alternative version that allowed any beyond-prescriptive-code items to stay as-is but corrected any below-code items to meet energy code.

For example, if a home was found to have R-44 ceiling insulation, both analyses would compare energy use for the as-found condition to an alternative version of the home with the prescriptive-code R-49. However, if the home was found to have R-60 ceiling insulation, the first analysis would reset ceiling insulation to R-49 and thus show some savings for the higher-than-required ceiling insulation; the second analysis would leave the beyond-prescriptive-code insulation level as-is, and thus show no lost savings for below-code ceiling insulation.

We pause here to note that there are some similarities with modeling to assess performance-path code compliance, but our analysis here does not consider some details required for a full performance-path analysis, such as window distribution and total area. Also, there are some differences in how we modeled prescriptive-code effective insulation R-values: Appendix E: Prescriptive-Code Modeling Details provides more details about these. Finally, we note here that residential energy codes generally do not address equipment efficiency as these are set by federal efficiency standards: for all but the beyond-prescriptive-code scenario that we cover later, the analyses here leave all equipment at the as-found efficiency levels.

The results of the first analysis (as-built compared to exactly-at-code) suggests that 75 percent of new Minnesota homes perform *better* than prescriptive energy code minimums, with the average home using about 7 percent less space-heating energy and having overall energy costs that are about 3.5 percent less than the same home would have if it was built exactly to prescriptive-code levels (Table 4). These results do not vary strongly across subgroups. As we will show later in the report, this result is largely attributable to the fact that most homes are considerably tighter than the maximum air leakage allowed by code. In addition, nearly all homes have windows that perform better than the prescriptive-code requirement.

Table 4. As-built modeled energy performance relative to performance if built exactly to prescriptive code (weighted population estimates).

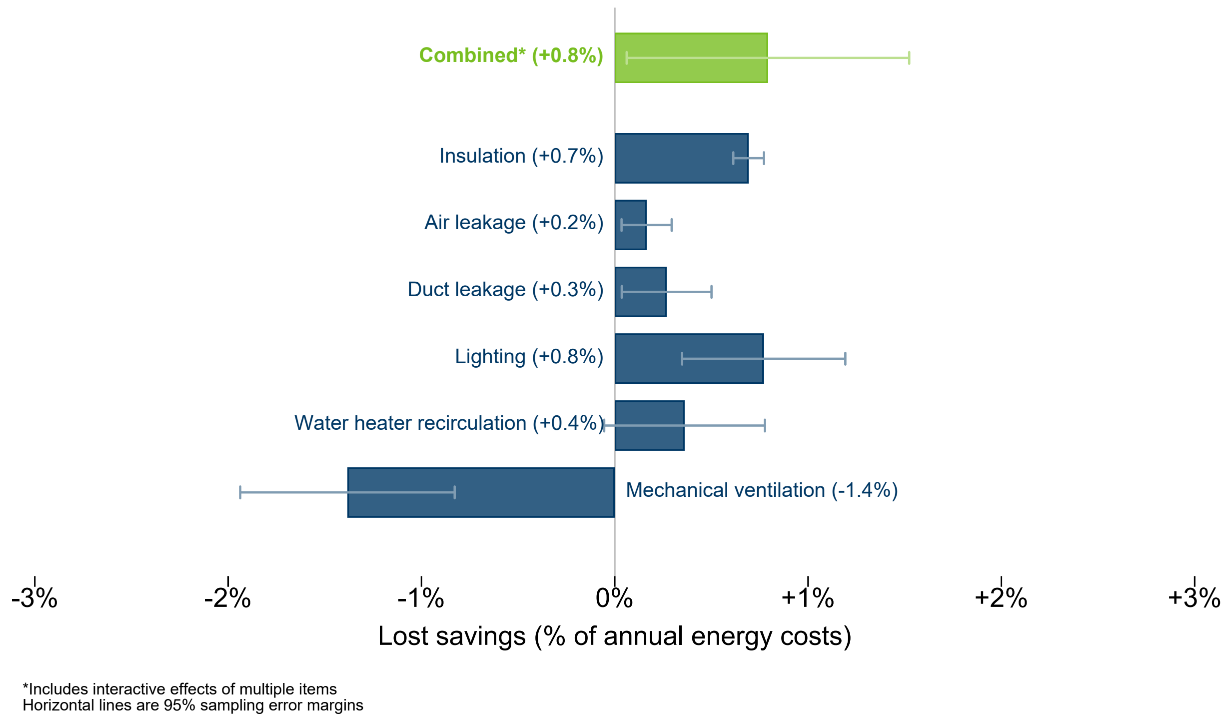
Group	Heating load (% difference from code-minimum)	Cooling load (% difference from code-minimum)	Annual energy cost (% difference from code-minimum)
Statewide	**-6.7%**	**-0.9%**	**-3.4%**
Has natural gas service	-6.4%	-1.8%	-3.3%
No natural gas service	-8.7%	+4.1%	-3.8%
Enforcement jurisdictions	-7.0%	-1.4%	-3.3%
Non-enforcement jurisdictions	-5.7%	+0.9%	-3.8%
Southern climate zone	-7.0%	-1.6%*	-3.4%
Northern climate zone	-5.2%	+3.2%*	-3.2%
Utility program non-participants	-6.8%	+0.9%*	-3.0%
Utility program participants	-7.2%	-3.4%*	-4.1%

*Subgroup differences are statistically significant at a 95% confidence level.

In terms of the second analysis (lost savings for below-code items), we evaluated the study sample for a number of potential lost-savings measures, including: insulation levels, air leakage, duct leakage, window thermal performance, mechanical ventilation, water heating recirculation and lighting. As described later, there is some uncertainty in some of the insulation items due to imperfect ability to observe the as-built condition. Also, for mechanical ventilation we did not attempt to model these systems as actually operated but rather made the simplifying assumption that when present and functional they were operated at the energy code-required ventilation rate.

Relative to the as-built condition, the results suggest that lost savings from homes being constructed below prescriptive energy code have less than a two percent impact on energy bills on average (Figure 15). While there are small savings to be had for various energy code items, about half of these total potential savings are offset by increases in energy costs associated with homes that do not meet the energy code's mechanical ventilation requirements, which largely stems for lack of certain controls that would otherwise increase the electricity consumption for mechanical ventilation—while also making the ventilation more effective. (We documented a high prevalence of issues related to mechanical ventilation in the sample homes: these are detailed later in this report.)

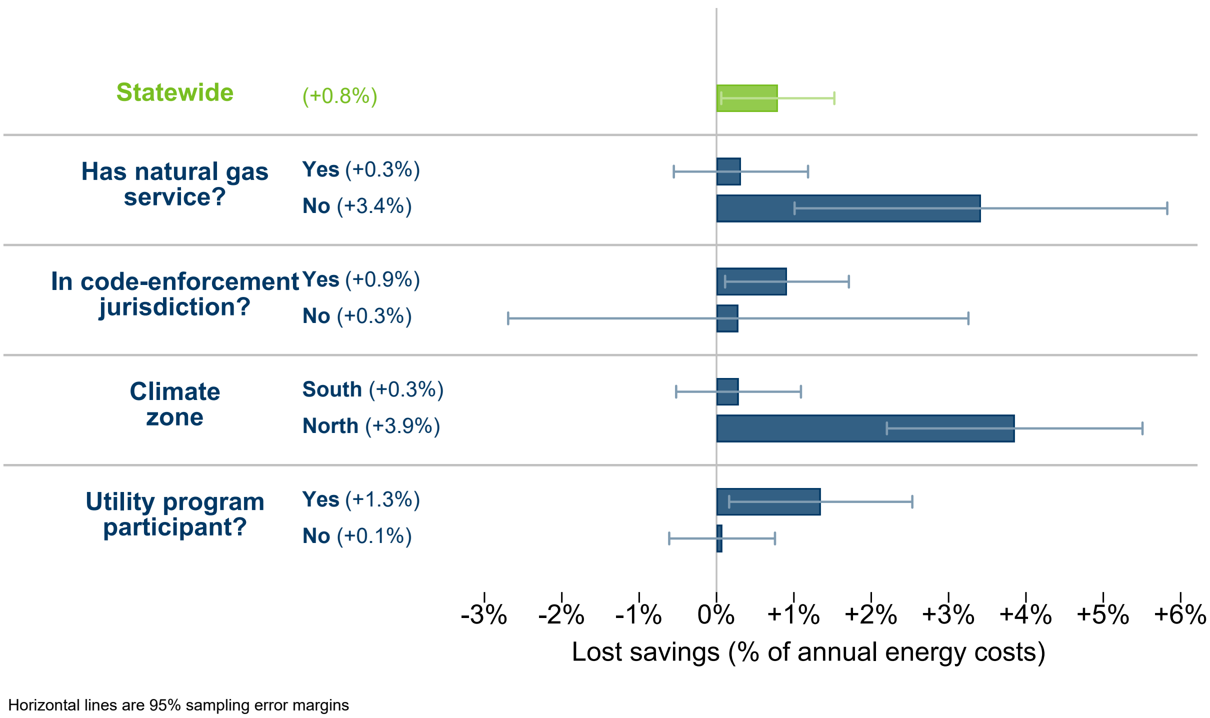
Figure 15. Aggregate average lost energy-cost savings relative to prescriptive energy code (weighted population estimates). Negative values mean higher energy costs for bringing homes up to prescriptive code.



It is also noteworthy that the magnitude of these lost savings are generally small for individual homes in the study sample as well. While we flagged many homes as having at least one item that was below prescriptive energy code, no home in the study showed overall lost energy-cost savings of more than 6 percent. Thus, while many homes are technically below prescriptive energy code levels in various ways, the energy implications of these issues appear to be small.

There is some indication that lost savings are higher in the northern climate zone and among homes without natural gas service (Figure 16). In terms of code-enforcement, however, the wide error bars associated with homes in non-enforcement areas preclude making conclusions about differences.

Figure 16. Average lost energy-cost savings relative to prescriptive energy code, by subgroup (weighted population estimates).



Beyond-prescriptive-code Savings Potential

We modeled the potential energy and energy-cost savings associated with 20 beyond-prescriptive-code measures, 15 of which we report on here.[6] For the most part, these measures represent the most efficient condition that we encountered in the study sample, and the analysis thus represents the potential savings from building all homes to these levels. For example, three homes in study sample had triple-pane windows, so our assessment considers the savings that could be achieved if all homes in the state were built with triple-pane windows. In this sense, the analysis provides a measure of technical potential: that is, the total savings that could be realized if all measures were implemented in all homes (where technically feasible). It is beyond the scope of the study to assess cost effectiveness or market potential for these measures. However, with a few exceptions, the measures that we considered are largely already being implemented in at least some homes, so moving toward this potential is mainly a matter of increasing market share and not overcoming technical or supply-chain barriers.

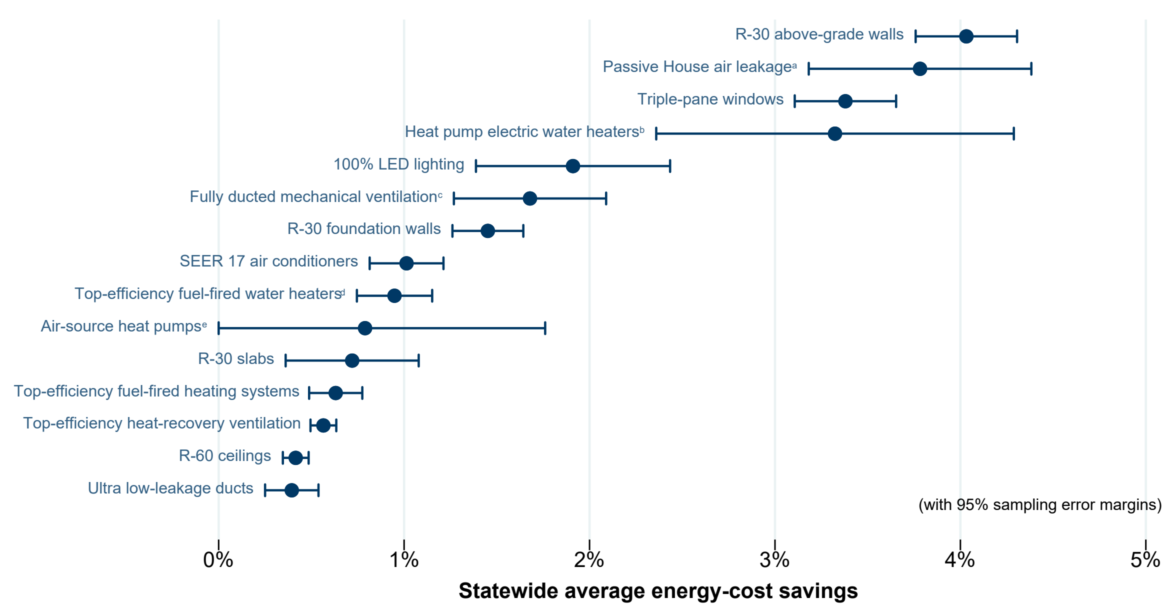
Unlike the prior analysis, for beyond code savings potential, we *do* consider upgrades to the efficiency of equipment such as furnaces, air conditioners and water heaters beyond what is currently being installed. However, in keeping with current CIP policy, we did not consider any fuel-switching measures.

[6] The measures omitted in this section are variants and alternatives that we considered for inclusion; they are covered in more detail later in this report.

In each case, we modeled the potential savings from installing the efficient alternative relative to either the as-built condition of the home or to prescriptive code if the home was found to be below prescriptive code. In other words, the beyond-prescriptive-code savings reported here are incremental to the lost savings reported in the previous section.

The modeling shows between about 0.5 and 4% energy-cost savings for individual measures (Figure 17) and about 24 percent savings potential collectively (Figure 18). Statewide, this potential for each year's crop of 13,500 new homes[7] translates into more than $7 million annually in energy cost savings—or, in terms of utility-program savings potential about 33 million kWh and 4.2 million therms of natural-gas savings potential (Table 5) . Top measures are R-30 walls, which can be achieved with structural insulated panel (SIP) or insulated concrete form (ICF) construction; aggressive air sealing to Passive-House levels; triple pane windows; and, heat pump water heaters for the 30 percent of new homes that have conventional electric water heaters installed. The energy-cost savings potential is higher among homes in the north and without natural gas, partly because of a higher incidence of electric resistance space-heating and water heating.

Figure 17. Beyond-prescriptive-code savings potential.



[a] 0.5 ACH50
[b] Value shown is average across all homes. Mean energy-cost savings is 11.2% for the 30% of homes with electric water heaters
[c] Avoids need for main air handler operation witch mechanical ventilation
[d] Value shown is average across all homes. Mean energy-cost savings is 1.3% for the 70% of homes with fuel-fired water heaters
[e] Instead of resistance electric heat. Value shown is average across all homes. Mean energy-cost savings is 12.5% for the 6% of homes with electric-resistance space heat

[7] The number of new homes built each year varies (see Figure 2); 13,500 represents a rounded average of Census data on housing starts for 2017 and 2018. It could well go down due to COVID 19.

Figure 18. Estimated average total energy-cost savings potential for all beyond-prescriptive-code measures combined.

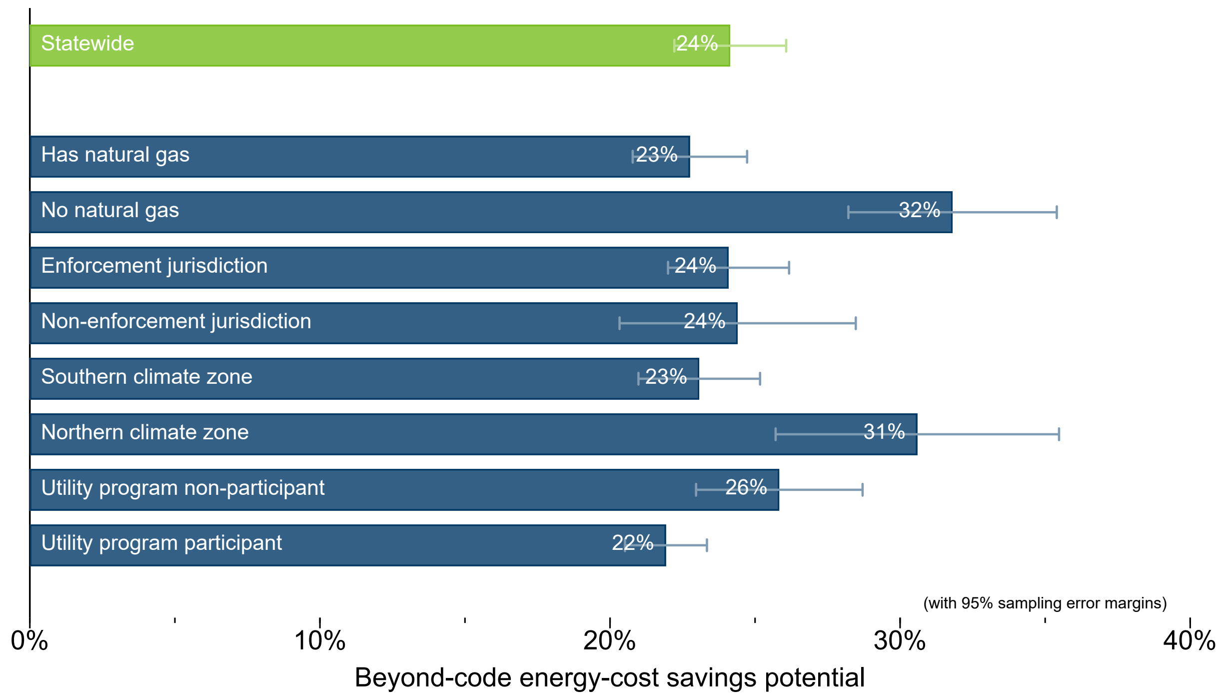


Table 5. Statewide beyond-prescriptive-code potential savings (weighted population estimates).

Measure	Total energy-cost savings ($/yr)	Total electricity savings (kWh/yr)	Total natural gas savings (therms/yr)
All measures combined[a]	**$7,198,000**	**31,648,000**	**4,234,000**
R-30 above-grade walls	$1,193,000	1,810,000	1,134,000
Passive house air leakage	$1,123,000	1,386,000	1,125,000
Heat pump electric water heaters	$1,072,000	11,052,000	-117,000
Triple-pane windows	$1,020,000	2,031,000	850,000
100% LED lighting	$561,000	5,446,000	-62,000
Top-efficiency heat-recovery ventilation	$464,000	4,335,000	-30,000
R-30 foundation walls	$406,000	150,000	451,000
Air-source heat pumps	$307,000	2,876,000	0
SEER 17 air conditioners	$289,000	2,360,000	0
Top-efficiency fuel-fired water heaters	$247,000	295,000	287,000

Measure	Total energy-cost savings ($/yr)	Total electricity savings (kWh/yr)	Total natural gas savings (therms/yr)
R-30 slabs	$217,000	579,000	158,000
Top-efficiency fuel-fired heating systems	$184,000	0	247,000
Fully ducted mechanical ventilation	$171,000	250,000	151,000
R-60 ceilings	$121,000	259,000	102,000
Ultra-low-leakage ducts	$119,000	338,000	92,000

[a]Includes effects of interaction between measures, so values are slightly less than the sum of individual measures.

Detailed Findings

In the many subsections that follow, we dive fully into the details about the energy code requirements, observed characteristics for the study sample and modeled savings potential for individual components and equipment in new single-family Minnesota homes.

Home size

Conditioned floor area for homes in the sample ranged from 1,200 ft^2 to 6,050 ft^2. On a weighted basis, northern homes tend to be smaller than southern homes. Otherwise, there appears be little difference across various subgroups.

Table 6. Mean home areas and volume (weighted population estimates).

Group	Mean stories	Mean conditioned floor area (ft^2)	Mean shell area (ft^2)	Mean conditioned volume (ft^3)
Statewide	**1.9**	**3,530**	**7,170**	**32,200**
Has natural gas service	1.9	3,590	7,200	32,600
No natural gas service	1.5	3,210	7,020	29,700
Enforcement jurisdictions	2.0*	3,560	7,170	32,300
Non-enforcement jurisdictions	1.3*	3,400	7,160	31,500
Southern climate zone	1.9	3,650*	7,270	33,300*
Northern climate zone	1.6	2,780*	6,540	25,700*
Utility program non-participants	1.8	3,420	7,100	31,500
Utility program participants	2.0	3,610	7,210	32,700

*Subgroup differences are statistically significant at a 95% confidence level.

Ceiling Insulation

Energy Code Requirements

Minnesota prescriptive code requires ceilings to be insulated to R-49, though this requirement is reduced to R-38 if raised-heel truss construction is used to allow full-depth insulation to be installed over the tops of the exterior walls. Enclosed ceilings that cannot meet these requirements due to limited cavity space must be insulated to at least R-30—and no more than 500 ft^2 or 20 percent (whichever is less) of the total ceiling area can be at this reduced insulation level.

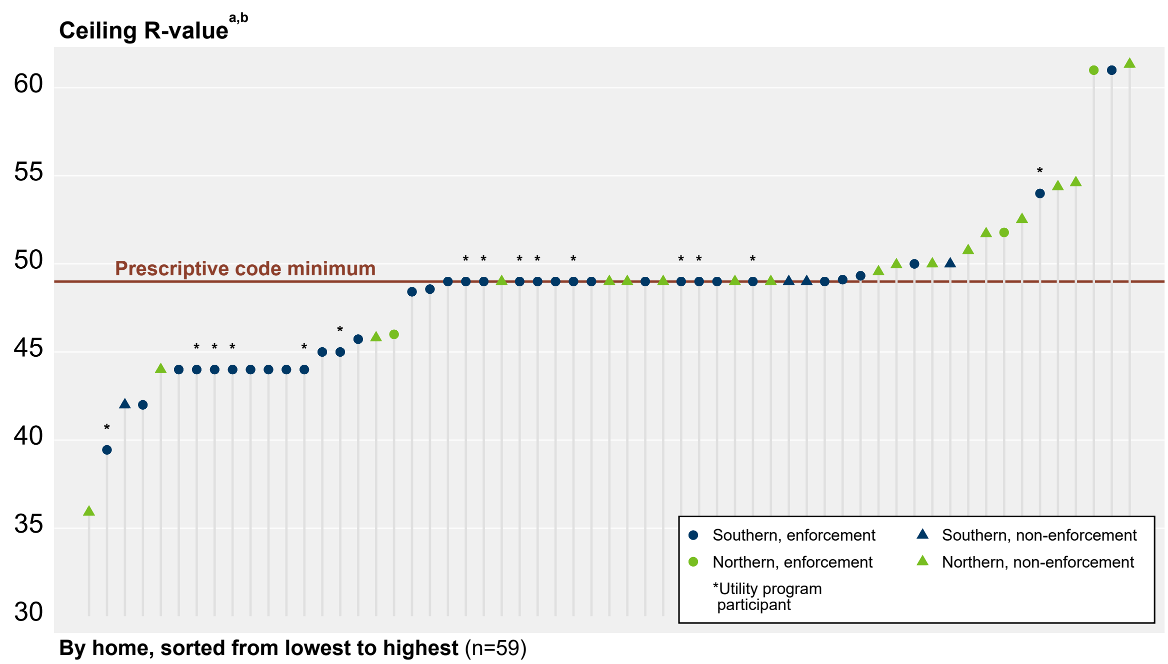
It is also notable that the U-factor path for code compliance specifies that ceiling assembly U-factors may not exceed 0.026, which is comparable to a ceiling insulation level of R-38.

Observed Characteristics

The study sample suggests that the average new home has about 1,700 ft^2 of ceiling area (Table 7), implying about 23 million square feet of ceiling space constructed annually around the state. Almost all this ceiling area is open-attic space, with only a tiny proportion constructed as enclosed vaulted or other ceiling spaces. All enclosed ceiling spaces encountered in the study sample occurred among northern homes in non-enforcement jurisdictions.

We were able to visually verify ceiling insulation for 59 homes with accessible attic spaces. Area-weighted average R-values for these ranged R-36 to R-61 (Figure 19).

Figure 19. Distribution of ceiling R-value for homes where ceiling insulation could be visually inspected.



[a]Inverse of area-weighted insulation U-value for all ceiling spaces
[b]For homes where attic spaces could be visually inspected

Building plans and code certificates provided information about insulation levels for another 20 homes: all of these indicated R-49 insulation. Infrared scans revealed a few homes with uninsulated attic hatches (Figure 20) or other small coverage issues (Figure 21). For homes where visual inspection was not possible, we imputed open-attic insulation levels to match to distribution found in homes that were inspected. Enclosed ceiling spaces were assumed to be insulated to listed nominal levels. This yielded a statewide average ceiling insulation of R-49 (Table 7).

Figure 20. Uninsulated attic hatch (Site 183).

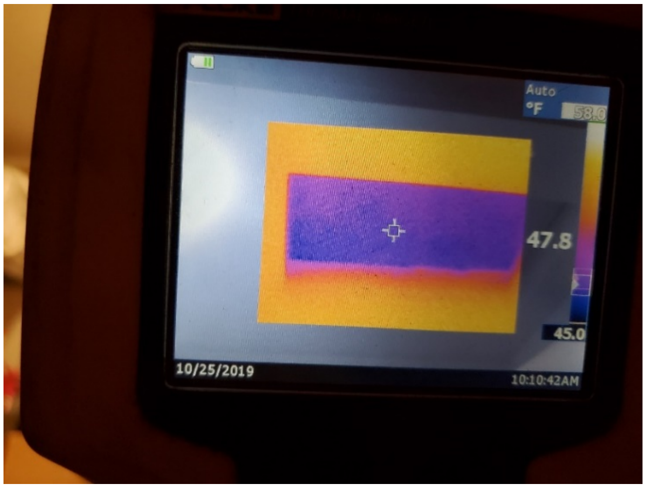


Figure 21. Small area of missing ceiling insulation (Site 127).

Table 7. Ceiling characteristics (weighted population estimates).

Group	Mean ceiling area (ft²)	Enclosed %[a]	Mean Insulation R-value[b,c]
Statewide	**1,680**	**2.0%**	**49.2**
Has natural gas service	1,640	0.1%*	48.6
No natural gas service	1,910	11.7%*	52.5
Enforcement jurisdictions	1,610	<1%	49.3
Non-enforcement jurisdictions	1,990	10.6%	48.6
Southern climate zone	1,660	<1%	48.7*
Northern climate zone	1,820	14.1%	52.1*
Utility program non-participants	1,750	3.4%	49.3
Utility program participants	1,580	<1%	48.8

[a]Percent of total ceiling area that is enclosed (i.e. not open attic)

[b]Inverse of per-home area-weighted insulation U-values.

[c]Based on: visual inspection (68%), bldg. plans (15%); code certificate (8%); assumed or homeowner self-report (9%). Non-inspected cases imputed to match distribution of observed cases.

*Subgroup differences are statistically significant at a 95% confidence level.

Lost Savings for Ceilings

The study sample suggests that about 30 percent of homes statewide have ceiling spaces with at least some areas where insulation is below the prescriptive energy code levels or where the area of enclosed, R-30 ceiling area exceeds the prescriptive code limits (Table 8). However, the average savings from bringing these fully up to prescriptive energy code is small because all homes in the sample were substantially insulated, even if somewhat below prescriptive code levels.

Table 8. Modeled lost savings from ceiling-insulation below prescriptive energy code (weighted population estimates).

Group	Lost savings incidence (% of homes)	Mean lost savings, % of total heating load	Mean lost savings, % of total cooling load	Mean lost savings, % of total htg/clg costs
Statewide	**31%**	**1.0%**	**0.6%**	**0.8%**
Has natural gas service	36%	0.9%*	0.5%	0.8%*
No natural gas service	8%	2.4%*	0.9%	2.3%*
Enforcement jurisdictions	33%	0.8%*	0.6%	0.7%*
Non-enforcement jurisdictions	26%	2.0%*	0.4%	1.7%*
Southern climate zone	35%	0.9%*	0.6%	0.8%*
Northern climate zone	9%	2.0%*	0.7%	2.0%*
Utility non-participants	36%	1.0%	0.6%	0.8%
Utility participants	27%	1.0%	0.5%	0.8%

(Non-interacted savings)
*Subgroup differences are statistically significant at a 95% confidence level.

Beyond-Prescriptive-Code Savings Opportunities for Ceilings

We modeled bringing all ceilings up to R-60. Because most ceilings are already highly insulated, the incremental savings are fairly small, even in terms of just space-conditioning costs (Table 9).

Table 9. Mean beyond-prescriptive-code savings for R-60 ceiling-insulation (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**1.5%**	**0.3%**	**19**	**9**	**1.2%**
Has natural gas service	1.5%	0.3%*	13	9	1.2%
No natural gas service	1.4%	0.1%*	54	—	1.4%

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Enforcement jurisdictions	1.3%*	0.3%	13	8	1.1%*
Non-enforcement jurisdictions	2.0%*	0.3%	44	13	1.8%*
Southern climate zone	1.4%	0.3%*	13	9	1.1%
Northern climate zone	1.9%	0.1%*	56	13	1.8%
Utility non-participants	1.6%	0.3%	28*	10	1.4%
Utility participants	1.3%	0.3%	7*	8	1.0%

(Non-interacted savings)
[a]For homes with natural gas service.

Above-Grade Walls

Prescriptive Energy Code Requirements for Above-Grade Walls

Minnesota prescriptive energy code requirements differ slightly between the southern (Zone 6) and northern (Zone 7) climate zones. In the southern zone, walls must either have R-20 cavity insulation or have at least R-13 cavity insulation plus R-5 continuous exterior insulation. In the northern zone, wall cavities must be insulated to R-21.

The above requirements apply to wood-framed walls. Walls constructed by other means, such as structural insulated panels (SIPs) or insulated concrete forms (ICFs) would likely be evaluated against the U-factor alternative code-compliance path, which has an upper limit on assembly U-value of 0.048. This is equivalent to an assembly R-value of about R-21. This is somewhat higher than the overall assembly R-value of a standard 2x6 wood frame wall with cavity insulation, which is generally in the range of R-16 to R-18, depending on the type of insulation used.

Observed Characteristics for Above-Grade Walls

Nearly all the homes in the sample were built with conventional 2x6 wood framing (Table 10). Most of these used 16-inch stud spacing, but three homes were built with 24-inch spacing. Only three conventional stud-frame homes had any continuous exterior insulation. The sample did include four homes that used structural insulated panel (SIP) construction, as well as one home with insulated concrete form (ICF) construction for above-grade walls.

Table 10. Above-grade wall characteristics (weighted population estimates).

Group	Mean gross [a] wall area (ft^2)	Mean net[a] wall area (ft^2)	% conventional 2x6 wood-frame construction	Mean assembly R-value[b]
Statewide	**2,550**	**2,150**	**97%**	**16.5**
Has natural gas service	2,630*	2,220*	99%	16.3*
No natural gas service	2,140*	1,750*	87%	17.6*
Enforcement jurisdictions	2,690*	2,270*	99%	16.4
Non-enforcement jurisdictions	1,950*	1,640*	89%	17.2
Southern climate zone	2,620*	2,220*	99%	16.4*
Northern climate zone	2,110*	1,730*	88%	17.5*
Utility program non-participants	2,400	2,010	97%	16.5
Utility program participants	2,740	2,320	98%	16.4

[a]Gross wall area includes windows and doors; net wall area excludes windows and doors

[b]Based on assumed framing factors for 16" and 24" O.C. framing and Grade I or Grade II installation quality, except where IR scans indicated Grade III. Cavity R-vaue assumed as climate-zone prescriptive level where not otherwise indicated.

*Subgroup differences are statistically significant at a 95% confidence level.

Because the site visits took place after construction was complete, it was generally not possible to observe cavity insulation details and installation quality for conventionally framed homes. We used nominal cavity insulation levels where noted on building plans (n=36) or code certificates (n=7) and used the climate-zone prescriptive levels of R-20 or R-21 where no other information was available.[8] Notably, 22 of 29 homes in the southern climate zone were shown as having R-21 cavity insulation on plans or code certificates even though the prescriptive energy code calls for only R-20 in that region. Exterior continuous insulation was visually verified, though, as noted above, this was rare in the sample

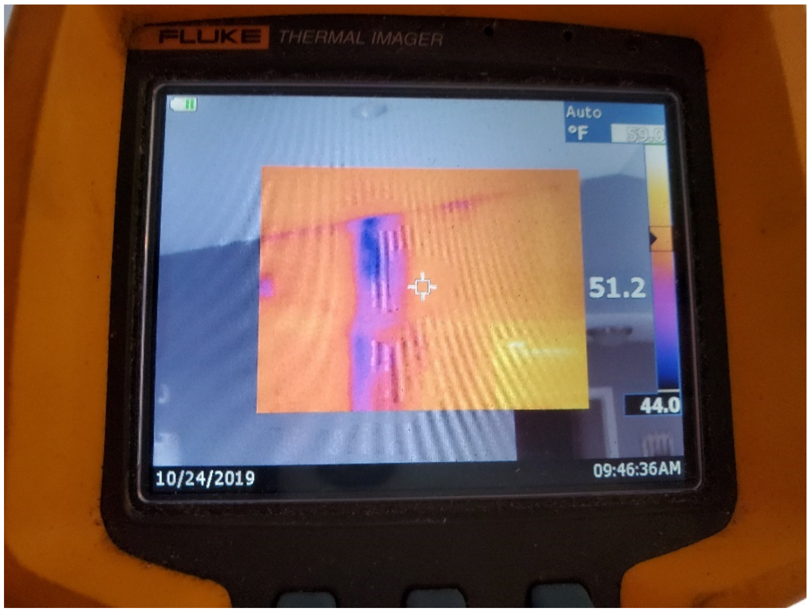
Insulation installation quality is graded as Grade 1, Grade 2 or Grade 3, with the first denoting insulation that is properly installed per manufacturer's specifications, the second allowing for moderate installation defects and the last denoting more serious defects.[9] From a modeling perspective, Rem/Rate's treatment of installation grade increases the heating load for walls by 10 to 11 percent when Grade 2 is selected instead of Grade 1 and by 18 to 19 percent for Grade 3. These penalties translate to about 4 percent - 6.5 percent, respectively, for overall heating loads, since above-grade walls make up only a portion of a home's heating load.

[8] The choice of R-19, R-20 or R-21 cavity insulation has little impact on modeled energy consumption in REM/Rate.

[9]These grades have more precise definitions that go beyond the discussion here.

Infrared (IR) scans conducted for most of the sampled homes revealed few significant installation issues with wall insulation—though IR scans by themselves cannot readily be used to grade installation quality. We did observe some notable coverage issues in two homes, one of which is shown in Figure 22.

Figure 22. Example of a wall-insulation coverage issue (Site 182).

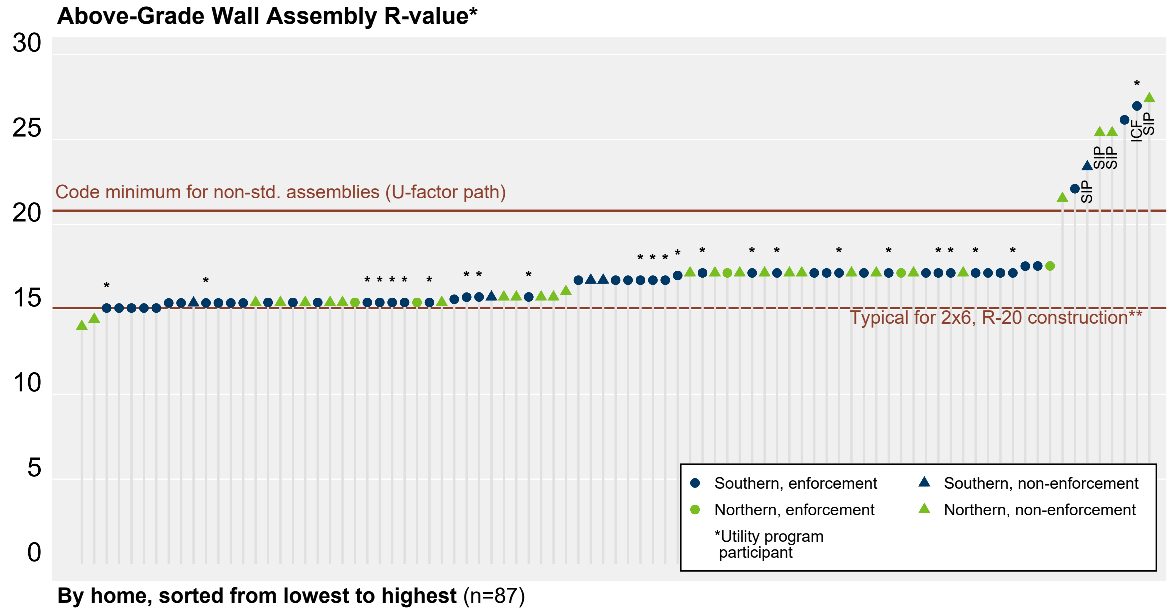


For analysis purposes, we assigned Grade 3 installation quality to the two homes with observable defects, and then randomly assigned Grade 1 and Grade 2 installation quality to all other homes with wood-framed walls. This middle-of-the-road approach thus carries about two percentage points of uncertainty in total heating loads related to unobservable wall-insulation installation quality.[10]

This approach led to modeling most homes as having an assembly R-value in a narrow range around the prescriptive energy code minimum levels for conventional wood-frame construction (Figure 23). The SIP and ICF homes—and three conventional wood-frame homes with higher insulation levels—stand apart with significantly higher assembly R-values.

[10] In other words, overall heating loads would be about two percent higher if all homes were assigned Grade 2 installation quality and two percent lower if all homes were assigned Grade 1.

Figure 23. Above-grade wall assembly R-value distribution



*Based on assumed framing factors and Grade I or Grade II cavity insulation for conventional stud-frame construction, except where IR scans indicated Grade III
**2x6, 16 in. OC; 25% framing factor; R-20 cavity insulation (Grade II); no exterior insulation
SIP = structural insulated panel; ICF = insulated concrete form

Lost Savings for Above-Grade Walls

The study sample suggests that nearly all new homes substantially meet the prescriptive energy code minimums for wall insulation. To the extent that they do not, it is likely due to installation issues that are difficult to observe after construction is complete. On average, the modeling suggests potential for about a 3 percent reduction in heating and cooling costs associated with bringing (mostly) Grade 2 insulation quality up to Grade 1 (Table 11). Because we observed very few cases where Grade 3 installation quality might be warranted and arbitrarily assigned Grade 2 installation quality to half of the remaining cases, subgroup results are not meaningful here.

Table 11. Modeled lost savings from sub-optimal above-grade wall insulation (weighted population estimates).

Group	Lost savings incidence (% of homes)	Mean lost savings, % of total heating load	Mean lost savings, % of total cooling load	Mean lost savings, % of total htg/clg costs
Statewide	**51%**	**3.5%**	**0.3%**	**2.9%**

(Non-interacted savings)

Beyond-Prescriptive-Code Savings Opportunities for Above-Grade Walls

We considered several potential beyond-prescriptive-code opportunities for above-grade walls. First, we examined how adding R-5 or R-10 (i.e. one or two inches) of continuous exterior insulation to conventional stud-frame walls would reduce heating and cooling energy requirements. We also looked at the potential savings for R-30 SIP or ICF wall assemblies.[11] The results (Table 12, Table 13 and Table 14) suggest roughly 7 to 12 percent savings potential on space-conditioning costs for these improvements.

Table 12. Mean beyond-prescriptive-code savings for adding R-5 exterior continuous insulation to above-grade walls (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**8.8%**	**0.7%**	**79**	**58**	**7.1%**
Has natural gas service	9.0%*	0.8%*	53	58	7.1%
No natural gas service	7.8%*	-0.6%*	239	—	7.4%
Enforcement jurisdictions	9.0%	0.9%*	59	60	7.2%
Non-enforcement jurisdictions	7.9%	-0.4%*	175	45	6.8%
Southern climate zone	9.0%*	1.0%*	57	59*	7.1%
Northern climate zone	7.8%*	-1.7%*	228	47*	7.1%
Utility non-participants	8.6%	0.4%*	108	56	7.2%
Utility participants	9.2%	1.0%*	40	61	7.1%

(Non-interacted savings)
[a]For homes with natural gas service.
*Subgroup differences are statistically significant at a 95% confidence level.

Table 13. Mean beyond-prescriptive-code savings for adding R-10 exterior continuous insulation to above-grade walls (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**13.6%**	**1.0%**	**121**	**90**	**10.9%**
Has natural gas service	13.8%*	1.3%*	81	90	10.9%
No natural gas service	12.0%*	-1.0%*	369	—	11.3%
Enforcement jurisdictions	13.9%	1.3%*	90	93	11.1%
Non-enforcement jurisdictions	12.1%	-0.7%*	270	70	10.4%

[11] Higher R-values are possible for SIP and ICF construction, but R-30 represents a more reasonable stretch beyond what we found for the few homes in the sample that used these assemblies.

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Southern climate zone	13.8%*	1.5%*	86	91	10.9%
Northern climate zone	12.2%*	-2.6%*	353	73	11.0%
Utility non-participants	13.2%	0.6%*	165	86	11.0%
Utility participants	14.2%	1.6%*	62	94	11.0%

(Non-interacted savings)
[a]For homes with natural gas service.
*Subgroup differences are statistically significant at a 95% confidence level.

Table 14. Mean beyond-prescriptive-code savings for R-30 SIP/ICF above-grade wall assembly (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**14.8%**	**1.1%**	**134**	**99**	**11.9%**
Has natural gas service	15.2%*	1.4%*	90	99	12.0%
No natural gas service	12.1%*	-1.0%*	378	—	11.4%
Enforcement jurisdictions	15.3%*	1.5%*	99	102	12.2%
Non-enforcement jurisdictions	12.4%*	-0.7%*	286	78	10.7%
Southern climate zone	15.2%*	1.7%*	95	100	12.0%
Northern climate zone	12.4%*	-2.6%*	369	82	11.2%
Utility non-participants	14.4%	0.6%*	183	96	12.0%
Utility participants	15.7%	1.7%*	69	103	12.1%

(Non-interacted savings)
[a]For homes with natural gas service.
*Subgroup differences are statistically significant at a 95% confidence level.

Foundation Walls and Slabs

Energy Code Requirements for Foundations

Minnesota prescriptive energy code requires the walls for conditioned basements (and crawlspaces) to be insulated to R-15, with at least R-10 of that on the exterior and no more than R-11 on the interior unless the interior insulation is spray foam.[12] However, the overall insulation requirement can be reduced to R-10 for homes with reduced air leakage and meeting certain foundation geometry requirements.[13] Slab-on-grade construction requires R-10 insulation to a depth of 3.5 feet (Zone 6) or 5 feet (Zone 7)—or to the top of the foundation footing, if it is less.

Observed Foundation Characteristics

The study sample indicates that while most new homes are built over conditioned basements, a significant minority of northern homes are slab-on-grade construction (Table 15). Five homes in the study had crawlspace foundations: four of these were enclosed crawlspaces where the crawlspace walls are insulated and the floor above is not; the fifth had an uninsulated crawlspace below an insulated floor.

Table 15. Dominant foundation type (weighted population estimates).

Group	Conditioned Basement[a]	Slab on grade	Conditioned crawlspace	Unconditioned crawlspace
Statewide	**87%**	**12%**	**1%**	**0%**
Has natural gas service	90%	10%	<1%	<1%
No natural gas service	70%	24%	5%	1%
Enforcement jurisdictions	91%	9%	<1%	<1%
Non-enforcement jurisdictions	70%	25%	4%	1%
Southern climate zone	92%*	8%	<1%	<1%
Northern climate zone	55%*	39%	6%	1%
Utility program non-participants	77%*	21%*	1%	0%
Utility program participants	99%*	1%*	<1%	<1%

n=87

[a]Includes walk-out basements and basements that are fully below-grade

Slabs can be separated into several subtypes:

- Fully slab-on-grade
- Walk-out basements that are at grade on one side and below grade on the other
- Basement or crawlspace slabs that are fully below grade

---

[12] We exclude here the uncommon situation of wood foundation walls.

[13] Specifically, for R-10 foundation insulation to be applicable, tested air leakage must be less than 2.6 ACH50 and the foundation wall area that is above grade must be less than 1.5 times the perimeter length of foundation walls that enclose conditioned space.

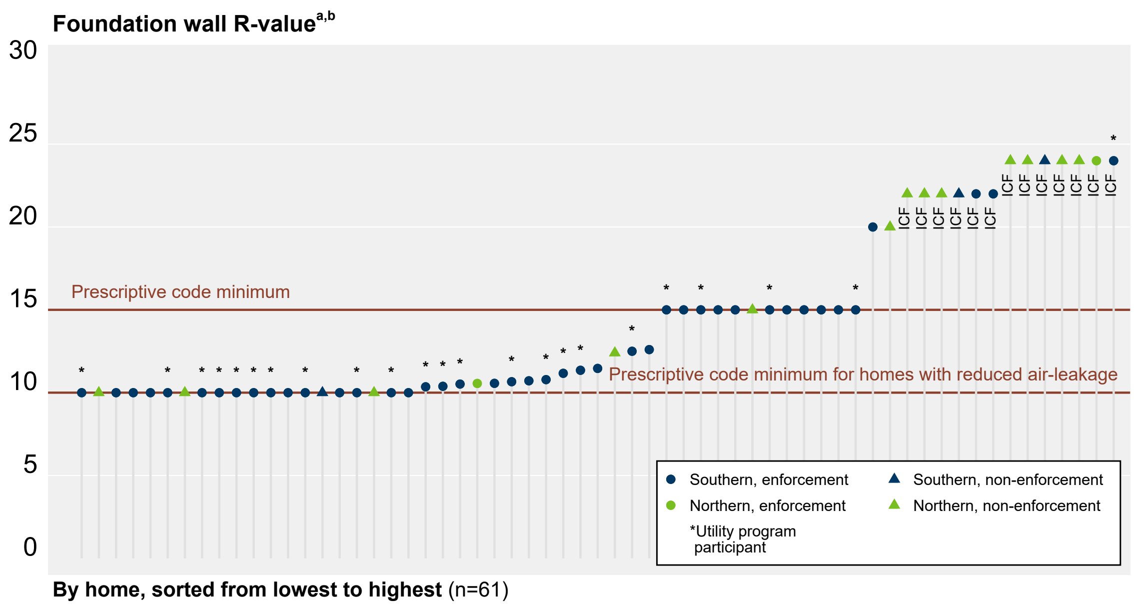
Further, slabs may be heated or unheated, the former meaning that the slab has hydronic piping embedded in it as part of a radiant space-heating strategy. Northern homes are much more likely to have fully on-grade slabs and have slabs that are heated (Table 16).

Table 16. Slab types and whether heated (weighted population estimates).

Group	Type: fully on-grade	Type: walkout basement	Type: fully below-grade	Heated
Statewide	**12%**	**27%**	**62%**	**16%**
Has natural gas service	10%	27%	64%	12%
No natural gas service	24%	26%	50%	41%
Enforcement jurisdictions	9%	30%	61%	7%*
Non-enforcement jurisdictions	26%	13%	62%	53%*
Southern climate zone	7%	27%	66%	10%*
Northern climate zone	39%	26%	35%	54%*
Utility program non-participants	21%	22%	57%	26%*
Utility program participants	<1%	33%	67%	2%*

n=86

Figure 24. Foundation wall R-value



[a] Area-weighted sum of interior and exterior insulation
[b] Based on: visual verification (62%), plan review (21%), code certificate (16%)

ICF = insulated concrete form

As shown in Figure 24, foundation wall insulation in the sample generally falls into three clusters: about R-10, R-15 and R-20 and higher. The first mostly comprises homes that meet the air-leakage requirements for reduced (R-10) foundation insulation. The second comprises homes that match the prescriptive energy code requirement. The third is almost entirely homes with ICF foundation walls.

Slab insulation is difficult to visually assess after construction, so values here are mostly derived from sites with plans or code certificates showing insulation levels. For unheated slabs, we confine the discussion to slab-on-grade homes and those with walk-out basements where at least part of the basement slab is at grade and where plans or the code certificate provided information about slab insulation levels. Of the 15 such non-radiant slabs in the sample, all but one had R-10 perimeter insulation and the single outlier showed R-5 insulation on the plans. Twelve of the fifteen had no under-slab insulation, two had R-10 and one had R-15.

Twenty-two homes in the study sample had radiant slabs, but only ten of these had plans that allowed slab insulation to be assessed. All showed R-10 under-slab insulation; five showed R-10 perimeter insulation and 5 showed higher (R-20 to R-25) levels.

Lost Savings Opportunities for Foundations

Lost-savings for foundation walls and slabs appear to be limited to homes with R-10 foundation walls that do not meet the air-leakage and foundation geometry code requirements for the reduced insulation level. This has a minor impact on energy costs for about one in ten homes (Table 17).

Table 17. Modeled lost savings from foundation-wall insulation below prescriptive energy code (weighted population estimates).

Group	Lost savings incidence (% of homes)	Mean lost savings, % of total heating load	Mean lost savings, % of total cooling load	Mean lost savings, % of total htg/clg costs
Statewide	**9%**	**3.4%**	**-2.0%**	**2.7%**
Has natural gas service	9%	3.0%	-0.7%*	2.3%
No natural gas service	11%	5.4%	-8.2%*	5.0%
Enforcement jurisdictions	9%	3.0%	-0.7%*	2.3%
Non-enforcement jurisdictions	9%	5.4%	-8.2%*	5.0%
Southern climate zone	9%	3.0%	-0.7%*	2.3%
Northern climate zone	12%	5.4%	-8.2%*	5.0%
Utility non-participants	3%*	5.4%	-8.2%*	5.0%
Utility participants	19%*	3.0%	-0.7%*	2.3%

(Non-interacted savings)

*Subgroup differences are statistically significant at a 95% confidence level.

Beyond-Prescriptive-Code Savings Opportunities for Foundations

We examined the potential savings for increasing foundation wall insulation to R-20 or R-30 as well as insulating slabs that are either on-grade or are part of a radiant system to these levels. The analysis suggests minimal electricity impacts and 25 to 40 annual therms of natural gas savings (Table 18 and Table 19).

Table 18. Mean beyond-prescriptive-code savings for R-20 foundation insulation (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**4.0%**	**-0.9%**	**5**	**26**	**2.9%**
Has natural gas service	4.2%	-0.9%	3	26	3.0%
No natural gas service	2.7%	-0.9%	22	—	2.4%
Enforcement jurisdictions	4.0%	-0.8%	5	26	2.9%
Non-enforcement jurisdictions	4.0%	-1.1%	8	28	3.0%
Southern climate zone	4.2%*	-0.8%	6	26	3.1%*
Northern climate zone	2.3%*	-1.3%	1	28	1.8%*
Utility non-participants	3.5%	-0.9%	7	21	2.6%
Utility participants	4.6%	-0.9%	3	28	3.2%

(Non-interacted savings)

[a]For homes with natural gas service.

*Subgroup differences are statistically significant at a 95% confidence level.

Table 19. Mean beyond-prescriptive-code savings for R-30 foundation insulation (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**6.2%**	**-1.4%**	**11**	**40**	**4.5%**
Has natural gas service	6.4%	-1.3%	4*	40	4.6%
No natural gas service	4.7%	-1.8%	52*	—	4.2%
Enforcement jurisdictions	6.3%	-1.3%	8	40	4.6%
Non-enforcement jurisdictions	5.5%	-1.8%	26	33	4.2%
Southern climate zone	6.6%*	-1.3%	9	40	4.8%*
Northern climate zone	3.6%*	-2.1%	25	35	2.9%*

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Utility non-participants	5.4%	-1.4%	16	32	4.1%
Utility participants	7.2%	-1.4%	5	45	5.1%

(Non-interacted savings)
[a]For homes with natural gas service.
*Subgroup differences are statistically significant at a 95% confidence level.

Floors and Rim/Band Joists

Energy Code Requirements for Floors and Rim/Band Joists

Minnesota Energy code requires R-30 insulation for floors that are exposed to outdoor conditions—unless the framing will not accommodate that level of insulation, in which case at least R-19 must be installed. Rim and band joist cavities must simply be air-sealed and insulated; there is no minimum R-value requirement for these.

Observed Characteristics for Floors and Band Joists

Exposed floors in the sample were about evenly divided between small cantilevered floors associated with minor building bump-outs and larger areas that were floors over unconditioned garages (Table 20). These enclosed spaces are difficult to visually assess post-construction but plans and code certificates (available in about half the cases) indicate that all were insulated to R-30 or, in a few cases, higher levels. The four homes in the sample with crawlspace foundations all had uninsulated floors with foundation wall insulation, as permitted by energy code.

Table 20. Insulated floor characteristics (weighted population estimates).

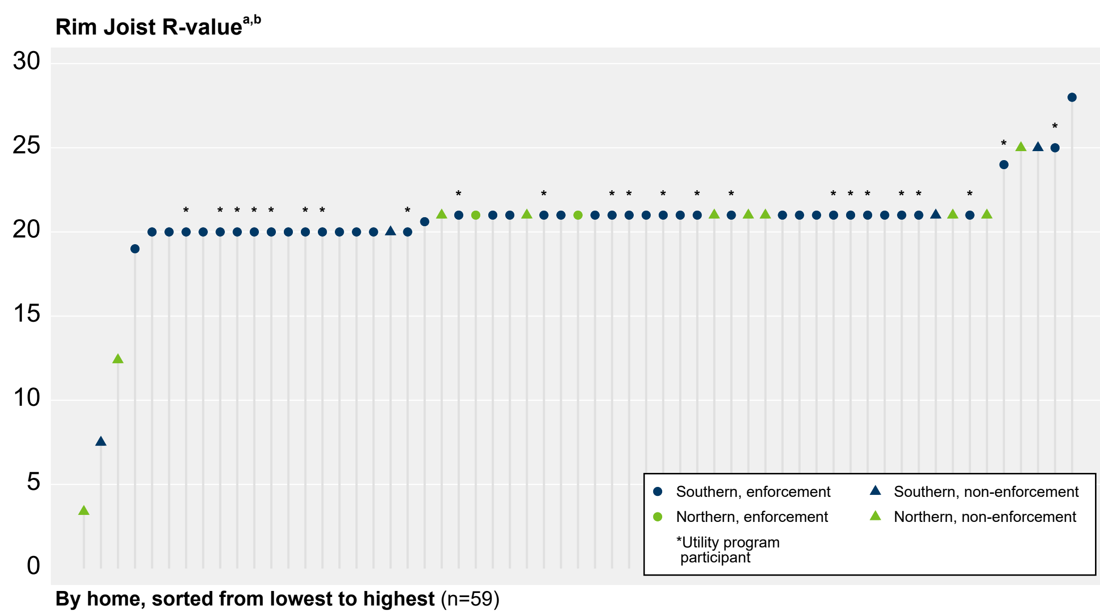
Group	% of homes with bump-out frame floor	Mean bump-out frame-floor area (ft^2)	% of homes with floor over garage	Mean floor area over garage (ft^2)
Statewide	**45%**	**38**	**43%**	**320**
Enforcement jurisdictions	46%	43	48%	300*
Non-enforcement jurisdictions	40%	24	21%	460*
Southern climate zone	53%*	42*	50%*	305
Northern climate zone	11%*	20*	14%*	425
Utility program non-participants	48%	41*	45%	300
Utility program participants	27%	18*	33%	405

About 8 in 10 homes in the sample had rim joist areas, the exceptions being single-story, slab-on-grade homes. These were typically found to be spray-foam insulated to about R-21, though a few homes had lower or higher levels of insulation (Table 21 and Figure 25). One home in the sample had some uninsulated joist areas.

Table 21. Rim joist characteristics (weighted population estimates).

Group	Mean rim/band joist area (ft²)	Mean rim/band joist R-value
Statewide	**290**	**20.0**
Has natural gas service	290	20.5
No natural gas service	300	17.9
Enforcement jurisdictions	290	20.8
Non-enforcement jurisdictions	290	16.4
Southern climate zone	290	20.4
Northern climate zone	310	17.2
Utility program non-participants	290	19.4
Utility program participants	280	20.7

Figure 25. Rim Joist Insulation.



[a]Inverse of area-weighted insulation U-value
[b]Based on: visual verification (76%), plan review (20%), code certificate (3%)

Lost Savings and Beyond-Prescriptive-Code Savings for Floor and Band Joist Insulation

We found no evidence of under-insulated frame floors or minimal uninsulated joist areas, so we did not ascribe lost savings to these. Further, since these spaces are not a large component of space conditioning loads, we did not consider them for beyond-prescriptive-code savings.

Air Leakage

Energy Code Requirements for Air Leakage

In addition to meeting a long list of specific air-sealing requirements related to various spaces and penetrations, Minnesota energy code requires homes to have a blower-door tested whole-home leakage rate of no more than 3 air changes per hour at 50 Pascals of induced pressure difference (ACH50).

Measured Air Leakage

We were able to conduct our own blower door test on all but one home in the study sample. Air leakage ranged from about 0.5 to more than 5.0 ACH50, with a statewide average of 1.88 ACH50 (Table 22 and Figure 26). The sample suggests that more than nine in ten homes in the state meet or exceed the 3 ACH50 code requirement and on average exceed it by more than a third. Although the sample shows somewhat higher tested air leakage among northern and non-enforcement homes, these differences are not statistically significant.[14]

Table 22. Air leakage characteristics (weighted population estimates).

Group	Mean air leakage (CFM50)	Mean air leakage (CFM50/ft² shell)	Mean air leakage (ACH50)	% of homes ≤ 3 ACH50
Statewide	**953**	**0.134**	**1.88**	**92%**
Has natural gas service	984	0.137	1.89	93%
No natural gas service	788	0.117	1.82	90%
Enforcement jurisdictions	952	0.133	1.82	94%
Non-enforcement jurisdictions	957	0.137	2.12	86%
Southern climate zone	978	0.135	1.83	95%
Northern climate zone	802	0.128	2.19	79%
Utility program non-participants	943	0.135	1.96	88%
Utility program participants	931	0.129	1.72	>99%

[14] The (95%) confidence intervals for mean ACH50 in Table 22 is ± 0.16 to 0.38, depending on the subgroup.

Figure 26. Air leakage for sample homes.

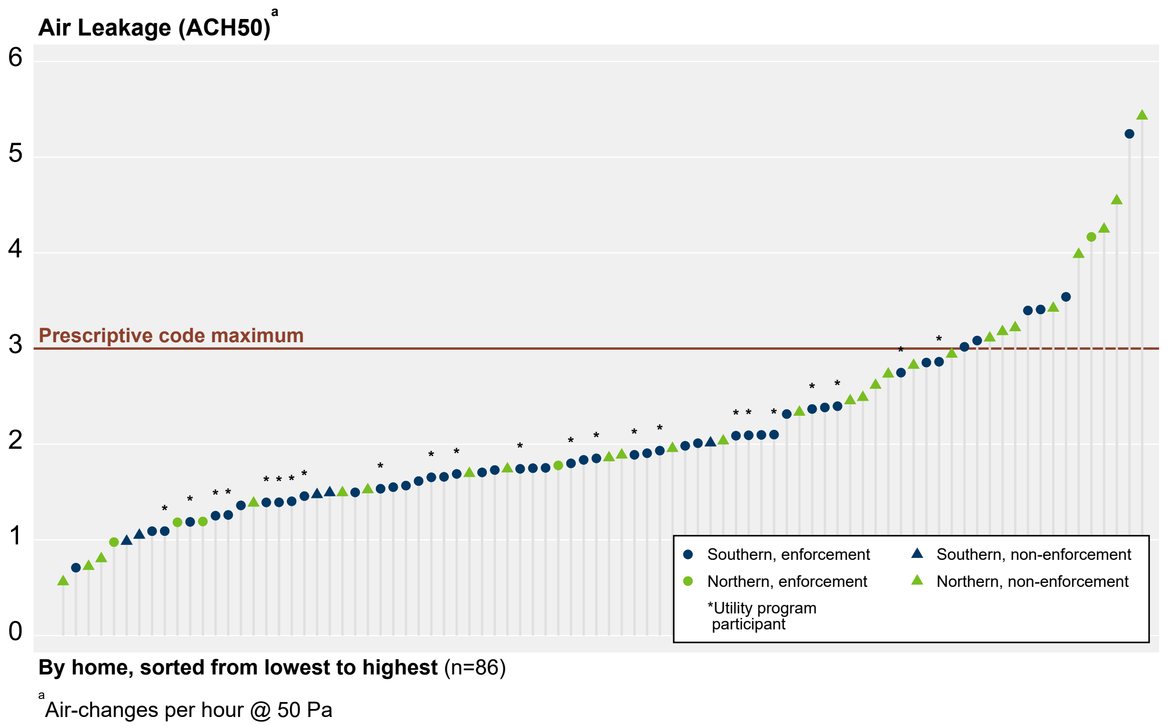
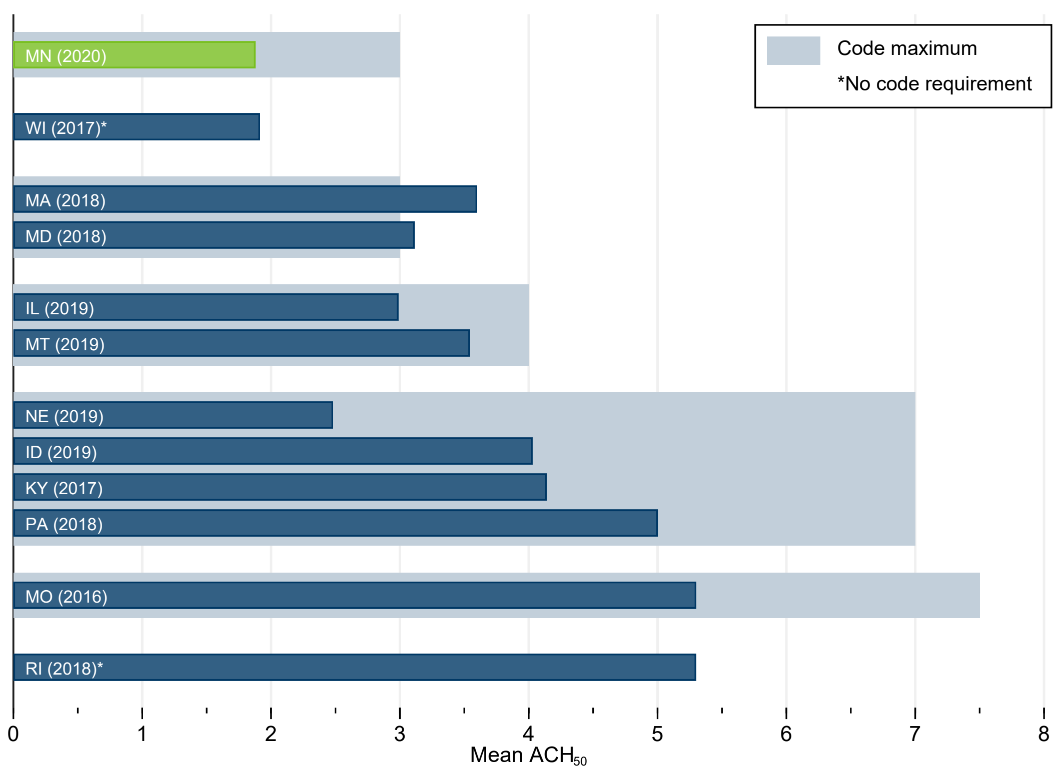


Figure 27. Air leakage comparison with other states.



The results here are very similar to findings from a similar study of non-program homes in Wisconsin that we conducted in 2017 (Pigg and Lord, 2017). Moreover, both states show average air leakage rates that are considerably below that found in energy and code studies in other cold-climate states (Figure 27). Wisconsin has no code requirement for tested air leakage yet shows the same average air leakage among non-program homes. Massachusetts and Maryland have significant new-homes program activity and have the same code requirement for air leakage yet show higher average air leakage. These contrasts suggest that air leakage rates may have as much or more to do with regional construction practices than energy code requirements or the influence of utility programs.

Lost Savings for Air Leakage

Lost savings for air leakage are derived from modeled savings for reducing air leakage from the tested value to the code maximum value of 3 ACH50 among homes in the sample that exceeded the energy code threshold. Statewide, we estimate about a 4 percent reduction in space-conditioning costs when the 7 percent of homes that are non-compliant are brought up to the code maximum leakage rate (Table 23).

Table 23. Modeled lost savings from air leakage above prescriptive energy code (weighted population estimates).

Group	Lost savings incidence (% of homes)	Mean lost savings, % of heating load	Mean lost savings, % of cooling load	Mean lost savings, % of htg/clg costs
Statewide	**7%**	**5.9%**	**-3.4%**	**5.1%**
Has natural gas service	7%	6.1%	-3.2%	5.2%
No natural gas service	10%	4.8%	-4.9%	4.7%
Enforcement jurisdictions	6%	4.8%	-0.6%*	4.1%
Non-enforcement jurisdictions	14%	7.8%	-9.6%*	6.9%
Southern climate zone	5%	4.6%	-0.2%*	3.9%
Northern climate zone	21%	7.7%	-9.1%*	6.8%
Utility non-participants	12%	5.9%	-3.7%	5.2%
Utility participants	<1%	(no data)	(no data)	(no data)

(Non-interacted savings)

*Subgroup differences are statistically significant at a 95% confidence level.

Beyond-Prescriptive-Code Savings Opportunities for Air Leakage

For beyond-prescriptive-code savings potential, we modeled the savings from reducing air leakage in all homes to 0.5 ACH50, which is comparable to tightness levels required for Passive House certification[15] (PHIUS, 2018) and only slightly tighter than the tightest home tested for the study (0.56 ACH50). The modeling results suggest about an 11 percent reduction in space-conditioning costs from this measure, making it one of the more substantial beyond-prescriptive-code measures in the study (Table 24).

Table 24. Mean beyond-prescriptive-code savings for 0.5 ACH50 air leakage (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**14.4%**	**-2.8%**	**103**	**98**	**10.9%**
Has natural gas service	14.8%	-2.4%*	56	98	10.9%
No natural gas service	12.2%	-5.1%*	360	—	11.3%
Enforcement jurisdictions	14.6%	-2.2%*	67	100	10.9%
Non-enforcement jurisdictions	13.6%	-5.4%*	257	84	11.3%
Southern climate zone	14.8%*	-2.1%*	63	100	11.0%
Northern climate zone	12.0%*	-7.0%*	341	74	10.7%
Utility non-participants	14.3%	-3.5%*	165	95	11.3%
Utility participants	14.2%	-1.9%*	18	97	10.2%

(Non-interacted savings)
[a]For homes with natural gas service.
*Subgroup differences are statistically significant at a 95% confidence level.

Windows

Energy Code Requirements for Windows

Minnesota prescriptive energy code requires a window U-value of no more than 0.32.[16] There is no requirement for solar heat gain coefficient (SHGC).

[15] The Passive House Institute US's PHIUS+ 2018 certification program requires air leakage of no more than 6 CFM50 per 100 ft^2 of building shell area (PHIUS 2018). A 0.5 ACH50 goal would be equivalent to an average of 5.6 CFM50 per 100 ft^2 for the study sample.

[16] Skylights have a U-value requirement of 0.55. Only one home in the study sample had skylights.

Observed Characteristics for Windows

The average Minnesota new home has 365 square feet of windows, which make up about 14 percent of the total gross wall area (Table 25). Three homes in the sample had triple-pane windows; the rest had double-pane windows. Unsurprisingly, National Fenestration Rating Council (NFRC) stickers showing the U-value and SHGC factors for the windows were mostly missing in these occupied homes. We did obtain information on these values for 35 homes, mainly from posted code certificates (Table 25).

Table 25. Window characteristics (weighted population estimates).

Group	Mean window area[a] (ft^2)	Percent of wall area[a]	Mean U-value[b]	Mean SHGC[b]
Statewide	**365**	**14%**	**0.28**	**0.29**
Has natural gas service	360	14%	0.29	0.29
No natural gas service	365	17%	0.25	0.28
Enforcement jurisdictions	380	14%	0.29	0.29
Non-enforcement jurisdictions	295	15%	0.25	0.28
Southern climate zone	365	14%	0.28	0.28
Northern climate zone	345	16%	0.28	0.37
Utility program non-participants	345	14%	0.27	0.29
Utility program participants	375	14%	0.29	0.29

[a]n=87 homes

[b]n=35 homes, based on: code certificate (69%), plan review (11%), product look-up (11%), NFRC sticker (9%)

In addition, we used a special instrument (Figure 28) to detect the presence and type of low-e coatings, which are used to control solar gain and improve the thermal performance of the windows. We tested representative operable and fixed windows in the above-grade walls, as well as (where present) foundation windows and sliding glass doors. Across 210 tests, only four windows lacked a low-e coating of some kind: these were minor fixed or foundation windows or (in one case) a sliding glass door.

Figure 28. Instrument used for recording window properties.

Low-e coatings are produced in two fundamentally different ways: hard (pyrolytic) coatings and soft (sputtered) coatings. The former has higher solar heat gain than the latter. Soft-coat low-e glazing can further be distinguished by the number of applied “silver” coatings, with solar heat gain declining as the number of coatings increases.

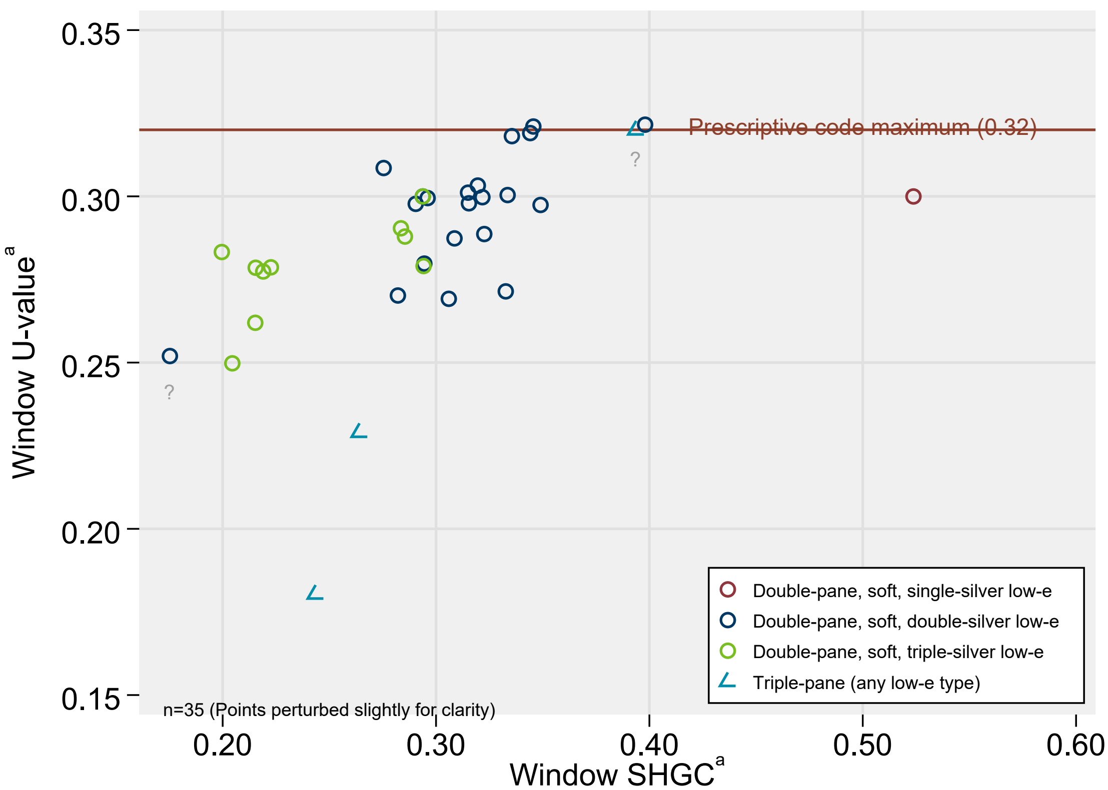
Most windows that we tested were double- or triple-silver, soft-coat low-e products (Table 26). Figure 29 shows the relationship between number of panes, U-value, SHGC and type of low-e coating for homes where we had information about all four parameters. Although there a few instances where the listed U-value and SHGC for the home were inconsistent with the number of panes or low-e coating type (as indicated by a “?” in the figure), the relationships were generally as expected, with triple-pane windows showing very low U-values and the double-pane windows showing lower U-value and SHGC factors for a higher number of soft-coat low-e layers.

This finding lends general credence to the reported U-values and SHGC factors found on the code-certificates and plans—and overall supports a conclusion that most windows in Minnesota new homes have U-values that are well below the prescriptive energy code requirement. The range of values found here is also in general alignment with what has been reported in other northern-climate residential new construction studies.

Table 26. Low-e coatings (unweighted sample).

Low-e coating type	Solar gain category	Operable windows (n=87)	Fixed windows (n=43)	Foundation windows (n=67)	Sliding glass doors (n=7)
Hard-coat	High	1%	0%	1%	0%
Soft-coat, single-silver	High	8%	2%	2%	0%
Soft-coat, double-silver	Moderate	70%	74%	73%	100%
Soft-coat, triple-silver	Low	21%	24%	24%	0%

Figure 29. Window U-value vs. Solar Heat Gain Coefficient (SHGC).



[a]Based on: code certificate (69%); plan review (11%); product look-up (11%); NFRC sticker (9%)

Lost Savings for Windows

The data from the sample suggest that there are very few windows in Minnesota homes that do not meet the prescriptive-code U-value requirement. We therefore did not ascribe lost savings for windows.

Beyond-Prescriptive-Code Savings Opportunities for Windows

We examined the energy savings that would accrue if all homes were built with triple-pane windows with an assumed U-value of 0.17 and an SHGC of 0.24. The results (Table 27) suggest significant savings on space-conditioning costs, on par with the savings from reducing air leakage to Passive House levels or adding R-10 exterior insulation to above-grade walls.

We also looked at the potential impact of using high solar-gain glazing on south-facing windows to increase internal gains in the winter and decrease heating costs. The results (Table 28) show about a two percent reduction in heating loads on average, but also an increase in cooling loads, with little net difference in space-conditioning costs. This analysis may be sensitive to assumptions about window shading and overhangs: we modeled employing an 18-inch overhang to help mitigate cooling load increases.

Table 27. Mean beyond-prescriptive-code savings for triple-pane windows (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**11.2%**	**4.1%**	**150**	**74**	**9.7%**
Has natural gas service	11.1%	3.6%	96	74	9.4%*
No natural gas service	12.0%	7.5%	449	—	11.8%*
Enforcement jurisdictions	11.5%	3.8%	110	77	9.8%
Non-enforcement jurisdictions	10.3%	5.5%	324	56	9.5%
Southern climate zone	11.3%	2.7%*	97	76*	9.5%*
Northern climate zone	10.8%	12.6%*	471	46*	11.5%*
Utility non-participants	11.0%	3.1%	178	69	9.6%
Utility participants	11.4%	5.1%	105	76	9.7%

(Non-interacted savings)
[a]For homes with natural gas service.
*Subgroup differences are statistically significant at a 95% confidence level.

Table 28. Mean beyond-prescriptive-code savings for high solar-gain windows on south-facing walls (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**1.9%**	**-6.8%**	**-56**	**13**	**0.2%**
Has natural gas service	1.8%	-6.7%	-70*	13	0.0%*
No natural gas service	1.9%	-7.8%	21*	—	1.3%*
Enforcement jurisdictions	1.8%	-6.4%	-66	13	0.1%
Non-enforcement jurisdictions	2.1%	-8.8%	-11	13	0.6%
Southern climate zone	2.0%*	-7.4%	-75*	14*	0.1%*
Northern climate zone	0.8%*	-3.4%	63*	-6*	1.1%*
Utility non-participants	2.0%	-8.1%	-50	15	0.4%
Utility participants	1.7%	-5.7%	-68	13	0.0%

(Non-interacted savings)

Modeled with SHGC 0.45 for windows facing southeast to southwest, with 18-inch overhang.

[a]For homes with natural gas service.

*Subgroup differences are statistically significant at a 95% confidence level.

Heating Systems

Energy Code Requirements for Heating Systems

While Minnesota residential energy code does contain provisions for sizing, controls and other aspects of heating systems, heating-system efficiency is subject to federal efficiency standards and not state code. Furnaces and boilers that are fueled by natural gas or propane must be at least 80 percent efficient, and can have a rated annual fuel utilization efficiency (AFUE) as high as 98 percent. Electric resistance heating is inherently 100 percent efficient—though typically an expensive option. Split-system electric heat pumps must have a rated heating-seasonal performance factor of at least 8.2 and highly efficient systems can have an HSPF rating of up to 15—though the field efficiency of heat pumps is affected by a number of design and installation choices not fully accounted for in the current test procedures for rated efficiency.[17]

[17] HSPF is related to another measure of efficiency, coefficient of performance (COP), which is the ratio of delivered energy to input energy, by a factor of 3.412. Thus, heat pump with an HSPF of 8.2 has a COP of 2.4 and a heat pump with an HSPF of 15 has a COP of 4.4.

Observed Characteristics for Heating Systems

The 87 homes in the new-construction sample employ 130 systems for providing space-heating (Table 29). Sixty-one percent of the homes in the sample have a single heating system, 30 percent have 2 heating system and 9 percent have three systems. Homes with multiple heating systems and homes with propane or electric heating systems are much more prevalent in northern and non-enforcement areas than in southern enforcement areas (Table 30). Forced-air furnaces are the most common heating system type.

Table 29. Heating systems in the unweighted study sample.

Heating system type	Number of systems	Notes
Gas or propane forced-air furnace	76	12 are part of a dual-fuel heat pump system
Gas or propane boiler	20	
Electric boiler	7	
Electric air-source heat pump	20	12 central, dual-fuel systems; 8 mini-split heat pumps
Electric baseboard	3	1 home with propane radiant heat on 1st floor and electric baseboard on 2nd floor; 1 home with combination of wood, electric baseboard and electric thermal storage; 1 home w/ 1kW electric baseboard in home w/ ductless heat pump and propane fireplace
Electric plenum heater	1	Employed in a home with a dual-fuel heat pump system
Propane fireplace	1	Only one home regularly relies on a fireplace for space heat; fireplaces in other homes are classified as supplementary heating sources
Wood stove	2	1 home entirely heated by wood; 1 home with wood and electric baseboard heat. (3 additional homes with occasionally used wood/pellet stoves not included here.)
Total	**130**	

Table 30. Number of heating systems and fuel (weighted population estimates).

Group	Mean number of heating systems present in home	% of homes with a natural gas heating system	% of homes with a propane heating system	% of homes with an electric heating system
Statewide	**1.24**	**85%**	**14%**	**11%**
Has natural gas service	1.13*	100%	<1%	3%*
No natural gas service	1.89*	<1%	89%	54%*
Enforcement jurisdictions	1.12*	92%*	8%*	7%
Non-enforcement jurisdictions	1.79*	53%*	37%*	31%
Southern climate zone	1.15*	93%*	7%*	6%*
Northern climate zone	1.83*	35%*	56%*	41%*
Utility program non-participants	1.39*	73%	24%	20%
Utility program participants	1.02*	100%	<1%	<1%

*subgroup differences are statistically significant at a 95% confidence level.

Furnaces

While nearly all furnaces encountered in the southern climate zone were natural gas, furnaces in the northern climate zone are much more likely to be propane (Table 31). Somewhat counter-intuitively, northern furnaces have smaller average output capacity than southern ones: this is likely because northern furnaces are less likely to be shouldering the full heating load of the home. Northern-zone furnaces also have a higher average AFUE rating than southern furnaces (Table 32). Across the sample, furnace efficiency ranged from 92% to 98%, with many furnaces at about 96 percent rated efficiency (Figure 30).

Table 31. Fuel-fired furnace incidence and fuel (weighted population estimates).

Group	% of homes with a furnace	% fueled by natural gas	% fueled by propane
Statewide	**96%**	**86%**	**14%**
Has natural gas service	99%*	100%	<1%
No natural gas service	76%*	<1%	100%
Enforcement jurisdictions	99%	91%*	9%*
Non-enforcement jurisdictions	80%	61%*	39%*

Group	% of homes with a furnace	% fueled by natural gas	% fueled by propane
Southern climate zone	100%*	93%*	7%*
Northern climate zone	72%*	40%*	60%*
Utility program non-participants	92%	73%	27%
Utility program participants	100%	100%	<1%

*subgroup differences are statistically significant at a 95% confidence level.

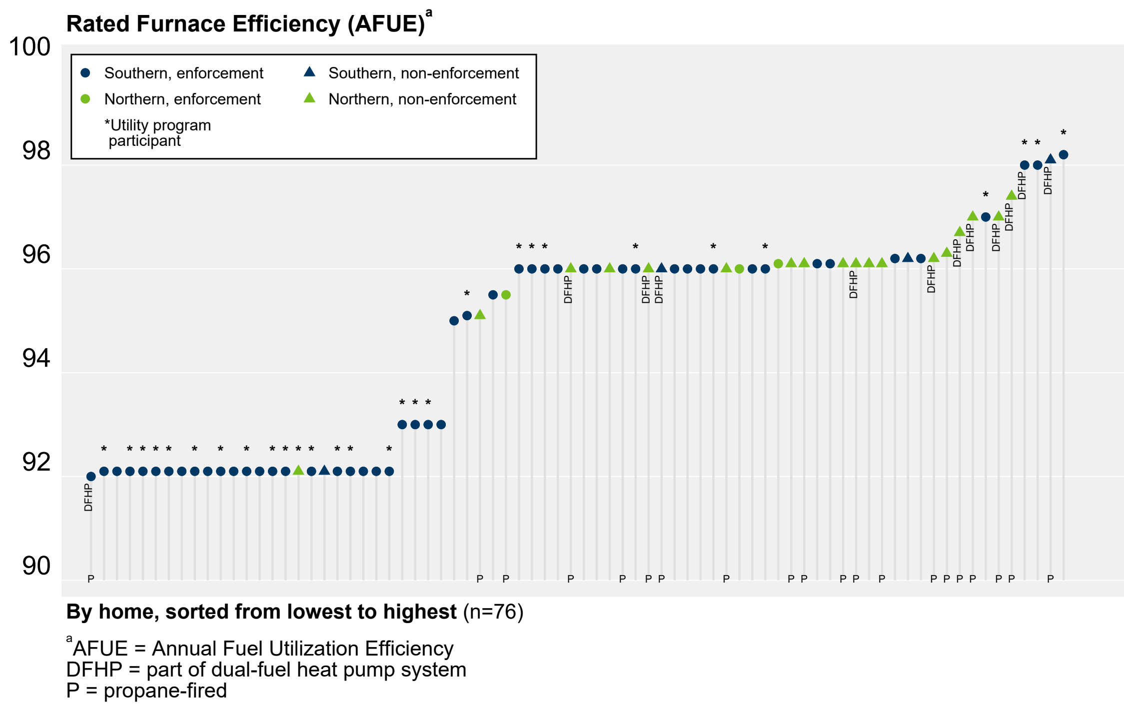
Table 32. Furnace characteristics (weighted population estimates).

Group	Mean output capacity (kBtuh)	Mean % of heating load served	Mean rated efficiency (AFUE)
Statewide	**71.9**	**91%**	**94.1**
Has natural gas service	72.8	92%	93.9
No natural gas service	66.6	85%	95.4
Enforcement jurisdictions	71.7	95%	93.9
Non-enforcement jurisdictions	72.6	74%	95.1
Southern climate zone	72.9*	93%*	93.9*
Northern climate zone	66.2*	77%*	95.7*
Utility program non-participants	70.5	88%	94.6
Utility program participants	73.4	95%	93.7

N=77

*subgroup differences are statistically significant at a 95% confidence level.

Figure 30. Furnace efficiency.



Boilers

Twenty-six homes in the sample had a boiler system, yielding an estimated incidence rate of 16 percent across the statewide new construction population—but northern homes show an incidence of more than 50 percent (Table 33) . All but one boiler system encountered was an in-floor radiant system with hydronic piping embedded in a basement or slab-on-grade foundation; the one outlier was a radiant system in an above-grade floor. Many of these systems also provide heat for domestic hot water (Table 34). Notably, nine boiler systems in the study sample include the garage as a heating zone. Two of the 19 fuel-fired boilers had an AFUE rating of 94%; the remaining 17 were rated at 95%.

Table 33. Boiler incidence and fuel type (weighted population estimates).

Group	% of homes with a boiler	% fueled by natural gas	% fueled by propane	% fueled by electricity
Statewide	**16%**	**47%**	**6%**	**47%**
Has natural gas service	12%	53%	<1%	47%
No natural gas service	41%	0%	54%	46%
Enforcement jurisdictions	7%*	46%	4%	51%
Non-enforcement jurisdictions	53%*	54%	17%	29%

Group	% of homes with a boiler	% fueled by natural gas	% fueled by propane	% fueled by electricity
Southern climate zone	10%*	51%	1%	48%
Northern climate zone	54%*	23%	39%	38%
Utility program non-participants	26%*	22%	9%	69%
Utility program participants	2%*	100%	<1%	<1%

n=77 homes; n=26 boiler systems

*subgroup differences are statistically significant at a 95% confidence level.

Table 34. Boiler characteristics (weighted population estimates).

Group	Mean output capacity (kBtuh)	Mean % of heating load served	% that also serve domestic hot water	Mean rated efficiency[a] (AFUE)
Statewide	**68.3**	**69%**	**36%**	**94.9**
Has natural gas service	68.8	71%	38%	95.0
No natural gas service	64.3	57%	21%	94.5
Enforcement jurisdictions	65.2	72%	39%	95.0
Non-enforcement jurisdictions	81.9	59%	23%	94.9
Southern climate zone	67.3	70%	36%	95.0
Northern climate zone	74.1	65%	35%	94.6
Utility program non-participants	52.5	72%	13%	94.8
Utility program participants	101.2	63%	84%	95.0

[a]for fuel-fired systems (n=19)
n=26 boiler systems

Heat Pumps

Twenty homes in the sample had an air-source heat pump; 12 of these were central ducted units that were part of a dual-fuel heating system pairing the heat pump with a propane or natural gas furnace; the other eight were ductless mini-split systems.

The dual-fuel systems ranged in capacity from 2 to 3.5 tons, with an average of 2.5 tons. Rated heating season performance factor (HSPF) ranged from 8.2 to 10.5 with an average of 8.8. Only one of the furnaces for these systems was fueled with natural gas (and coincidentally was also reported by the homeowner as not used for heating). The other 11 dual fuel heat pump systems were backed up by propane furnaces.

The eight mini-split systems ranged from 1 to 3.5 tons, with an average of 2 tons, and ranged in HSPF from 8.5 to 10.6, with an average of 9.6. On average, the mini-split systems were judged to serve only about a quarter of the heating load in the homes where they are installed. Half of these systems were in homes with either an electric boiler or electric baseboard heat; the remainder were in homes with propane-fuel space heating.

Supplementary Heating

We found 103 supplementary heating systems among 74 of the 87 homes in the study sample, dominantly gas or propane fireplaces (Table 35). The sample suggests that southern-zone homes are about twice as likely to have a gas or propane fireplace as northern homes, and that the latter are much more likely to be propane when present (Table 36).

Table 35. Supplementary heating systems in the study sample.

Heating system type	Number of systems	Notes
Gas or propane fireplace	66	
Gas or propane garage heater	10	Excludes 9 homes with radiant heating systems that include a zone for the garage
Wood fireplace	7	
Wood/pellet stove	3	Excludes 2 homes where wood is used for primary heat
Electric space heater	12	
Other Electric	5	2 homes w/ electric fireplaces; 2 homes with an electric radiant panel; 1 home w/ an electric wall heater
Total	103	

N=87 homes; 74 with at least one supplementary heating source

Table 36. Gas/propane fireplace incidence and fuel (weighted population estimates).

Group	% of homes with a fireplace	% fueled by natural gas	% fueled by propane
Statewide	**71%**	**84%**	**16%**
Has natural gas service	75%	>99%	<1%
No natural gas service	52%	0%	100%
Enforcement jurisdictions	78%	92%*	8%*
Non-enforcement jurisdictions	45%	46%*	54%*
Southern climate zone	76%*	96%*	4%*
Northern climate zone	43%*	12%*	88%*

Group	% of homes with a fireplace	% fueled by natural gas	% fueled by propane
Utility program non-participants	69%	72%	28%
Utility program participants	79%	>99%	<1%

N=87 homes; 30 homes with a gas/propane fireplace
*Subgroup differences are statistically significant at a 95% confidence level.

Garage Heat

As noted above, 10 homes in the sample were found to have a dedicated garage heater (Figure 31) and an additional nine homes had a radiant-slab heating system that included a garage zone. This suggests a statewide incidence for heated garages of about 17 percent (Table 37).

Table 37. Incidence and type of heated garages (weighted population estimates).

Group	% of homes with garage heat	% heated by dedicated heater	% heated by radiant-slab zone
Statewide	17%	77%	23%
Has natural gas service	17%	83%*	17%*
No natural gas service	18%	34%*	66%*
Enforcement jurisdictions	14%	92%	8%
Non-enforcement jurisdictions	29%	10%	90%
Southern climate zone	16%	82%	18%
Northern climate zone	25%	44%	56%
Utility program non-participants	22%	64%	36%
Utility program participants	11%	100%	<1%

N=87 homes; 19 homes with garage heat
*Subgroup differences are statistically significant at a 95% confidence level.

Figure 31. Example of a garage heater, with thermostat set to 60F (Site 125).

Lost Savings for Heating Systems

Because there are no Minnesota energy code requirements for heating-system efficiency, we attributed no lost savings for heating systems.

Beyond-Prescriptive-Code Savings Opportunities for Heating Systems

We considered two types of beyond-prescriptive-code savings opportunities for heating systems: (1) installation of top-efficiency fuel-fired equipment; and (2) use of air-source heat pumps to offset or eliminate resistance electric heat. In terms of the former, we modeled the savings from upgrading gas- and propane-fired furnaces and boilers to 97% AFUE equipment. For the latter, we modeled replacing all electric-resistance heat with air-source heat pumps having a seasonal coefficient of performance (COP) of 2.5. In keeping with current CIP policy, we did not examine savings associated with switching heating fuels.

Modeled savings are modest for high-efficiency fuel-fired equipment because existing efficiency levels are already high (Table 38). Potential savings are substantial for heat pumps (Table 39), but the number of affected homes is fairly small limiting the savings.

Table 38. Mean beyond-prescriptive-code savings for top-efficiency fuel-fired space heating (weighted population estimates).

Group	% of homes with any fuel-fired heat	Natural gas (therms/yr)[a]	% of space conditioning costs[b]
Statewide	97%	22	2.0%
Has natural gas service	100%	22	2.2%*
No natural gas service	82%	—	0.8%*
Enforcement jurisdictions	100%	23	2.1%
Non-enforcement jurisdictions	85%	13	1.6%
Southern climate zone	100%	22*	2.1%*
Northern climate zone	83%	9*	1.2%*
Utility non-participants	97%	17	1.6%
Utility participants	100%	25	2.4%

(Non-interacted savings)
[a]For homes with natural gas space heat.
[b]For homes with fuel-fired space heating equipment.
*Subgroup differences are statistically significant at a 95% confidence level.

Table 39. Mean beyond-prescriptive-code savings for heat pumps instead of resistance electric heat (weighted population estimates).

Group	% of homes with any electric resistance heat	Electricity (kWh/yr)[a]	% of space conditioning costs[a]
Statewide	6%	3,370	23%
Has natural gas service	2%	(insuff. data)	(insuff. data)
No natural gas service	28%	3,080	16%*
Enforcement jurisdictions	2%	(insuff. data)	(insuff. data)
Non-enforcement jurisdictions	23%	3,080	16%*
Southern climate zone	2%*	(insuff. data)	(insuff. data)
Northern climate zone	31%*	3,080	16%*
Utility non-participants	11%	3,930	26%
Utility participants	<1%	(insuff. data)	(insuff. data)

(Non-interacted savings)
[a]For homes with resistance electric heat.
*Subgroup differences are statistically significant at a 95% confidence level.

Cooling Systems

Energy Code Requirements for Cooling Systems

As with space heating systems, cooling-system efficiency is subject to federal efficiency standards and not state code. Federal standards require that split-system air conditioners have a seasonal energy efficiency ratio (SEER) of 13 but systems with a rated SEER of 18 or higher are available.

Observed Characteristics for Cooling Systems

Eighty-three of the 87 homes in the new-construction sample have a cooling system: 74 have a central, split-system air conditioner or central heat pump, eight have a ductless mini-split system and one home uses a window air conditioner (Table 40). Mini-split systems are most prevalent in the northern climate zone. Central ducted and ductless systems ranged in cooling capacity from one ton (12 kBtuh) to 4.5 tons, with an average of a bit more than 2.5 tons (Table 41). About half of the cooling systems encountered have rated efficiency at the federal minimum Seasonal Energy Efficiency Ratio (SEER) of 13.0; systems with high SEER values are almost all higher-end heat pumps (Figure 32).

Table 40. Cooling system type (weighted population estimates).

Group	Central air conditioner or heat pump	Ductless heat pump	Room air conditioner	None
Statewide	**95%**	**3%**	**0%**	**1%**
Has natural gas service	99%	1%	<1%	<1%
No natural gas service	75%	17%	1%	7%
Enforcement jurisdiction	99%	1%	<1%	<1%
Non-enforcement jurisdiction	80%	14%	1%	6%
Southern climate zone	>99%	<1%	<1%	0%
Northern climate zone	71%	23%	1%	5%
Utility program non-participant	92%	6%	0%	2%
Utility program participant	>99%	<1%	<1%	<1%

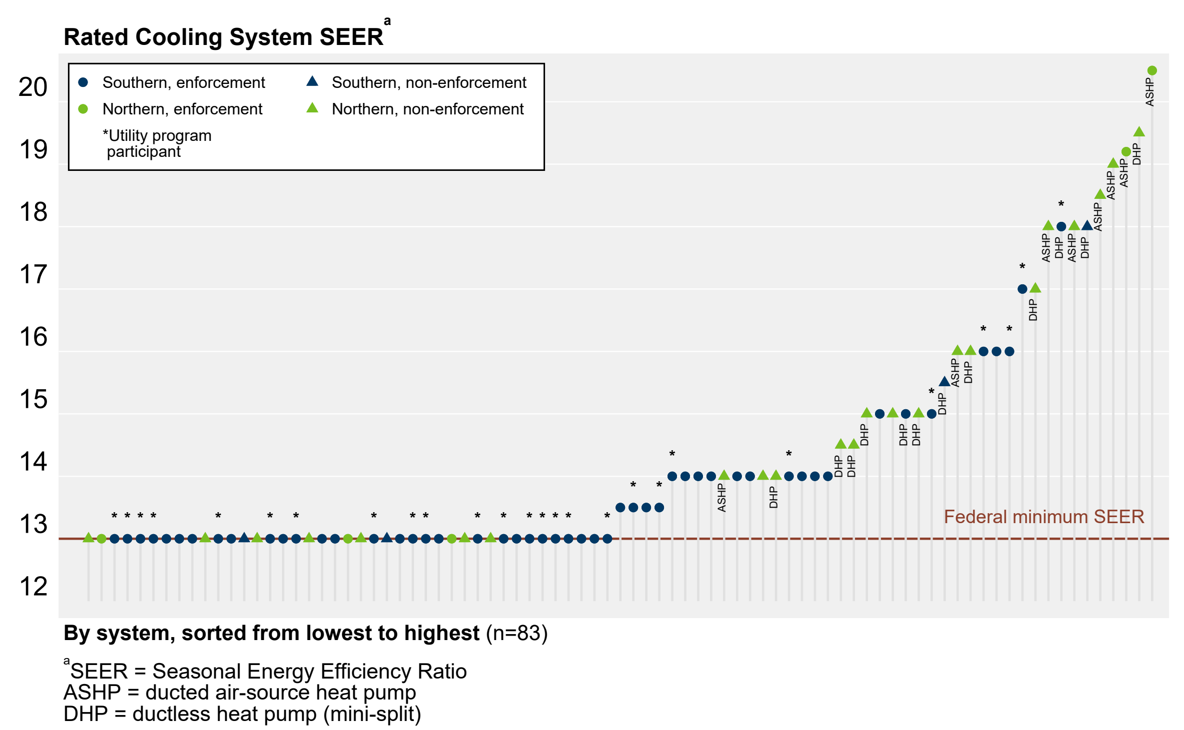
N=87 homes

Table 41. Cooling system characteristics (weighted population estimates).

Group	Mean rated output capacity (kBtuh)	Mean SEER
Statewide	**32.3**	**13.8**
Has natural gas service	32.9	13.6
No natural gas service	28.7	15.0
Enforcement jurisdiction	32.2	13.7
Non-enforcement jurisdiction	32.7	14.3
Southern climate zone	32.8	13.6
Northern climate zone	29.1	14.8
Utility program non-participant	32.4	14.0
Utility program participant	31.6	13.6

N=83 homes with central ducted or ductless cooling system.

Figure 32. Cooling System efficiency.



Lost Savings for Cooling Systems

Because there are no Minnesota energy code requirements for cooling-system efficiency, we attribute no lost savings for these.

Beyond-Prescriptive-Code Savings Opportunities for Cooling Systems

We assessed beyond-prescriptive-code savings potential by modeling the savings from installing high-efficiency cooling systems. We used SEER 17 as the upper benchmark for central A/C systems, SEER 19.5 for central, ducted air-source heat pumps and SEER 20.5 for ductless heat pumps. The results suggest potential for a 2 to 4 percent reduction in space-conditioning costs, depending on climate zone (Table 42).

Table 42. Beyond-prescriptive-code savings potential for top-efficiency space-cooling systems (weighted population estimates).

Group	Electricity (kWh/yr)	% of space conditioning costs
Statewide	**175**	**3.3%**
Has natural gas service	195*	3.7%*
No natural gas service	61*	0.5%*
Enforcement jurisdiction	193*	3.5%
Non-enforcement jurisdiction	97*	2.3%
Southern climate zone	192*	3.6%*
Northern climate zone	68*	1.1%*
Utility program non-participant	140	2.7%
Utility program participant	211	4.0%

*Subgroup differences statistically significant at a 95% confidence level.

Ducts

Energy Code Requirements for Ducts

Minnesota energy code follows the IECC 2012 requirement that if any ductwork is outside the home's thermal envelope, ducts must be tested for leakage, and total leakage may not exceed 4 cfm per 100 ft^2 of conditioned floor area (CFA) at a pressure differential of 25 Pascals (CFM25). Ducts in unconditioned spaces must also be insulated, generally to R-8.

Observed Characteristics for Ducts

The study sample shows that most Minnesota homes have ductwork for space-heating and cooling, and that statewide, about one in four homes has some ductwork outside the thermal envelope (Table 43). On average, of about a third of the ductwork is outside the thermal envelope among homes that have such ducts, but this ranged in the sample from less than 5 percent to nearly 100 percent. These exterior ducts are most common in garage ceilings (64% of homes with exterior ducts), buried under insulation in attics (34%) or insulated ducts that are exposed in attics (11%). A few homes with unconditioned crawlspaces also have exterior ducts. Where observable, ducts were generally found to be insulated to the required R-8.

Table 43. Presence and type of ducts for space-heating and cooling (weighted population estimates).

Group	% of homes with heating/cooling ductwork	% of homes with ducts outside the thermal envelope[a]
Statewide	**96%**	**24%**
Has natural gas service	99%	28%
No natural gas service	76%	4%
Enforcement jurisdiction	99%	28%
Non-enforcement jurisdiction	80%	8%
Southern climate zone	>99%	26%
Northern climate zone	72%	11%
Utility program non-participant	92%	25%
Utility program participant	>99%	25%

N=87 homes

[a]Percent of all homes, including those that do not have ductwork

The study protocol called for testing duct leakage in all homes with exterior ducts, along with a sample of homes with ducts that were entirely within the thermal envelope. Site-visit time constraints and other hurdles prevented full execution of the protocol, but we completed leakage testing in 15 of 21 sampled homes that had exterior ductwork, plus seven homes with no exterior duct runs.

We also observed that six homes in the study had been sealed by an Aeroseal™ contractor, as evidenced by the presence of posted report providing information about measured leakage at the conclusion of sealing.[18] In addition, two homes had code-compliance certificates that listed tested duct-leakage values. We made use of these data in addition to our own test results.

[18] Aeroseal is a proprietary process that injects an aerosolized sealant into the duct system to seal cracks.

The duct leakage testing uses a calibrated fan to measure total leakage flow with the duct system pressurized to 25 Pascals (CFM25) with all registers sealed off (Figure 33). In addition, we measured leakage to outside (LTO) by repeating the measurement with the house pressurized to the same level as the duct system to eliminate leakage flow between the ducts and conditioned spaces. While total duct leakage is the basis for the Minnesota code requirement, leakage to outside is arguably the better measure of the energy implications of duct leakage—and is the value used by Rem/Rate to model the energy implications of duct leakage.

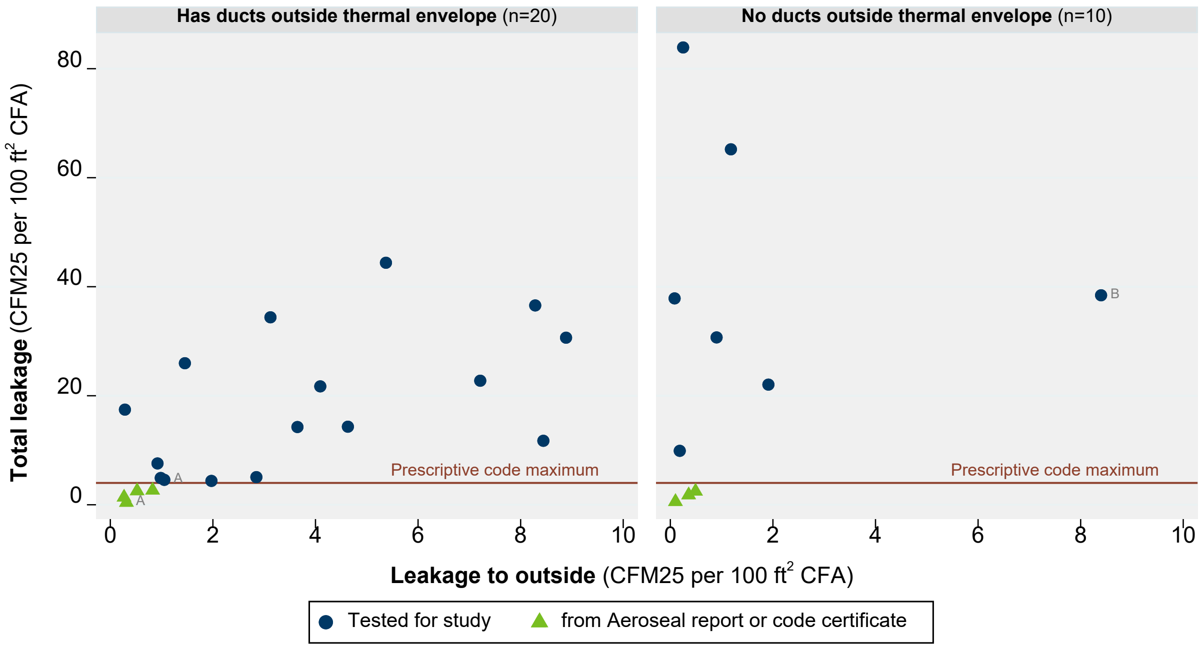
Figure 34 plots total duct leakage against leakage to the outside for the 30 homes with test results or Aeroseal and code certificate information. Notably, none of the homes that we tested passed the energy code requirement of total leakage of less than 4 CFM25 per 100 ft^2 CFA, though some were close—and of course, homes that we tested that lacked exterior ducts are exempt from this requirement. All of the Aeroseal or code certificate values were below the code threshold. For the one home that we tested that also had an Aeroseal report (labeled “A” in the figure), our results differed somewhat from the Aeroseal report.

The distribution of results here—and the failure of many homes to meet the 4 CFM25 per 100 ft^2 CFA duct-leakage requirement—has been a recurrent theme noted in several code-compliance and/or new-home characterization studies in other states.

As might be expected, homes with exterior ducts are more likely to show leakage to the outside, as can be seen by comparing the left and right panels in Figure 34 and the statistics in Table 44 and Table 45. The only home lacking exterior duct runs that showed significant leakage to the outside is a modular home that was also notable in having insulation coverage and other issues (labeled as “B” in the figure).

Figure 33. Duct leakage test (Site 170).

Figure 34. Duct leakage test results.



CFM25 = Cubic feet per minute @ 25 Pa pressure difference
CFA = Conditioned floor area
(Leakage to outside estimated for Aeroseal cases)

Table 44. Total duct leakage (CFM25 per 100 ft² of conditioned floor area).

Group	n	Minimum	Maximum	Mean	Median
No ducts outside thermal envelope	10	0.57	83.9	29.3	26.4
Some or all ducts outside thermal envelope	19	1.38	44.4	16.2	14.3
Overall	**29**	**0.57**	**83.9**	**20.7**	**14.3**

Includes 23 homes tested for study, plus posted Aeroseal test reports for 4 homes and code-compliance certificate for 2 homes.

Table 45. Duct leakage to outside (CFM25 per 100 ft² of conditioned floor area).

Group	n	Minimum	Maximum	Mean	Median
No ducts outside thermal envelope	10	0.08	8.40	1.39	0.42
Some or all ducts outside thermal envelope	19	0.27	8.89	3.41	2.85
Overall	**29**	0.08	8.89	2.71	1.18

Includes 23 homes tested for study, plus posted Aeroseal test reports for 4 homes and code-compliance certificate for 2 homes.

Lost Savings for Ducts

To calculate lost savings for homes that exceed the prescriptive-code limit for duct leakage, we modeled the savings that would occur if all homes with exterior duct runs are reduced to total leakage of 4 CFM25 per 100 ft^2 of floor area. We assumed that the same percentage reduction in total duct leakage required to get down to the code threshold for total leakage would also apply to leakage to outside.

The study suggests that about 17 percent of all new homes are subject to the energy code duct-leakage requirement but do not achieve the target tightness level (Table 46). Modeled average energy-cost savings from reducing duct leakage to the code-required level is a bit less than 4 percent overall.

Table 46. Modeled lost savings from duct leakage above prescriptive energy code (weighted population estimates).

Group	Lost savings incidence[a] (% of homes)	Mean lost savings, % of total heating load	Mean lost savings, % of total cooling load	Mean lost savings, % of total htg/clg costs
Statewide	**17%**	**3.7%**	**3.6%**	**3.6%**
Has natural gas service	19%	3.6%*	3.6%	3.5%
No natural gas service	4%	6.6%*	4.5%	6.5%
Enforcement jurisdictions	19%	3.1%*	3.1%	3.1%*
Non-enforcement jurisdictions	8%	8.7%*	9.0%	8.7%*
Southern climate zone	18%	3.1%*	3.1%	3.1%*
Northern climate zone	11%	8.7%*	9.0%	8.7%*
Utility non-participants	17%	5.7%*	6.1%*	5.8%*
Utility participants	18%	1.1%*	0.5%*	0.9%*

(Non-interacted savings)

[a]Includes homes that do not have ductwork or do not have exterior ductwork and therefore are not subject to leakage requirements.

*Subgroup differences are statistically significant at a 95% confidence level.

Beyond-Prescriptive-Code Savings for Ducts

For beyond-prescriptive-code savings, we assumed further tightening the duct system to 1.5 CFM25 per 100 ft^2 and deeply burying all exposed attic ducts to effectively bring them inside conditioned space. The results suggest small savings, even for the roughly 25 percent of homes with duct runs outside the thermal envelope (Table 47).

Table 47. Mean beyond-prescriptive-code savings for duct sealing in homes with exterior ducts (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**1.7%**	**1.5%**	**59**	**14.0**	**1.8%**
Has natural gas service	1.9%	1.7%	67	14.0	2.0%
No natural gas service	0.5%	0.6%	10	—	0.5%
Enforcement jurisdictions	1.8%	1.6%	69	13.3*	1.9%
Non-enforcement jurisdictions	1.2%	1.4%	14	30.4*	1.2%
Southern climate zone	1.9%	1.6%	70	13.7	1.9%
Northern climate zone	1.1%	1.2%	13	17.8	1.1%
Utility non-participants	1.9%	1.9%	75	15.4	2.0%
Utility participants	1.4%	0.9%	29	12.0	1.4%

(Non-interacted savings)
[a]For homes with natural gas service.
*Subgroup differences are statistically significant at a 95% confidence level.

Thermostats

Energy Code Requirements for Thermostats

Minnesota energy code requires a programmable thermostat for forced-air heating systems.

Observed Characteristics for Thermostats

Most new homes have a standard programmable thermostat, but about one in five has an advanced thermostat such as a Nest or EcoBee (Table 48). Only three of 75 sampled homes with a forced-air furnace lacked a programmable thermostat.

About half of households with a programmable thermostat regularly use the programmable features (Table 49). Reported setpoints averaged about 68°F during the day in the winter and 73°F during the day in the summer (Table 50).

Lost Savings and Beyond-Prescriptive-Code Savings for Thermostats

Because the estimated population incidence of homes that have a forced-air heating system but lack a programable thermostat is very low (3%), we did not ascribe any lost energy savings for this. We also did not attempt to estimate beyond-prescriptive-code savings for advanced thermostats.

Table 48. Type of thermostat (weighted population estimates).

Group	% Non-programmable	% Standard programmable	% Advanced programmable[a]
Statewide	6%	73%	21%
Has natural gas service	4%	76%	19%
No natural gas service	17%	51%	32%
Enforcement jurisdiction	4%	79%	17%
Non-enforcement jurisdiction	14%	46%	40%
Southern climate zone	4%	79%*	18%
Northern climate zone	21%	36%*	44%
Utility program non-participant	6%	65%	29%
Utility program participant	6%	83%	11%

N=87 homes

[a]Tier 2 or Tier 3

*subgroup differences are statistically significant at a 95% confidence level

Table 49. Reported use of thermostat program (weighted population estimates).

Group	Do you usually run it on a program in the winter? (% Yes)	Do you usually run it on a program in the summer? (% Yes)
Statewide	57%	55%
Has natural gas service	56%	56%
No natural gas service	64%	46%
Enforcement jurisdiction	54%	53%
Non-enforcement jurisdiction	71%	64%
Southern climate zone	58%	57%
Northern climate zone	51%	41%
Utility program non-participant	62%	58%
Utility program participant	46%	46%

N=73 homes with a programmable thermostat

Table 50. Reported thermostat setpoints (weighted population estimates).

Group	Winter, day (F)	Winter, night (F)	Summer, day (F)	Summer, night (F)
Statewide	68.4	66.5	72.9	72.8
Has natural gas service	68.2	66.4	73.1	73.0
No natural gas service	69.4	67.2	71.4	71.6
Enforcement jurisdiction	68.6	67.0	72.9	72.9
Non-enforcement jurisdiction	67.3	64.5	72.5	72.7
Southern climate zone	68.3	66.4	73.0	72.9
Northern climate zone	68.8	67.0	72.0	72.5
Utility program non-participant	68.2	65.8	73.3	73.4
Utility program participant	68.7	67.9	72.3	72.0

N=87 home

Mechanical ventilation

Code Requirements for Mechanical Ventilation

Minnesota is unique in the nation in requiring *balanced* mechanical ventilation in all new homes. While the energy code does not require heat-recovery of ventilation air, in practice nearly all homes employ systems that do so. Key provisions of the code are as follows:

- Mechanical ventilation systems must be sized to meet flow requirements for both continuous and total (intermittent) mechanical ventilation.[19]
- The required total ventilation rate (TVR) is 2 CFM per 100 ft^2 of conditioned floor area + 15 CFM per bedrooms+1. The required continuous ventilation rate (CVR) is half the TVR, but not less than 40 CFM. The CVR needs to be met on an hourly basis.
- The system must be balanced so that intake flow is within 10 percent of exhaust flow.

[19] There is some ambiguity in the code language about how the intermittent portion of required ventilation can be met. One section of the code (R403.5.5) states that exhaust fans may be used to meet the intermittent flow requirements. However, the introductory paragraph to the mechanical ventilation section (R403.5) states that a *balanced* system (emphasis added) must be used for both the continuous and total ventilation flow. This has been interpreted by state officials as meaning that if exhaust fans are used for the intermittent ventilation requirement, they must be paired with supply fans of equal flow to make the system balanced. In practice, it appears that builders simply install a balanced system sized to meet the total ventilation requirement, and also install bath fans that are not considered part of the code-required system.

- For systems that use the ductwork of a forced-air heating/cooling system for both intake and exhaust air, interlock controls are required so that the air handler for the forced-air system operates whenever the mechanical ventilation system operates.
- Dampers must be installed to prevent backflow of air when the mechanical ventilation system is not operating.

Observed Characteristics for Mechanical Ventilation

The required continuous ventilation for the homes in the sample ranges from 40 to more than 90 cfm (Figure 35), with an estimated statewide average of 63 cfm (Table 51). Because they are larger on average, homes in the southern part of the state tend to have a higher CVR requirement than northern homes.

Figure 35. Required continuous ventilation rate.

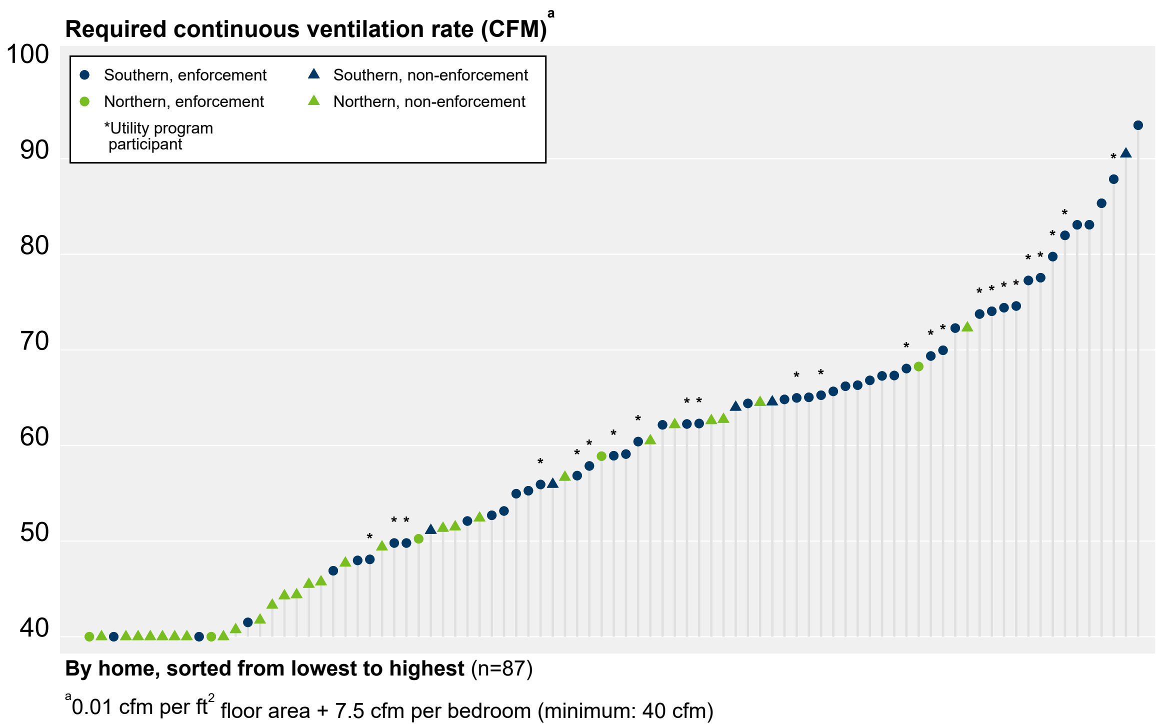


Table 51. Code-required ventilation rate (weighted population estimates).

Group	Mean required total ventilation rate[a] (cfm)	Mean required continuous ventilation rate[b] (cfm)
Statewide	**126**	**63**
Has natural gas service	129	65
No natural gas service	110	56
Enforcement jurisdiction	128	64
Non-enforcement jurisdiction	119	60
Southern climate zone	131*	66*
Northern climate zone	99*	51*
Utility program non-participant	121	61
Utility program participant	132	66

N=87 homes

[a]0.02 cfm per ft^2 conditioned floor area + 15 cfm per bedroom

[b]larger of ½ of required total ventilation rate or 40 cfm

*Subgroup differences are statistically significant at a 95% confidence level.

Table 52. Type of balanced mechanical ventilation system present (weighted population estimates).

Group	HRV	ERV	No balanced system
Statewide	**48%**	**46%**	**6%**
Has natural gas service	43%	53%*	4%
No natural gas service	76%	8%*	16%
Enforcement jurisdiction	52%	48%	<1%
Non-enforcement jurisdiction	33%	35%	32%
Southern climate zone	45%	51%	5%
Northern climate zone	69%	16%	15%
Utility program non-participant	52%	37%	10%
Utility program participant	45%	55%	<1%

N=87 homes

HRV = Heat Recovery Ventilator; ERV = Energy Recovery Ventilator

*Subgroup differences are statistically significant at a 95% confidence level.

Homes are about evenly divided between heat recovery ventilators (HRVs), which recover heat but not moisture from ventilation air, and energy recovery ventilators (ERVs), which recover both heat and moisture (Table 52). We did not encounter any homes that employed balanced ventilation without heat recovery, but a small proportion of homes did not have any type of balanced ventilation system.

The typical balanced system has a rated power draw of about 100 watts and a rated sensible heat-recovery efficiency of 70 percent (Table 53).[20] However, recovery efficiencies in the sample ranged from less than 60 percent to more than 80 percent (Figure 36).

Table 53. Balanced mechanical ventilation system characteristics (weighted population estimates).

Group	Mean rated cfm[a]	Mean rated watts[b]	Mean rated sensible recovery efficiency (%)[c]
Statewide	**112**	**98**	**71**
Has natural gas service	116	100	71*
No natural gas service	84	83	67*
Enforcement jurisdiction	114	100	71*
Non-enforcement jurisdiction	103	89	68*
Southern climate zone	118*	102	71
Northern climate zone	75*	73	69
Utility program non-participant	105	95	69*
Utility program participant	118	98	72*

N=73 homes with an HRV or ERV where make/model could be determined

[a]for lowest rated flow meeting or exceeding the home's required total ventilation rate

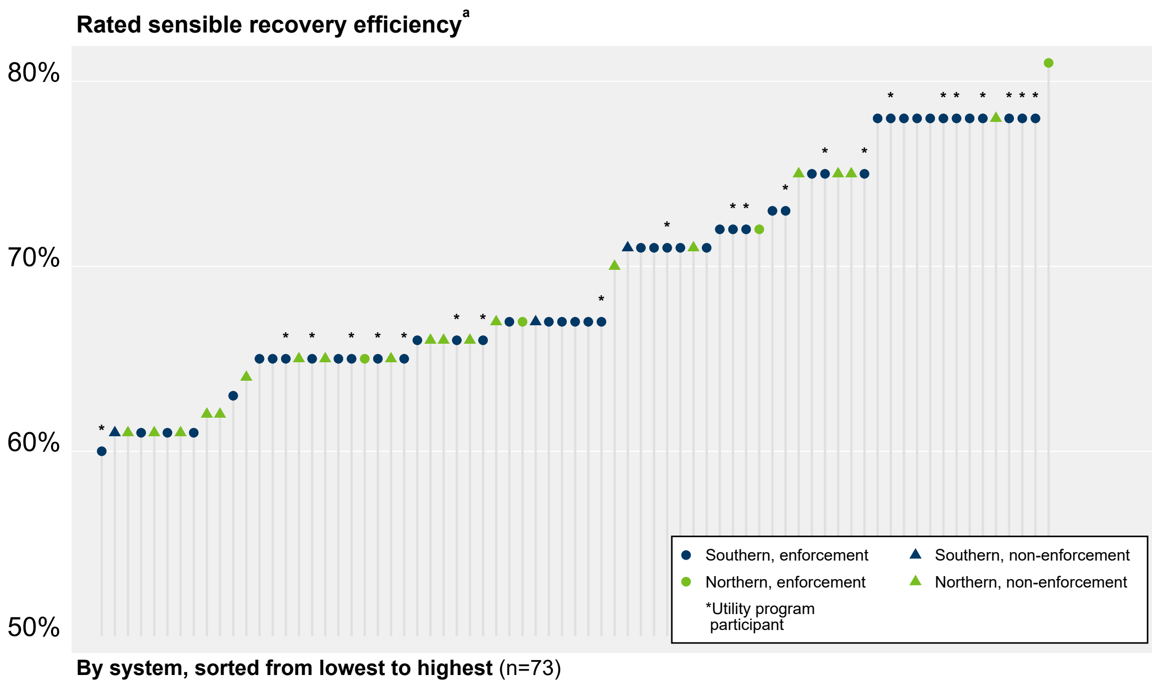
[b]at rated flow

[c]at 32°F and at rated flow

*Subgroup differences are statistically significant at a 95% confidence level.

[20] Sensible heat recovery is a measure of the unit's ability to bring the temperature of the incoming fresh air up to the temperature of room air it is replacing. It excludes moisture recovery for ERVs.

Figure 36. Rated HRV/ERV sensible recovery efficiency.



[a]at 32F for the lowest rated flow meeting or exceeding the home's required continuous ventilation rate

Balanced ventilation systems can be ducted in a variety of ways (Figure 37), but these fall into three general categories: (a) fully-ducted systems that do not share any ductwork with heating or cooling systems; (b) simplified systems that rely on heating/cooling ductwork for stale-air removal and fresh-air deliver to living spaces; and, (c) hybrid systems that are partly independently ducted and partly share heating/cooling ductwork.

A large majority of homes have simplified systems that use the main heating/cooling distribution system for ventilation (Table 54). About half of these use the return side of the heating/cooling distribution system for both stale-air pickup and fresh-air delivery, but systems that pick up stale air on the return side and deliver fresh air to the supply side are common as well (Table 55). Very few homes have fully ducted ventilation systems.

Control systems for HRVs and ERVs are somewhat difficult to characterize, as many systems have user-selectable controls that allow for multiple modes of operation at different speeds and operating intervals. Seventy-five percent of homeowners reported that their system either ran continuously or under some form of automatic control and about 20 percent reported using the system only when needed. The remaining five percent either did not use the system at all or were unaware or unsure of it. About one in five systems appears to be under the control of a humidistat, meaning that it operates only when indoor humidity exceeds a set threshold.

Figure 37. Balanced-ventilation duct configurations encountered in the study.

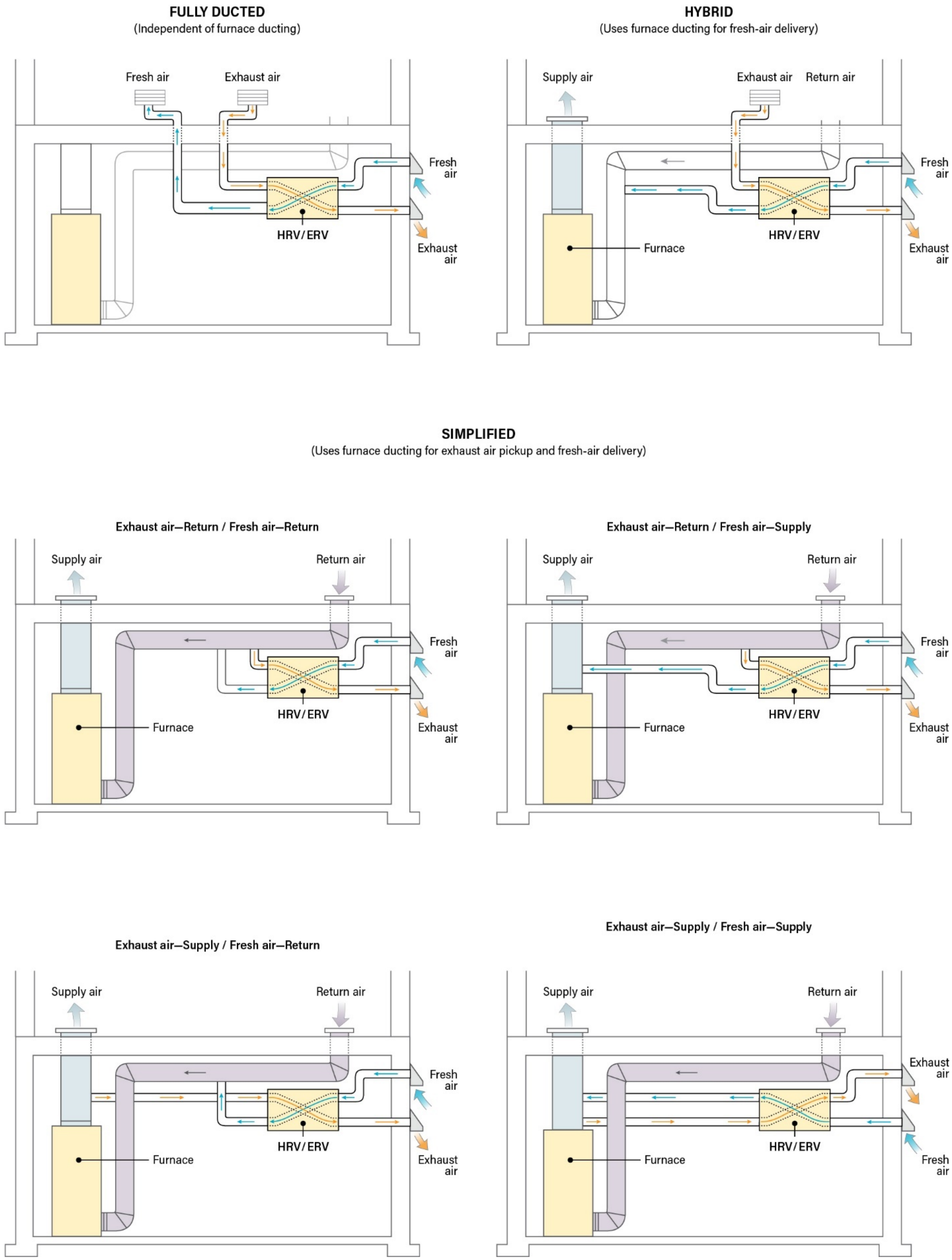


Table 54. Balanced mechanical ventilation ducting configurations (weighted population estimates).

Group	Fully ducted[a]	Simplified[b]	Hybrid[c]
Statewide	**3%**	**80%**	**16%**
Has natural gas service	1%	82%	17%
No natural gas service	17%	73%	11%
Enforcement jurisdiction	1%	90%*	9%*
Non-enforcement jurisdiction	13%	37%*	49%*
Southern climate zone	<1%	82%	18%
Northern climate zone	23%	71%	6%
Utility program non-participant	6%	75%	19%
Utility program participant	<1%	87%	13%

N=78 homes with an HRV or ERV

[a]Does not share any ductwork with forced-air heating or cooling system(s)

[b]Uses heating/cooling system ductwork for both stale-air removal and fresh-air delivery.

[c]Uses independent ducting for stale-air removal from living space and heating/cooling ductwork for fresh-air delivery

*Subgroup differences are statistically significant at a 95% confidence level.

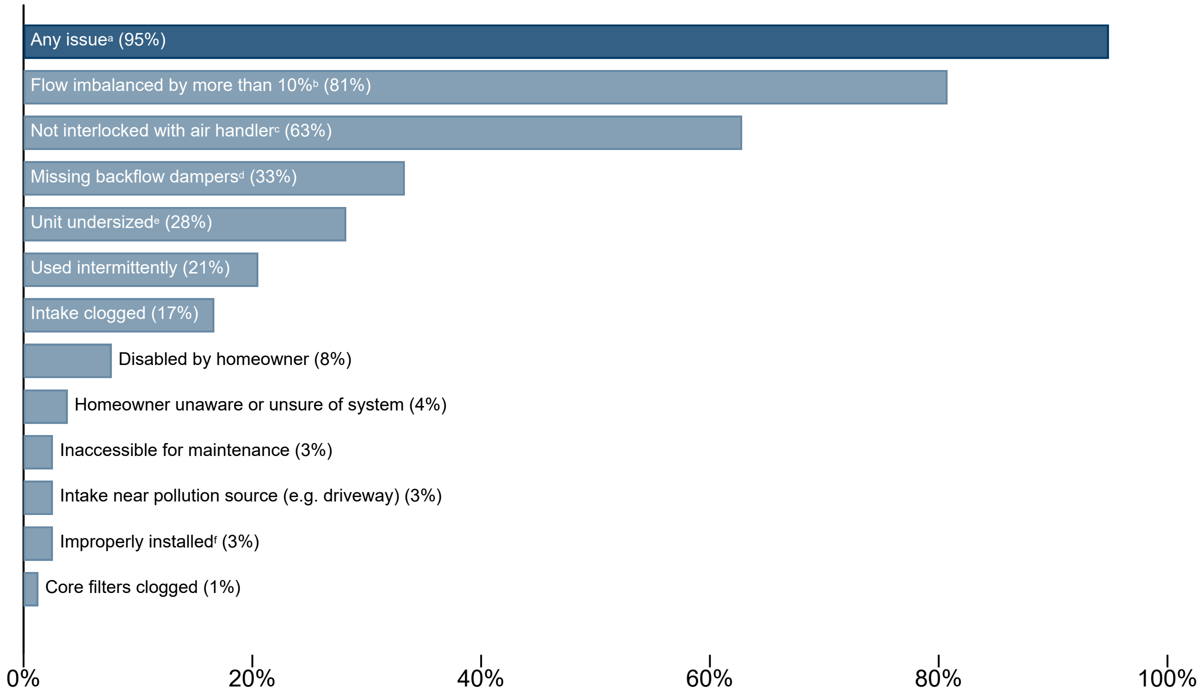
Table 55. Subtypes for simplified balanced mechanical ventilation ducting (unweighted sample).

Exhaust air picked up from heating/cooling…	Fresh air delivered to heating/cooling…	% of simplified systems
Return	Return	49%
Return	Supply	39%
Supply	Return	10%
Supply	Supply	2%

N=49 homes with simplified ducting, where subtype could be determined

Data collected for the study sample suggest that issues with HRVs and ERVs are pervasive in the new-home population (Figure 38). The most significant of these are imbalance between the intake and exhaust flows and lack of an interlock control for simplified systems that rely on the main heating/cooling system for ventilation distribution.

Figure 38. Incidence of balanced-ventilation issues (unweighted sample).



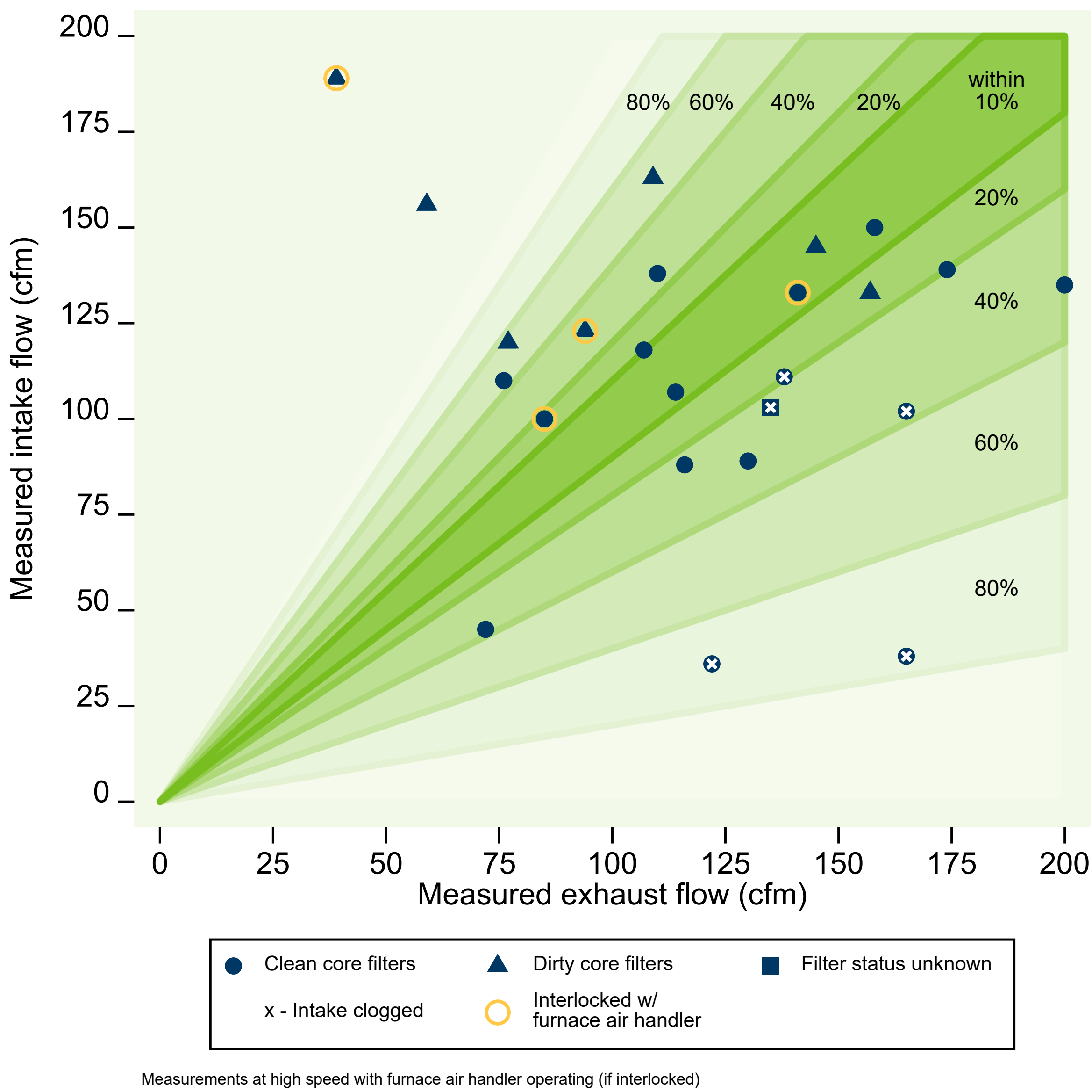
[a] Based on randomly-imputed values for missing data on specific issues (primarily imbalanced flow)
[b] Based on 26 measured systems
[c] Percentage includes fully-ducted and hybrid systems where interlock is not needed and therefore not an issue
[d] Flagged as an issue if no integral dampers or no exterior damper observed for at least one port
[e] Highest rated flow < 90% of code-required total ventilation rate
[f] Based on one non-functional system and one system where intake both the intake and exhaust flow paths were configured for exhaust

Imbalanced Flow

Some HRVs and ERVs have built-in test ports that allow ready measurement of system flow by using built-in test ports to read the intake- and exhaust-path pressure drops across the core and then referencing a chart printed on the unit. We were able to make these measurements for 24 systems. As found, few systems fell within the ±10 percent code requirement for balance (Figure 39).[21] While some imbalanced systems can be attributed to maintenance issues such as clogged intakes or dirty core filters (which can also affect the accuracy of the flow estimates themselves), the data generally suggest that balanced systems are more the exception than the rule. For the 12 measured systems with clean filters and intake ports, flow imbalance ranged from 5 to 45 percent with a median of 22 percent. Only three systems (25%) fell within the code-required 10 percent balance requirement.

[21] In addition to the 24 systems where intake and exhaust flow could be determined, there were two systems where we were not able to look up flow values but where the difference in pressure drops was large enough to determine that the system was imbalanced

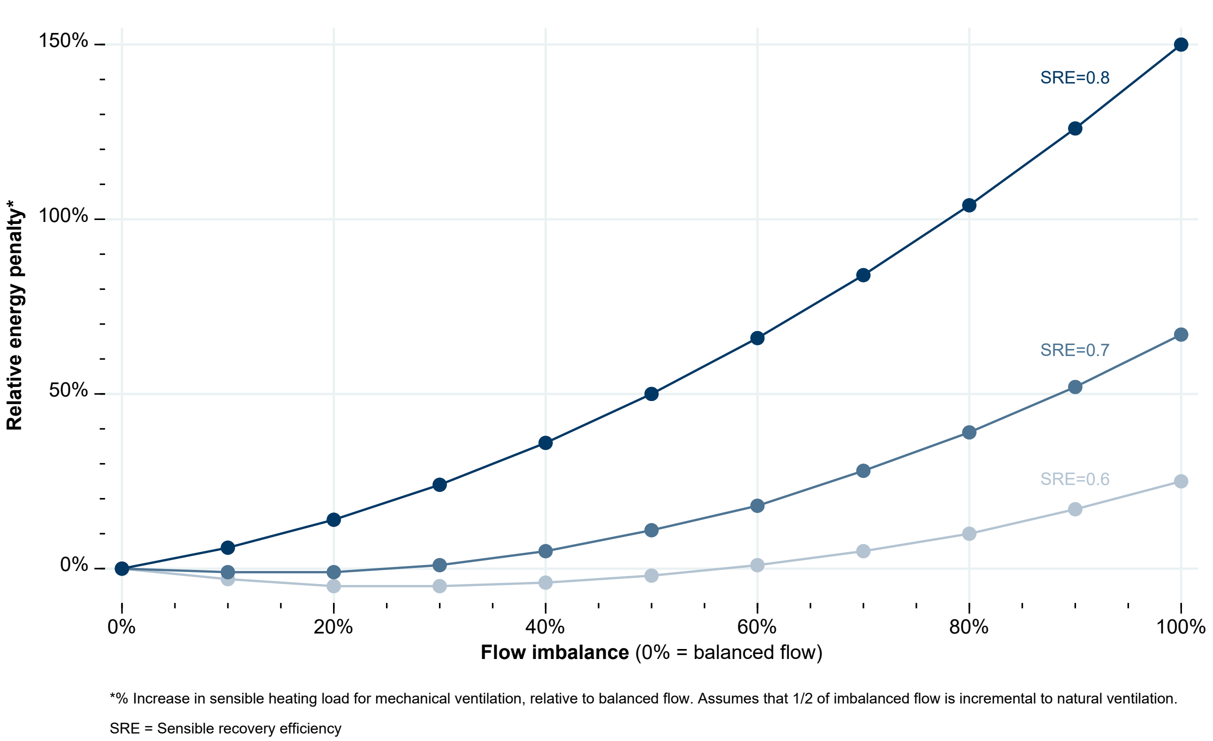
Figure 39. Measured HRV/ERV intake versus exhaust flow (n=24).



To explore the impact of HRV/ERV imbalance on ventilation-related energy consumption we undertook a generic engineering analysis accounting for both changing heat exchanger performance with imbalance as well as the energy penalty from induced infiltration from imbalanced flow. At perfect balance, an HRV/ERV induces no additional ventilation and is assumed to perform at its rated sensible recovery efficiency (SRE). At 100 percent imbalance, the unit simply becomes an exhaust (or supply) fan with no heat recovery. At intermediate degrees of imbalance, the unit both recovers heat from the air that flows through it and induces additional infiltration due to pressure effects from the imbalanced flow. We make a common simplifying assumption here that only half of the flow imbalance is incremental to naturally occurring infiltration.

The results suggest that the heating energy penalty from flow imbalance is modest unless the degree of imbalance is large—but that the penalty is also sensitive to the SRE of the unit (Figure 40). At 50 percent flow imbalance, an HRV with a 60% SRE will have no energy penalty but a unit with an SRE of 80% will carry a heating load that is 50 percent more than it would under balanced flow.[22]

Figure 40. Engineering analysis of relative energy penalty from imbalanced HRV/ERV flow.



Interlock Controls

Minnesota code requires that simplified systems that rely on the heating/cooling ductwork for distribution of ventilation air have an interlock control so that the main air-handler is engaged whenever the HRV or ERV operates. This is to avoid short-circuiting of the ventilation distribution in which the system only ventilates a short section of ductwork without providing air exchange to actual living spaces. The study data shows that more than half of simplified systems lack the required interlock control, and likely receive little effective ventilation during mild weather when there is little cause for the heating and cooling systems to otherwise operate.

Simplified systems are typically installed in order to eliminate the cost for installing dedicated ventilation ductwork to living spaces. The trade-off is that these construction-cost savings come at the expense of higher operating costs from having to run the main air handler in tandem with the ventilation system.

[22] Another way to look at this is to consider that while high- and low-efficiency HRV/ERVs have different levels of energy performance at balanced flow, they all become simple exhaust/supply fans at 100-percent imbalance and have the same (poor) energy performance. This means that high-efficiency units give up their energy performance at a faster rate as imbalance increases from zero to 100 percent.

Even with modern electrically efficient furnaces, the additional air handler operation for an interlocked system will typically consume 250 to 750 kWh of additional electricity per year.[23]

Lost Energy Savings for Mechanical Ventilation

The specification, installation, operation and maintenance of balanced ventilation systems is a complex topic, with numerous issues identified from the site visits conducted for the study. For the purposes here, we made some simplifying assumptions. First, we set aside considerations regarding how homeowners actually operate their ventilation systems and modeled each HRV/ERV as providing the required continuous ventilation rate for the home if the system was capable of meeting that flow rate. Specifically, we modeled each unit at the lowest rated flow that met or exceeded the home's CVR, then adjust the duty cycle of the unit so that the average hourly flow matched the CVR. In theory, homes where the CVR exceeded the highest rated flow for the unit would be modeled as operating continuously at less than the required flow rate; in practice only four homes fell short in this regard, and only by a few cfm in each case.

Second, we modeled the additional electricity needed for furnace air-handler operation with interlocked systems as a simple adder to the wattage draw for the HRV/ERV. We assumed 1 watt of main air-handler power for each kBtuh of furnace input rating (e.g., 75 watts of air-handler power for a 75,000 kBtuh furnace). This is consistent with typical air-handler power draw for electrically efficient furnaces, which are now the norm under new federal furnace-fan efficiency standards. We then derated this value by 15 percent to account for the typical fraction of the year that the air handler would be operating anyway to provide heating or cooling.

Third, we did not attempt to model the effects of flow imbalance or missing backflow-prevention dampers for ventilation systems. In terms of the former, the results for the 24 systems where we were able to make these measurements suggest that severe imbalance with significant ventilation-energy implications is more likely to be the result of inadequate maintenance than installation issues. We judged the energy consequences of missing dampers as being too complex of a topic for this study.

We thus confined our assessment of the lost savings associated with non-compliant ventilation systems to three items:

- Homes that lack a functioning balanced ventilation system entirely
- Systems that are undersized in terms of being able to provide the required continuous ventilation rate for the home
- Simplified systems that lack the required interlock control for the main air handler

We modeled the change in heating, cooling and ventilation energy associated with correcting these issues in each home. In the study sample, this meant modeling the addition of a missing or non-functional system for 11 homes, increasing the system flow for four homes very slightly and adding

[23] A prior CARD field monitoring study (Pigg, et al. 2016) suggests an average of about 1,200 to 1,600 annual operating hours for forced-air space heating and cooling system air-handler, leaving about 7,200 to 7,600 hours of additional air handler operation for a continuously operating ventilation system. The same study suggests about 80 watts of power draw for fan-only operation of an electrically efficient furnace, which translates into 720 to 760 kWh per year of air-handler operation. For a ventilation system that cycles 20 minutes out of the hour, the annual air-handler energy would be about one-third of this range.

interlock control for 47 homes. In most respects, the "lost savings" are negative, because these actions increase heating and cooling loads as well as electricity consumption associated with operating the ventilation system including —for interlocked systems—the main air-handler.

On a statewide population basis, the study suggests that nearly 8 in 10 new homes have lost energy savings opportunities in these respects, with space-conditioning costs that are about 1.5 percent lower than would otherwise be the case (Table 56). Much of this increase is attributable to additional electricity needed to operate air handlers for interlocked systems. The modeling suggests that correcting ventilation systems will increase electricity costs associated with ventilation by about 50 percent (Table 57).

Table 56. Modeled lost savings for mechanical ventilation below prescriptive code (weighted population estimates).

Group	Lost savings incidence (% of homes)	Mean lost savings, % of heating load	Mean lost savings, % of cooling load	Mean lost savings, % of htg/clg costs[a]
Statewide	**79%**	**-1.8%**	**0.0%**	**-1.4%**
Has natural gas service	77%	-1.8%	0.1%	-1.4%
No natural gas service	91%	-1.8%	-0.7%	-1.6%
Enforcement jurisdictions	78%	-0.6%	-0.4%*	-0.4%*
Non-enforcement jurisdictions	87%	-7.1%	1.6%*	-5.8%*
Southern climate zone	79%	-2.2%*	0.1%*	-1.7%*
Northern climate zone	80%	0.3%*	-0.9%*	0.2%*
Utility non-participants	77%	-2.7%	-0.1%	-2.1%
Utility participants	80%	-0.8%	0.0%	-0.6%

(Non-interacted savings)

[a]Includes electricity for mechanical ventilation

*Subgroup differences are statistically significant at a 95% confidence level.

Table 57. Modeled mechanical-ventilation electricity consumption for as-built and compliant conditions (weighted population estimates).

Group	As-built electricity for ventilation[a] (kWh/yr)	Compliant electricity for ventilation[a] (kWh/yr)	Difference (kWh/yr)	Percent difference
Statewide	**928**	**1,346**	**418**	**+45%**
Has natural gas service	986*	1,372	386	+39%
No natural gas service	608*	1,203	595	+98%
Enforcement jurisdictions	1,007*	1,399*	392	+39%
Non-enforcement jurisdictions	586*	1,118*	531	+91%
Southern climate zone	968*	1,389*	420	+43%
Northern climate zone	687*	1,092*	405	+59%
Utility non-participants	841	1,293	452	+54%
Utility participants	1,043	1,397	355	+34%

(Non-interacted savings)

[a]Based on rated HRV/ERV power draw plus estimated incremental furnace air-handler operation for interlocked systems. Modeled at code-required total ventilation rate for compliant case and at lesser of required total ventilation rate or highest rated flow for as-built case. Excludes homes without a functional balanced mechanical ventilation system as-built (n=77).

*Subgroup differences are statistically significant at a 95% confidence level.

Beyond-Prescriptive-Code Savings for Mechanical Ventilation

We considered two strategies for energy savings related to mechanical ventilation. The first is to install an HRV or ERV with a high sensible recovery efficiency. For the purposes here, we assumed a rated SRE of 84%. The second strategy is to install fully ducted or hybrid systems that do not require an air-handler interlock and thus avoid the additional electricity associated with operating the main air handler.

The results of the analysis show modest space-conditioning cost savings for high-SRE systems (Table 58) and several hundred kWh per year worth of electricity savings for avoiding the need for a an air-handler interlock (Table 59), decreasing total energy bills by about 1.5% on average.

Table 58. Mean beyond-prescriptive-code savings for high SRE mechanical ventilation (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of space conditioning costs
Statewide	**2.1%**	**-0.6%**	**19**	**13**	**1.6%**
Has natural gas service	2.1%	-0.5%*	9	13	1.5%
No natural gas service	2.5%	-1.1%*	71	—	2.2%
Enforcement jurisdictions	2.0%	-0.5%*	10	13	1.5%
Non-enforcement jurisdictions	2.6%	-1.1%*	54	15	2.1%
Southern climate zone	2.1%	-0.4%*	10	13	1.6%*
Northern climate zone	2.4%	-1.5%*	69	17	2.1%*
Utility non-participants	2.6%*	-0.8%*	32	15	2.0%*
Utility participants	1.7%*	-0.3%*	1	12	1.2%*

(Non-interacted savings)

[a]For homes with natural gas service.

*subgroup differences are statistically significant at a 95% confidence level.

Table 59. Mean beyond-prescriptive-code savings for fully-ducted or hybrid ducting for mechanical ventilation instead of simplified systems (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of total energy costs
Statewide	**-0.4%**	**1.3%**	**321**	**-3**	**1.7%**
Has natural gas service	-0.4%	1.3%	326	-3	1.8%
No natural gas service	-0.4%	1.4%	294	—	1.0%
Enforcement jurisdictions	-0.5%	1.3%	352	-3	1.8%
Non-enforcement jurisdictions	-0.3%	1.2%	188	-2	1.1%
Southern climate zone	-0.4%	1.3%	330	-3	1.8%
Northern climate zone	-0.4%	1.5%	270	-3	1.2%
Utility non-participants	-0.4%	1.4%	315	-3	1.6%
Utility participants	-0.4%	1.2%	331	-3	1.8%

(Non-interacted savings)

[a]For homes with natural gas service.

*subgroup differences are statistically significant at a 95% confidence level.

Water heating

Energy Code Requirements for Water Heating

As with other mechanical systems, water heaters are subject to federal efficiency standards and not state energy code. The energy efficiency of water heaters is based on their uniform energy factor (UEF), which accounts for typical hot-water use patterns and varies by size and type of water heater.[24] While a typical 40-gallon gas or propane storage water heater must have a UEF of at least 0.58 for a so-called medium use scenario, the UEF of high-efficiency tankless units can exceed 0.9. A conventional electric storage water heater must have a UEF of at least 0.92. The UEF of heat pump water heaters can exceed 3.0. Minnesota residential code does require domestic hot-water pipes to be insulated between the water heater and the kitchen, and for all pipes to be insulated if a non-demand recirculation system is present.

Observed Characteristics for Water Heating

We encountered 89 water heaters in the 87 study homes, though some of these were boilers that provided both space heating and domestic hot water. We classify domestic hot water systems into four types:

- Conventional fuel-fired tank-type water heaters
- Conventional electric tank-type water heaters
- Fuel-fired tankless water heaters
- Fuel-fired indirect water heaters where a boiler heats a storage tank for domestic hot water

Most water heaters among new homes are conventional tank-type units, but tankless water heaters make up a significant fraction of northern homes (Table 60). Propane water heaters are most common in the northern region (Table 61). We encountered no atmospherically vented water heaters in the study. Electric water heaters have somewhat larger storage volumes than fuel-fired water heaters (Table 62).

Ten of the 17 tankless water heaters encountered in the study and three of the four indirect-fired water heaters were part of a system that also provided space heat (Figure 41). All of these units were condensing equipment with combustion efficiencies above 90 percent, though indirect-fired water heaters have tank losses that make their seasonal efficiency lower (Figure 42).

[24] UEF replaces the older energy factor (EF) rating, which is typically slightly higher. For example, a gas water heater with a UEF rating of 0.58 will have an EF rating of about 0.60. The REM/Rate software continues to use the older EF values, however, so those are reported here.

Table 60. Water heater characteristics (weighted population estimates).

Group	% Conventional fuel-fired	% Conventional electric	% fuel-fired tankless	% indirect-fired
Statewide	**54%**	**30%**	**12%**	**3%**
Has natural gas service	63%*	25%	9%	3%
No natural gas service	10%*	58%	29%	3%
Enforcement jurisdiction	59%	32%	5%	4%
Non-enforcement jurisdiction	33%	24%	40%	3%
Southern climate zone	61%*	26%*	10%	3%
Northern climate zone	16%*	57%*	24%	4%
Utility program non-participant	43%	34%	22%	2%
Utility program participant	73%	19%	1%	7%

N=87 homes *Subgroup differences are statistically significant at a 95% confidence level

Table 61. Conventional fuel-fired water heater characteristics (weighted population estimates).

Group	% fueled by natural gas	% fueled by propane	Mean tank volume (gallons)	Mean efficiency (EF)
Statewide	**93%**	**7%**	**51**	**0.68**
Has natural gas service	>99%	<1%	51	0.69
No natural gas service	<1%	>99%	50	0.66
Enforcement jurisdiction	>99%	<1%	51	0.69
Non-enforcement jurisdiction	67%	33%	50	0.68
Southern climate zone	99%*	1%*	51	0.69*
Northern climate zone	45%*	55%*	50	0.65*
Utility program non-participant	86%	14%	52	0.67
Utility program participant	>99%	<1%	50	0.69

N=36 homes with conventional fuel-fired water heater

*Subgroup differences are statistically significant at a 95% confidence level.

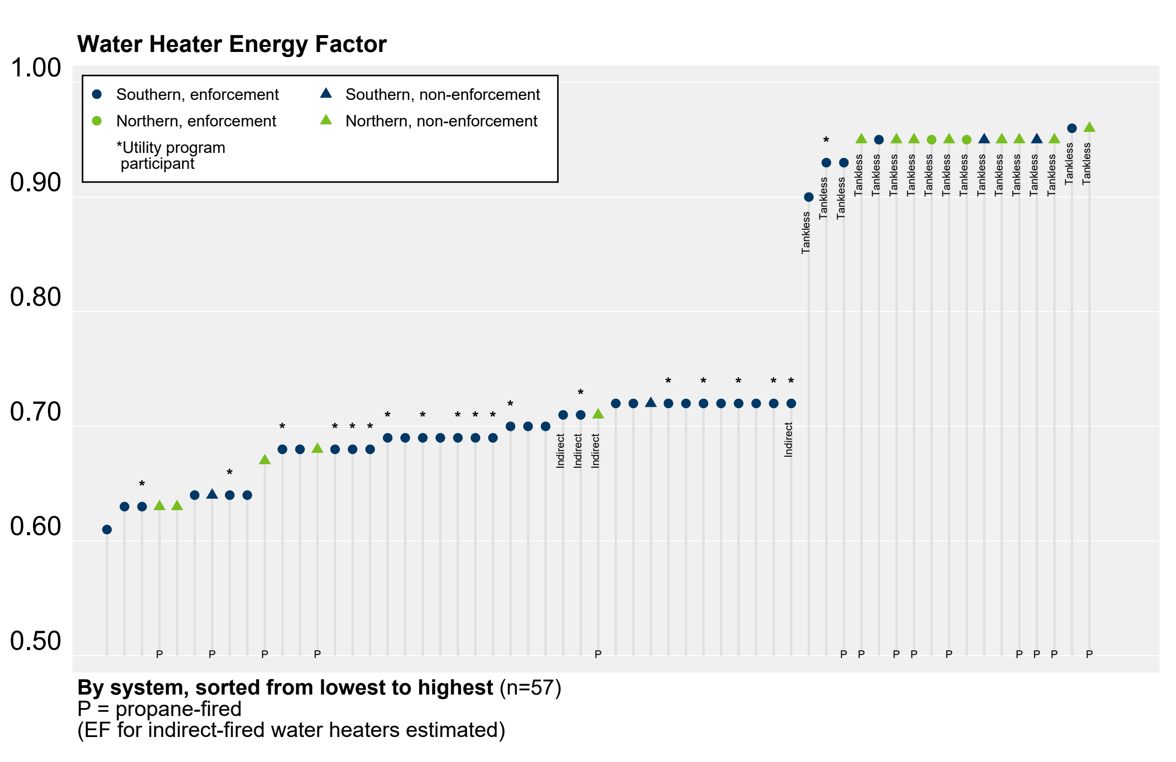
Table 62. Conventional electric water heater characteristics (weighted population estimates).

Group	Mean tank volume (gallons)	Mean efficiency (EF)
Statewide	**59**	**0.91**
Has natural gas service	56	0.91
No natural gas service	67	0.92
Enforcement jurisdiction	61	0.91
Non-enforcement jurisdiction	54	0.93
Southern climate zone	61	0.91
Northern climate zone	53	0.93
Utility program non-participant	65	0.91
Utility program participant	58	0.90

N=30 homes with a conventional electric water heater

Figure 41. Example of a condensing tankless system that provides both space heating and domestic hot water (Site 144).

Figure 42. Water heater efficiency for fuel-fired units.



Recirculation Systems

Five homes in the sample had domestic hot water recirculation systems like that shown in Figure 43 and only one of these appeared to have fully insulated water lines. However at least three of the five homes used adaptive recirculation pumps that—depending on the setting—should mitigate line losses compared to traditional timer-based systems.

Figure 43. Domestic hot water recirculation system with adaptive circulator and uninsulated lines (Site 141).

Lost Energy Savings for Water Heating

Our analysis of lost energy savings is confined to homes with recirculation systems that lack the required full pipe insulation. The results suggest a 3 percent incidence of such homes, with average water heating consumption and cost savings of 35 percent when applicable.

Beyond-Prescriptive-Code Savings Opportunities for Water Heating

We considered separate beyond-prescriptive-code measures for fuel-fired and electric water heaters. For the former, we modeled the savings from upgrading all water heaters to 0.95 EF condensing tankless units. On the electric side, we modeled the impact of universally installing heat pump water heaters with an EF of 2.7.

The results suggest about 30 therms/year of gas savings for high-efficiency gas water heaters (Table 63). Heat pump water heaters show significant energy-cost savings (Table 64) that are a combination of direct savings for reduced electricity for making domestic hot water, slightly increased heating costs from the heat pump water heater extracting heat from indoor spaces during the winter and conversely, indirect savings for summer cooling bills. These interactions are complex, however, and we do not know how well the REM/Rate modeling software handles them.

Table 63. Mean beyond-prescriptive-code savings for condensing-efficiency fuel-fired water heaters (weighted population estimates).

Group	Natural gas (therms/yr)[a]	% of water heating costs saved[b]
Statewide	**30.2**	**23.0%**
Has natural gas service	33.5	24.5%*
No natural gas service	0.0	9.5%*
Enforcement jurisdictions	35.3*	25.5%
Non-enforcement jurisdictions	10.5*	13.2%
Southern climate zone	32.5*	23.9%
Northern climate zone	7.0*	14.1%
Utility non-participants	23.9*	19.9%
Utility participants	36.9*	26.1%

(Non-interacted savings)

[a]For homes with natural gas space heat.

[b]For homes with fuel-fired water heating equipment.

*Subgroup differences are statistically significant at a 95% confidence level.

Table 64. Mean beyond-prescriptive-code savings for heat pump water heaters for homes with electric water heaters (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	% of water heating costs	% of total energy costs
Statewide	**-7%**	**22%**	**2,760**	**66%**	**11%**
Has natural gas service	-7%	21%	2,800	66%	13%*
No natural gas service	-6%	23%	2,640	66%	8%*
Enforcement jurisdictions	-7%	21%	2,890	66%	12%*
Non-enforcement jurisdictions	-6%	27%	2,030	65%	7%*
Southern climate zone	-7%	21%	2,800	66%	12%
Northern climate zone	-6%	24%	2,640	65%	9%
Utility non-participants	-7%	22%	2,620	66%	10%*
Utility participants	-8%	23%	3,030	66%	14%*

(Non-interacted savings)
*subgroup differences are statistically significant at a 95% confidence level.

Lighting

Energy Code Requirements for Lighting

Minnesota energy code requires that at least 75 percent of lamps in hard-wired fixtures be high-efficacy[25] or 75 percent of fixtures have only high-efficacy lamps. High-efficacy generally means LEDs, CFLs and linear fluorescent lamps with a T-8 diameter or smaller.

Observed Characteristics for Lighting

We counted lamp sockets by lamp type for hard-wired and plug-in interior luminaires, exterior fixtures and garage fixtures. We also asked homeowners whether any changes had been made to the lighting since construction: 11 homes where non-trivial changes to fixtures or lamps had been made are omitted here.

The average new home has about 100 lamps, with most installed in hard-wired interior fixtures (Table 65). About three-quarters of hard-wired fixtures have LED bulbs and a similar proportion of homes meet the prescriptive code requirement for 75 percent high-efficacy lighting (Table 66).[26]

[25] Efficacy measures how well a light source produces visible light.

[26] Our assessment of the percent of homes with the prescriptive code requirement is based on the percent of lamps that are high-efficacy and assumes that all observed LEDs, CFLs and linear fluorescents meet the energy code requirements for high-efficacy lighting.

Table 65. Lighting socket counts (weighted population estimates).

Group	Mean total sockets	Mean sockets in interior hard-wired fixtures	Mean sockets in interior plug-in fixtures	Mean sockets in exterior fixtures	Mean sockets in garage fixtures
Statewide	98.8	75.0	7.0	9.2	7.6
Has natural gas service	98.3	76.1	7.2	8.6	6.4
No natural gas service	100.7	70.0	6.2	11.8	12.7
Enforcement jurisdiction	93.3	71.9	7.3	8.5*	5.6*
Non-enforcement jurisdiction	122.3	88.5	5.7	12.0*	16.0*
Southern climate zone	101.1	77.0	7.4*	9.0	7.7
Northern climate zone	84.9	63.0	4.6*	10.4	6.8
Utility program non-participant	103.4	76.4	6.5	10.3*	10.2*
Utility program participant	89.3	71.2	8.3	6.9*	2.9*

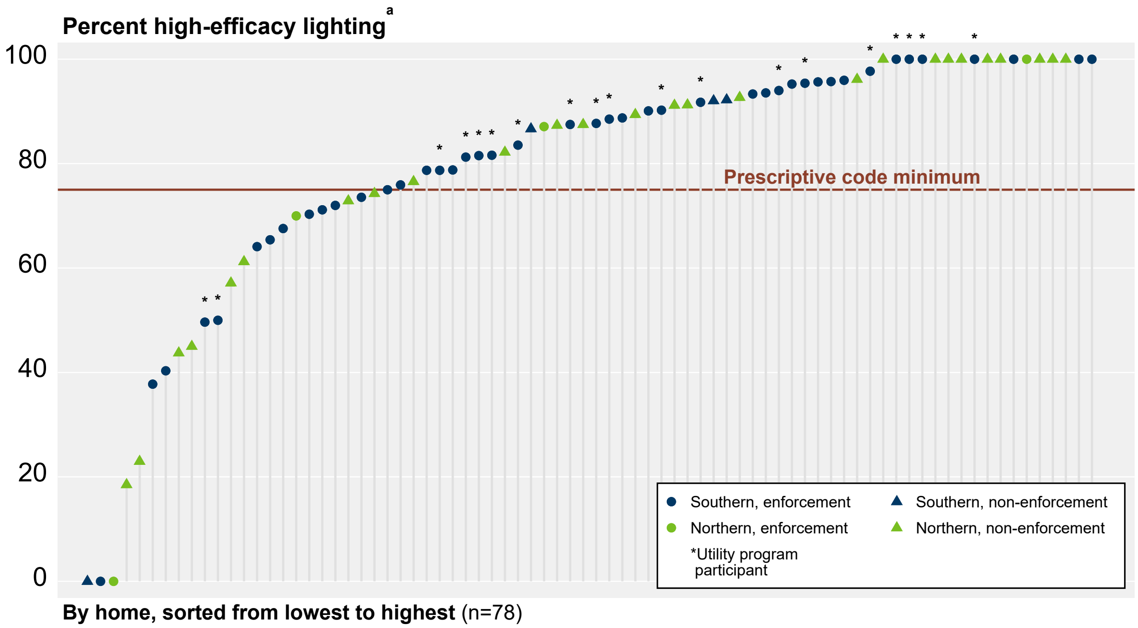
N=76 homes with no substantial lighting changes since construction
*subgroup differences are statistically significant at a 95% confidence level

Table 66. Lamp-type proportions for hard-wired fixtures (weighted population estimates).

Group	% LED	% CFL	% Linear fluorescent	% Incandescent	% of homes meeting prescriptive code requirement
Statewide	75%	5%	2%	17%	76%
Has natural gas service	78%	6%	1%	15%	79%
No natural gas service	64%	4%	7%	24%	63%
Enforcement jurisdiction	75%	6%*	2%	16%	76%
Non-enforcement jurisdiction	74%	2%*	4%	20%	75%
Southern climate zone	76%	6%	2%	16%	78%
Northern climate zone	71%	4%	5%	21%	67%
Utility program non-participant	73%	4%	3%	20%	67%
Utility program participant	78%	7%	2%	13%	91%

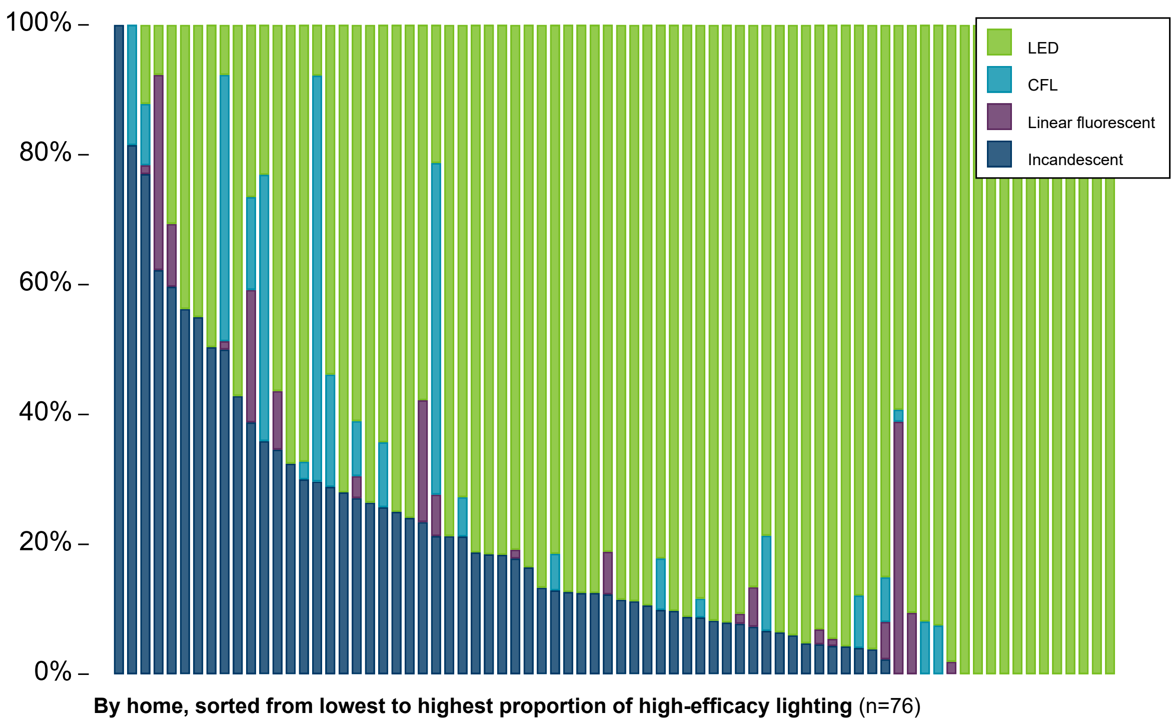
N=76 homes with no substantial lighting changes since construction; prescriptive code requirement also includes 2 additional homes where household reported that home was mostly or all incandescent at time of construction.
*subgroup differences are statistically significant at a 95% confidence level.

Figure 44. Percent high-efficacy lighting.



[a] Hard-wired fixtures only. High efficacy means LED, CFL or linear fluorescent.
Based on site-visit counts for homes where household reported no major changes to lighting since construction.
Also includes two homes where household reported all incandescents at time of construction

Figure 45. Lamp-type proportions by home.



Lost Energy Savings for Lighting

We assessed lost energy savings for lighting relative to the energy code requirement that 75 percent of hard-wired fixtures be high efficacy lighting. For homes in the sample that did not meet this threshold, we increased the proportion of LED lighting until it just met the code threshold. The results indicate that about a quarter of new homes in the state could reduce their lighting energy use by about 20 percent, with about a three percent of their total energy bill, if hard-wired lighting was brought up to the energy code requirement (Table 67).

Table 67. Modeled lost savings for lighting (weighted population estimates).

Group	Lost savings incidence[a] (% of homes)	Mean lost savings % of lighting kwh	Mean lost savings % of total annual energy costs
Statewide	**26%**	**22%**	**2.9%**
Has natural gas service	24%	19%	2.6%
No natural gas service	38%	35%	4.2%
Enforcement jurisdictions	27%	21%	2.8%
Non-enforcement jurisdictions	23%	28%	3.4%
Southern climate zone	26%	22%	2.9%
Northern climate zone	31%	23%	3.0%
Utility non-participants	34%	22%	2.7%
Utility participants	16%	23%	3.3%

[a]Percent of homes with fewer than 75% high-efficacy lamps in hard-wired fixtures.

Beyond-Prescriptive-Code Energy Savings for Lighting

For beyond-prescriptive-code lighting savings, we examined the impact of increasing all lighting to 100 percent LED, which some homes have already achieved. The results (Table 68) show about 25 percent savings on lighting costs, with slightly negative heating impacts and positive cooling savings. The combine effect is an average 2 percent reduction in total energy costs.

Table 68. Mean beyond-prescriptive-code savings for 100% LED lighting (weighted population estimates).

Group	% of total heating load	% of total cooling load	Electricity (kWh/yr)	Natural gas (therms/yr)[a]	% of lighting costs
Statewide	**-0.9%**	**2.6%**	**403**	**-5**	**23.1%**
Has natural gas service	-0.8%	2.5%	408	-5	22.5%
No natural gas service	-1.0%	3.2%	380	—	26.3%
Enforcement jurisdictions	-0.9%	2.6%	422	-6	24.0%
Non-enforcement jurisdictions	-0.7%	2.5%	322	-4	19.2%
Southern climate zone	-0.9%	2.5%	420	-5	23.1%
Northern climate zone	-0.8%	3.0%	304	-5	23.1%
Utility non-participants	-1.0%	3.0%	428	-6	25.6%
Utility participants	-0.7%	2.0%	365	-5	19.9%

(Non-interacted savings)

[a]For homes with natural gas service.

*Subgroup differences are statistically significant at a 95% confidence level.

Single-Family Renovation

Additions and renovations to existing homes are also subject to energy code requirements and can offer beyond-prescriptive-code energy efficiency opportunities. Many renovation projects involve kitchens, bathrooms, decks, and other areas that have little or no energy-use implications. Heated additions and major home renovations involving the thermal shell are our focus here, but we also look at window replacement and re-siding as potential efficiency upgrade opportunities. Our analysis is confined to code-enforcement jurisdictions because renovation permits were the only ready way for us to identify projects to study.

We obtained building permit data for 2016 through mid-2019 from a number of jurisdictions (Table 69) and reviewed these to identify additions and renovation projects that might trigger energy-code compliance or that might offer energy upgrade opportunities. We used this information both to assess the incidence of renovation activity in the state and to recruit a sample of homes for on-site data collection. Results for the latter are described later in this section: here we examine what the permit data indicate about the scale of renovation activity in Minnesota.

We reviewed the work description associated with permits to ascertain renovation rates for key activities such as additions and major remodels, which we express in terms of number of projects per year per 10,000 single-family homes in the jurisdictions. The calculated rates vary among the jurisdictions, in some cases apparently because some jurisdictions do not require permits for some activities (e.g. re-siding) so they only appear in work descriptions in association with other activities that do require a permit. We removed these outlier values, and then calculated population-weighted average incidence rates.

The results suggest that about 10 in 10,000 single-family households each year undertakes an addition or major remodel.[27] A small number of households (about 1 in 10,000) convert a porch to heated space annually. The incidence of homes being re-sided (45 in 10,000) or receiving new windows (30 in 10,000) is much higher. Among the 75 percent of permits involving windows that specified the number replaced, on average, six windows were noted for replacement, though this varied from one to almost 50. Only about 15 percent of siding jobs also mentioned window replacement.

Table 69. Reviewed permits by jurisdiction and year.

Jurisdiction	2016	2017	2018	2019	Total
Bloomington	0	56	38	259	353
Duluth	215	193	188	72	668
Eden Prairie	1,642	1,421	1,291	561	4,915
Edina	433	224	152	49	858
Maple Grove	1,598	2,683	1,571	643	6,495
Minneapolis	522	1,807	1,403	0	3,732
Minnetonka	1,274	1,060	940	372	3,646
Rochester	3,666	3,688	3,548	1,243	12,145
St Louis Park	341	329	305	117	1,092
Total	9,691	11,461	9,436	3,316	33,904

Table 70. Annual renovation incidence (per 10,000 existing homes).

Jurisdiction	Addition	Major remodel	Four-season porch conversion	Re-siding	New Windows
Bloomington	9.5	2.6	0.4	2.6*	22.8
Duluth	12.1	0.6*	0.0	41.4	8.2*
Eden Prairie	4.5	5.0	3.6	43.2	30.1
Edina	4.5	3.3	1.4	2.0*	20.8
Maple Grove	2.4	1.2	0.3	48.5	93.2
Minneapolis	4.3	9.7	0.6	4.9*	18.9

[27] Some households undertake both at the same time, so the combined incidence rate for the two is somewhat less than the sum of their individual rates.

Jurisdiction	Addition	Major remodel	Four-season porch conversion	Re-siding	New Windows
Minnetonka	12.1	4.8	2.7	47.7	12.1
Rochester	0.3*	2.4	2.4	1.4*	30.0
St Louis Park	1.8	1.8	0.9	8.8*	4.5*
Overall (weighted)	**6.0**	**5.4**	**1.2**	**45.1**	**20.1**

*omitted from weighted average

Code Requirements

Code requirements for additions and renovations are generally the same as those for new construction, with some important exemptions:

- Unaltered spaces are not required to be brought up to code
- Ceilings, walls and floors that are exposed during construction are only required to have cavities filled with insulation and are not required to meet current prescriptive R-values.
- Re-roofing and re-siding alone do not require bringing existing ceilings and walls up to current code
- Alterations to existing buildings are exempt from the mechanical ventilation requirements of the code.

Lost Savings and Beyond-Prescriptive-Code Savings Potential for Sampled Renovation Projects

As noted above, to explore the energy implications of additions and renovations of single-family homes, we recruited a sample of 13 homes that had recently been renovated. The recruiting focused on additions or major renovations in 2016 or later. Although we attempted to recruit from all nine jurisdictions for which we had obtained permit data, we were only successful in two and conducted site visits to 12 homes in the City of Minneapolis and one home in Rochester.

The 13 homes in the sample, ranged in age from less than 15 to more than 100 years old (Table 71), with assessed values that ranged from less than $250,000 to more than $1,000,000. All of the sampled projects involved some kind of addition to the heated floor area of the house, but this ranged from less than 100 ft^2 to more than 1,600 ft^2. Four of the projects also involved significant renovation of existing spaces.

We evaluated each project in terms of lost savings relative to prescriptive energy code and also evaluated the potential for beyond-prescriptive-code energy savings using the same list of measures as for the new-construction analysis (Table 72). In addition to analyzing the savings potential for the added or renovated space, we also looked for beyond-prescriptive-code savings for the remainder of the home if this could have been readily addressed during the project: for the most part, this came down to considering bringing all attic areas up to the beyond-prescriptive-code R-60 level. We only considered beyond-prescriptive-code air leakage reductions in whole-home gut rehab projects and increased the target air-change rate to 3 ACH50 for renovation. In addition, for mechanical systems, we only considered efficiency upgrades for the beyond-prescriptive-code analysis if new equipment was installed at the time of the renovation.

For the most part, modeled lost-savings relative to prescriptive energy code were small for the sample (Table 73). Four homes were fully at or above prescriptive energy code and thus had no lost savings. Most of the rest of the homes had minor lost savings because insulation levels were close to prescriptive levels, the affected areas were small, or both.

The notable exception to this is Site 172, which bears additional explanation. This 4,900 square-foot, turn-of-the-20th-century home in Minneapolis has a current assessed value of about $900,000. The renovation project involved a complete gut rehab of the basement and first of two floors of the existing home and a small addition (connecting the home to the existing detached garage). As part of the project, a furnace to serve the second floor was installed in the existing uninsulated third-story walk-up attic (Figure 46). Per energy code, installing space-conditioning equipment with uninsulated ducts changes the space from unconditioned to conditioned—and that in turn triggers a requirement to insulate the space. Leaving the attic uninsulated thus represents a substantial lost-savings opportunity for this home.

Site 172 also showed considerable beyond-prescriptive-code energy savings potential due to the extensive nature of the renovation and the poor existing thermal shell (Table 74). With a few other exceptions, however, the modeled beyond-prescriptive-code savings potential for the sample are fairly small in terms of energy-cost savings. Due to mostly shell improvements, there are some homes with considerable gas savings potential but little in the way of electricity savings.

Figure 46. Furnace installed in an uninsulated walk-up attic at Site 172.

Table 71. Summary of renovation projects included in the study

Site ID	Year home built	Description of Renovation
167	1980	Rear 450 ft^2 addition on raised frame-floor
168	1927	Gut rehab of home, plus 315 ft^2 addition over new crawlspace that connects to existing basement
169	1900	274 ft^2 addition over new basement.
170	1962	364 ft^2 addition over ICF walk-out basement; replacement of some windows
171	1906	Second floor rehab and 150 ft^2 addition; converted 3rd floor attic to living space
172	**1904**	**Gut rehab with small addition (130 ft^2); furnace installed in uninsulated walk-up attic.**
173	2005	Rear 720 ft^2, two-story addition on new walkout basement
174	1922	Gut rehab of home with rear 264 ft^2 addition over new semi-conditioned crawlspace; all new windows
175	1918	Rear 288 ft^2 addition over new basement; residing and new windows
176	1922	Rear addition (132 ft^2) over new frame-floor foundation; heated with baseboard electric
177	1911	Small (<100 ft^2) rear addition over enclosed crawlspace and frame floor to expand kitchen
178	1998	Walk-out two-story addition (1,640 ft^2) to rear of home, served by added furnace and A/C
179	1950	Converted 1.5 story to full two-story, served by mini-split heat pump

Table 72. Lost-savings and beyond-prescriptive-code opportunities for the renovation sample.

Site ID	Lost-savings	Beyond-prescriptive-code opportunities
167	None	Ceilings*; above-grade walls; windows
168	None	Ceilings*; foundation walls; slab; windows; A/C upgrade
169	None	Foundation walls; slab; windows; A/C upgrade
170	Walk-out slab uninsulated	Above-grade walls; slab; windows; A/C upgrade
171	Spray-foam ceiling ins. below code	Ceilings; windows

Site ID	Lost-savings	Beyond-prescriptive-code opportunities
172	**Converted walk-up attic left uninsulated.**	**Ceilings*; above-grade walls; air leakage**
173	Foundation walls and slab not insulated	Ceilings*; above-grade walls; foundation walls; slab; windows
174	None	Ceiling; above-grade walls; windows; air leakage; furnace and A/C efficiency upgrade
175	Ceiling and foundation walls under-insulated	Ceilings*; above-grade walls; foundation walls; windows
176	Ceiling and above-grade walls under-insulated	Ceilings*; above-grade walls; frame floor; windows; mini-split heat pump
177	Ceiling under insulated; windows below code	Ceiling; above-grade walls; crawlspace foundation walls*; windows
178	Ceiling exceeds vaulted ft^2 limit; foundation walls under insulated; slab uninsulated	Above-grade walls; foundation walls; slab; windows; furnace and A/C upgrade
179	Ceiling exceeds vaulted ft^2 limit	Windows

*Savings includes spaces outside of the renovation project that could have been readily addressed at the time of the project

Table 73. Modeled lost savings for the renovation sample.

Site ID	Heating load (%)	Cooling load (%)	Nat gas (therms/yr)	Electricity (kWh/yr)	Energy costs ($/yr)	Energy costs (%)
167	0.0%	0.0%	0	0	$0	0.0%
168	0.0%	0.0%	0	0	$0	0.0%
169	0.0%	0.0%	0	0	$0	0.0%
170	4.8%	-2.2%	35	-16	$22	1.4%
171	6.0%	2.0%	118	41	$83	2.8%
172	**28.5%**	**19.3%**	**795**	**459**	**$579**	**16.6%**
173	7.8%	-3.5%	58	-7	$37	2.1%
174	0.0%	0.0%	0	0	$0	0.0%
175	1.0%	-0.4%	9	4	$7	0.4%
176	0.8%	-0.7%	8	13	$6	0.4%
177	0.3%	1.3%	4	8	$4	0.2%

Site ID	Heating load (%)	Cooling load (%)	Nat gas (therms/yr)	Electricity (kWh/yr)	Energy costs ($/yr)	Energy costs (%)
178	6.8%	-2.9%	90	10	$61	2.4%
179	1.2%	0.6%	10	22	$9	0.5%
Median	**1.0%**	**0.0%**	**9**	**4**	**$7**	**0.4%**
Mean	**4.4%**	**1.0%**	**87**	**41**	**$62**	**2.1%**

Table 74. Modeled beyond-prescriptive-code savings for renovation sample.

Site ID	Heating load (%)	Cooling load (%)	Nat gas (therms/yr)	Electricity (kWh/yr)	Energy costs ($/yr)	Energy costs (%)
167	11.5%	-0.1%	154	99	$113	4.4%
168	6.9%	-3.7%	37	81	$34	2.1%
169	4.9%	-5.1%	48	105	$44	2.4%
170	10.9%	-4.1%	76	105	$62	4.0%
171	2.7%	-1.3%	49	6	$33	1.2%
172	**39.5%**	**37.7%**	**786**	**66**	**$529**	**18.1%**
173	21.8%	12.3%	150	3	$100	5.7%
174	32.0%	-15.0%	288	170	$210	12.6%
175	6.2%	-1.1%	56	32	$40	2.5%
176	2.3%	-1.6%	98	-323	$33	1.9%
177	3.0%	-0.7%	41	-1	$27	1.3%
178	15.5%	-5.7%	204	43	$140	5.6%
179	1.1%	-0.2%	9	17	$8	0.5%
Median	**6.9%**	**-1.3%**	**76**	**43**	**$44**	**2.5%**
Mean	**12.2%**	**0.9%**	**154**	**31**	**$106**	**4.8%**

Putting these various estimates together and focusing on natural gas savings, we estimate that, statewide, about 1,200 homes with natural-gas heat undertake an addition or major remodel each year. At the median values for lost savings and beyond-prescriptive-code savings above, this translates into statewide totals of about 11,000 therms of lost savings relative to prescriptive energy code and about 90,000 therms worth of beyond-prescriptive-code savings opportunities. There is considerable uncertainty in these estimates owing to the imprecise nature of assessing the scale of activity from permit work descriptions as well as the fact that the small on-site sample showed considerable variability in the magnitude of the savings.

In addition, the permit data suggest that about 5,000 gas-heated homes per year receive new siding and about half that number install new windows. However, since these types of jobs were not included in the on-site sample, we did not attempt to estimate savings potential for them.

Low-Rise Multifamily New Construction

Multifamily buildings that are three stories or less in height are also subject to residential energy code. Census data on building permits do not differentiate low-rise from mid- and high-rise permit data, but we estimate that about 80 percent of new multifamily properties are low-rise, which would translate into roughly 7,000 to 9,000 housing units and 100 to 150 such properties constructed annually in Minnesota.

We did not collect any primary data for low-rise multifamily new construction as part of this study. Instead, we rely here on data collected for a concurrent Department of Energy (DOE) study that included Minnesota among the four states that it examined (Davis et al. 2020).[28]

The Minnesota sample included site-visits to 25 new properties subject to residential code, with detailed air-leakage testing for an additional 12 properties. In addition to detailed on-site data collection, the study involved modeling with prototype buildings to assess lost energy savings. Here, we summarize some of the key data from the effort. We also leverage the modeling results to calculate a rough estimate of beyond-prescriptive-code savings potential in this housing stock.

The 25 properties in the study ranged from 10 to 71 units, with an average of about 43 units and an average conditioned floor area of about 51,000 square feet. Most (23 of 25) were common-entry style buildings but two had a separate outdoor entrance for each unit and lacked hallways or other common-area spaces. Code= path was captured as part of the study for all but one property: 70 percent followed the prescriptive path and 30 percent followed a performance path. In addition, nearly 40 percent were certified under the federal Energy Star Multifamily New Construction program.

The sampled properties employed a number of foundation types, including underground garages. Because of this complexity—and the fact the parking garages are subject to commercial code—we did not further assess foundation energy consumption or savings opportunities.

In terms of mechanical systems, two-thirds of the properties used individual gas furnaces, almost all of which were a popular package system that combines a gas furnace with a packaged air conditioner. Four properties employed gas-boiler based water-source heat pump systems and three properties had conventional central, gas-fired hydronic boiler systems. All but three of the gas-based systems had condensing high efficiency systems.

[28] The four states involved in the DOE study are: Minnesota, Illinois, Oregon and Washington. Slipstream was a member of the project team and conducted market research as well as fieldwork in Illinois. The Center for Energy and Environment conducted the Minnesota fieldwork and led an air-leakage testing task under the study.

Only one property in the study employed electric-resistance heat. In this regard, the sample may be biased toward areas with natural gas service, as Census data indicate that 40 percent of Minnesota households residing in multifamily properties built in 2010 or later use electricity for space heating.[29] We will return to this topic briefly at the end of this section.

The properties in the DOE sample mainly rely on the aforementioned packaged furnace/air-conditioner system for space cooling as well as the water-loop heat pumps for the properties that employed that heating strategy. Only three properties relied on window A/C units and two properties used individual split-system air conditioners.

For domestic hot water, nearly all of the properties (22 of 25) used central boiler-based systems, with an average efficiency of more 96.6%.

Only 7 of the 25 sampled properties (29%) appear to have the code-required balanced ventilation system. Assessing the energy implications of this is beyond the scope of this study—but deserves additional consideration.

We summarize the findings for key attributes of the sample relative to prescriptive energy code levels in Table 75. For several attributes, all buildings in the sample were at or above prescriptive code: we label these as ">95%" to allow for the probability that there are at least a few buildings in the population that do not meet these thresholds.

Table 75. Low-rise multifamily attributes relative to prescriptive energy code by component.

Component	Prescriptive code requirement	% at or above prescriptive code
Ceilings	R-49	68%
Above-grade walls	R-20/21	82%
Foundations	R-15 walls R-10 slabs	>95%
Floors[a]	R-10	83%
Windows	U-0.32	80%
Air leakage[b]	3 ACH50	>95%
Lighting[c]	75%+ high-efficacy	>95%

[a]Applicable to half of properties in the sample

[b]Based on 12 properties that were tested for air leakage

[c]For common-area and in-unit hard-wired lighting. Excludes parking and garage lighting.

With regard to air-leakage, the 12 tested properties had whole-building air leakage that ranged from 0.95 to 2.23 ACH50, with an average of 1.34 ACH50. Average leakage for the multifamily properties was thus even tighter than that for single-family homes (1.88 ACH50)

[29] The source for this estimate is the 2013-2017 American Community Survey Public Use Microdata Sample.

Some properties had building components that were below prescriptive-code levels. We used modeling-based scaling factors from the DOE study to estimate the average impact on space-conditioning energy from bringing all properties up to prescriptive energy code levels, as well as for going to the beyond-prescriptive-code levels that we defined for single-family new construction, which we compare to the results for the same components from the single-family analysis.[30]

The results suggest that lost-savings potential is similarly low for multifamily properties and that beyond-prescriptive-code savings potential while still considerable is perhaps somewhat less than for single-family housing (Table 76).

Table 76. Estimated lost savings and beyond-prescriptive-code savings for multifamily heating and cooling.

Component	Multifamily lost savings below prescriptive code[a] (% of htg/clg costs)	(for comparison) Single-family lost savings below prescriptive code[a] (% of htg/clg costs)	Multifamily beyond-prescriptive-code savings potential[b] (% of htg/clg costs)	(for comparison) Single-family beyond-prescriptive-code savings potential[b] (% of htg/clg costs)
Ceilings	0.5%	0.2%	1.4%	3.3%
Above-grade walls	0.6%	1.5%	3.6%	11.9%
Windows	0.5%	0.0%	9.5%	9.7%
Air leakage	0.0%	0.4%	4.7%	10.9%
Total	**1.6%**	**2.1%**	**19.2%**	**35.8%**

[a]Includes cases where as-built condition is at or above prescriptive code and lost savings are therefore zero.
[b]R-60 ceilings; R-30 (assembly) walls; triple-pane (U-0.17/SHGC 0.24) windows; 0.5 ACH50 air leakage.

One beyond-prescriptive-code measure that could be significant in the low-rise multifamily housing segment—but that we were not able to adequately evaluate—is displacing electric resistance space heating with heat pumps. Census data show that 40 percent of recently built (2010 or later) multifamily housing units are heated with electricity, though the data do not tell us how much of this is resistance-electric heating. Because the DOE study included only one electrically-heated property, we are left somewhat in the dark regarding the opportunity incidence for heat pumps in low-rise multifamily new construction. The Census data suggest that about three quarters of these properties are in the service territories of investor-owned utilities and mostly in Xcel Energy's service area.

[30] The DOE-study modeling results were not amenable to this approach for air-leakage, which we estimated separately with our own prototype model at 5.6% space-conditioning savings per 1 ACH50 reduction in air leakage.

Discussion and Recommendations

The data gathered for this study suggest that Minnesota builders are doing a good job of constructing single family housing units that on average actually exceed the minimum energy performance required by state energy code. Generally speaking, opportunities for improving construction practices that are below prescriptive energy code appear to be few, and the energy savings to be had from these are relatively minor.

The one item that stands apart in this regard is mechanical ventilation, where the study found widespread issues with the specification, installation, and operation of code-required balanced systems, which appear to be nearly universally heat-recovery and energy-recovery ventilators. This is concerning from the perspective of indoor air quality, because—along with neighboring Wisconsin—Minnesota new homes appear to be among the tightest in the nation in terms of air leakage. Given the old mantra "build tight, ventilate right," Minnesota builders are proving more successful at the former than the latter. This suggests a broad need for education and training related to mechanical ventilation by the State and Minnesota utilities.

From a utility program perspective, the mechanical-ventilation issues identified here pose something of a challenge, since a consequence of correcting some problems found in the study will be an increase in ventilation-related energy consumption. However, the goal of utility new construction programs should be to encourage the construction of efficient housing without compromising indoor air quality and health. Programs that encourage tight construction should simultaneously take steps to ensure proper specification and installation of mechanical ventilation, as well as provide homeowners with information and training about how to properly operate and maintain the systems. Treating code-compliant mechanical ventilation and occupant education as a program requirement to ensure that beyond-code air sealing does not compromise comfort and health might be one way to sidestep issues what would otherwise seem to be negative energy impacts.

In one sense, Minnesota's unique balanced-ventilation energy code requirement offers an opportunity for utility programs in the state to push the national envelope in terms of building tightness and energy savings. In other states, the installation of balanced heat-recovery ventilation poses a significant first-cost hurdle, which limits the willingness of the industry to move toward ultra-tight, Passive-House levels of air sealing. That particular hurdle is absent in Minnesota, where energy code already requires the installation of such systems universally.

While the study suggests a need for more research on the operation and maintenance of these systems, there are at least two immediate ways that Minnesota utility programs can improve energy efficiency related to mechanical ventilation. First programs can incentivize the installation of high-efficiency heat recovery systems. Second, they can encourage the installation of systems with ducting arrangements that do not require an interlock with the main air-handler for the home.

Looking beyond mechanical ventilation, the study suggests that there is still considerable room for utility programs to improve the energy efficiency of new homes in ways that go well beyond current energy code. The study suggests that currently there is very little difference in modeled energy performance between program and non-program homes. At an estimated 40 percent market share in Minnesota, it may be that these programs have transformed the entire residential new-construction market in the state. Or it may be that the bar has simply been set too low for these programs and utilities have been claiming savings relative to energy code-minimum construction when builders are in fact generally building beyond energy code.

The current study was not designed to distinguish between these possibilities, but either way the results suggest it may be time for utilities to increase efforts to promote measures that go beyond current practice. This would help stimulate builders to increase adoption of features such as triple-pane windows and high R-value walls that are already being incorporated in a small proportion of homes in the state. Utility programs have an important role to play in increasing the market adoption of these features.

Related to the above is the question of the appropriate baseline for calculating new-construction program savings, which is strongly determined by the program logic model, i.e. the underlying theory of how utility programs affect the broader new construction market. In the face of the results from this study, it would only be appropriate to use an energy code-minimum baseline under a program logic model in which the utility programs have indeed transformed the market to higher-than-code standard practice but where withdrawal of these programs would cause a general reversion to energy code-minimum construction. Under alternative logic-models—such as where market transformation has locked in better-than-code construction, or where programs have not affected practices beyond program participants themselves—the more appropriate baseline would be the practices observed in this study.

It is beyond the scope of this study to make recommendations about the appropriate logic model going forward for utility new construction programs, but we recognize that revised baselines could have a significant impact on program cost-effectiveness, participation and claimed savings. This suggests a need for a conversation between utilities and policymakers regarding the role of residential new-construction programs in the broader market. Although Minnesota is a “gross savings” state in that free-ridership and program spillover are not formally assessed for utility programs, a common understanding of how much utility programs affect the broader residential new-construction market may need to be reached in order to make decisions about their future direction and basis for claimed savings.

Perhaps surprisingly, the study revealed no large gaps in energy performance between homes built in non-enforcement jurisdictions compared to those in enforcement areas. However, one in five new homes built in these areas are distinguished in that they are much less likely to have natural gas service, and thus tend to be heated with a more complicated mix of propane and electricity. Displacing electric resistance space heat (and water heaters) with heat pumps in these areas is an attractive opportunity, though the large majority (85%) of these homes are served by cooperative electric utilities that generally have fewer resources to devote to energy efficiency programs, especially those devoted to new construction. A jointly operated program addressing new construction in areas that lack natural gas service could help address the unique needs of this part of the market, especially given the higher prevalence of slab-on-grade and crawlspace foundations that are rare in the rest of the market.

The single-family renovation market appears to offer far less savings potential than the new-construction market, though there is more uncertainty here owing to the small and geographically-focused sample included in the study—as well as the fact that one of the 13 homes in the sample showed a major lost-savings opportunity associated with an uninsulated attic. What is clear is that beyond-prescriptive-code savings opportunities that do not go beyond the project at hand are much more limited than for new-construction where the entire shell and all mechanical systems are potentially up for grabs.

Finally, review of the data for low-rise multifamily new construction in the state suggests that lost-savings associated with below-prescriptive-code construction in this segment are similarly low. Beyond-prescriptive-code savings potential may be somewhat lower than for single-family new construction, but this conclusion is based on comparison of only some building components. Finally, Census data suggests that there may be a significant opportunity for heat pumps in this segment, though the available field data did not allow for a good assessment of this.

Specific recommendations from the study are as follows:

- Utility programs should consider re-calibrating new-construction baselines to current construction practices, and re-orient new construction programs toward incentivizing efficiency features that go beyond current practice.
- Utilities and policymakers should work together for a common understanding of the potential market-transformational role of residential new-construction programs and how this affects program design. (This is already underway in a separate CARD-funded project that is seeking to provide a roadmap for future codes and standards in Minnesota.)
- Related to mechanical ventilation:
    - The State and utilities should step up efforts to ensure proper specification, installation, and operation of mechanical ventilation systems in new homes.
    - Utilities should specifically incentivize mechanical-ventilation systems that operate as efficiently as possible.
    - More research is needed on how these systems actually operate in the field, particularly with regard to control strategies and maintenance.
- Electric cooperatives and some investor-owned utilities (such as Xcel Energy, Minnesota Power and Otter Tail Power) with significant new construction activity in areas that lack natural-gas service could jointly implement a whole-home program targeted to the unique needs of that part of the market. (Municipal electric utilities are excluded from this recommendation because only about 5 percent of single-family new construction is served by this class of electric utility, and the vast majority of that activity involves homes with natural gas service.)

References

Bartlett R, J Hathaway, M Halverson, Y Xie, V Mendon and M Zhao. 2016. "Maryland Residential Energy Code Field Study: Baseline Report", Pacific Northwest National Laboratory, PNNL-25970, September, 2016. Available at: https://www.energycodes.gov/sites/default/files/documents/Maryland_Residential_Field_Study.pdf

Bartlett R, J Hathaway, M Halverson, Y Xie, V Mendon and M Zhao. 2017a. "Pennsylvania Residential Energy Code Field Study: Baseline Report", Pacific Northwest National Laboratory, PNNL-26450, May, 2017. Available at: https://www.energycodes.gov/sites/default/files/documents/Pennsylvania_Residential_Field_Study.pdf

Bartlett R, J Hathaway, M Halverson, Y Xie, V Mendon and M Zhao. 2017b. "Kentucky Residential Energy Code Field Study: Baseline Report", Pacific Northwest National Laboratory, PNNL-26727, August, 2017. Available at: https://www.energycodes.gov/sites/default/files/documents/Kentucky_Residential_Field_Study.pdf

Bartlett R, M Halverson and Y Xie. 2019a. "Idaho Residential Energy Code Field Study," Pacific Northwest National Laboratory, PNNL-28380, February, 2019. Available at: https://www.energycodes.gov/sites/default/files/documents/Idaho_Field%20Study_State_Report.pdf

Bartlett R, M Halverson and Y Xie. 2019b. "Montana Residential Energy Code Field Study," Pacific Northwest National Laboratory, PNNL-28472, April, 2019. Available at: https://www.energycodes.gov/sites/default/files/documents/Montana_Field_Study_State_Report_Final.pdf

Davis, Robert, et al. 2020. "Residential Building Energy Efficiency Field Studies: Low-Rise Multifamily," report prepared for U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Ecotope, June 2020.

DOE (Department of Energy). 2020a. Phase_I_Data_for_States_07192019.xlsx. Available at: https://www.energycodes.gov/compliance/energy-code-field-studies. Accessed May 14, 2020.

DOE (Department of Energy). 2020b. Phase_III_Data_for_States_05122020.xlsx. Available at: https://www.energycodes.gov/compliance/energy-code-field-studies. Accessed May 14, 2020.

DOE (Department of Energy). 2020c. Additional_States_Public_Data_050820.xlsx Available at: https://www.energycodes.gov/compliance/energy-code-field-studies. Accessed May 14, 2020.

Halverson Mark, YuLong Xie and Rosemarie Bartlett. 2019. "Residential Compliance Evaluation Results for the State of Nebraska," memorandum to Lynn Chamberlin, PNNL-SA-141366. Available at: https://www.energycodes.gov/sites/default/files/documents/Nebraska_Residential_Compliance_Evaluation_final.pdf

NMR Group, Inc. 2018a. "MA RLPNC 17-2: 2017 Massachusetts Single-Family New Construction Mini-Baseline/Compliance Study," final report submitted to Massachusetts Electric and Gas Program Administrators, January 3, 2018. Available at: http://ma-eeac.org/wordpress/wp-content/uploads/RLPNC-17-2-Single-Family-New-Construction-Mini-Baseline-Study.pdf

NMR Group, Inc. 2018b. "Rhode Island Baseline Study of Single-Family Residential New Construction," final report submitted to National Grid Rhode Island, January 16, 2018. Available at: http://rieermc.ri.gov/wp-content/uploads/2018/03/ri-rnc-baseline-study_16jan2018_final.pdf

PHIUS (Passive House Institute US). 2018. "PHIUS+ 2018 Passive Building Standard: Standard-Setting Documentation, Version 1.0." November 2, 2018. Available at: https://www.phius.org/.

Pigg, Scott and Melanie Lord. 2017. "New Homes Baseline and Market Characterization Study," report prepared for Wisconsin Focus on Energy, Seventhwave, October 5, 2017. Available at: https://www.focusonenergy.com/node/8966

Appendix A: Single-Family New-Construction Sampling Details

The single-family new construction sample was implemented with a two-stage sampling procedure: first, counties were sampled for inclusion in the study, then property-tax rolls were requested from sampled counties and individual households were recruited for the study. This appendix describes the details for the sampling procedures used, the development of case weights for the sample of homes and the calculation of sampling uncertainty associated with using the sample to estimate statistics for the full population of new Minnesota homes.

County Sampling

Sampling for the study began with selecting a subset of Minnesota's 87 counties to target for recruitment of households into the study. The county sampling process started with construction-permit statistics for 2016 and 2017 from the U.S. Census Bureau's Building Permits Survey (BPS),[31] which provides counts of housing starts by city and township. We merged these data with a database of code jurisdictions and enforcement status maintained by the Minnesota Department of Labor and Industry.[32] Combining these two data sources allowed us to estimate the total number of single-family housing starts in each county, along with the number of housing starts that were in enforcement and non-enforcement jurisdictions. We then classified counties according to whether they fell into the southern or northern climate zone (corresponding to IECC Climate zones 6 and 7, respectively) and whether the majority of the county's housing starts were in enforcement jurisdictions. This yielded four county strata:

- Southern, 50+ % of housing starts in enforcement jurisdictions
- Northern, 50+ % of housing starts in enforcement jurisdictions
- Southern, <50% of housing starts in enforcement jurisdictions
- Northern, <50% of housing starts in enforcement jurisdictions

To avoid selecting counties with little construction activity, we excluded those in the bottom 10 percent of each stratum in terms of housing starts. This reduced the starting list of counties considerably—to 38 of Minnesota's 87 counties—while excluding only 7.5% of statewide housing starts.

We then drew a random sample of counties within each stratum, using an approach designed to equalize the probability of any individual home being included in the study. Specifically, the sampling was done with probability proportional to size (PPS) and "with replacement." PPS sampling means that counties with more housing starts were more likely to be sampled than counties with fewer housing starts. In this case, the measure of "size" for each county was the number of 2016/17 housing starts from the BPS data. "With replacement" means that a given county can be sampled more than once.

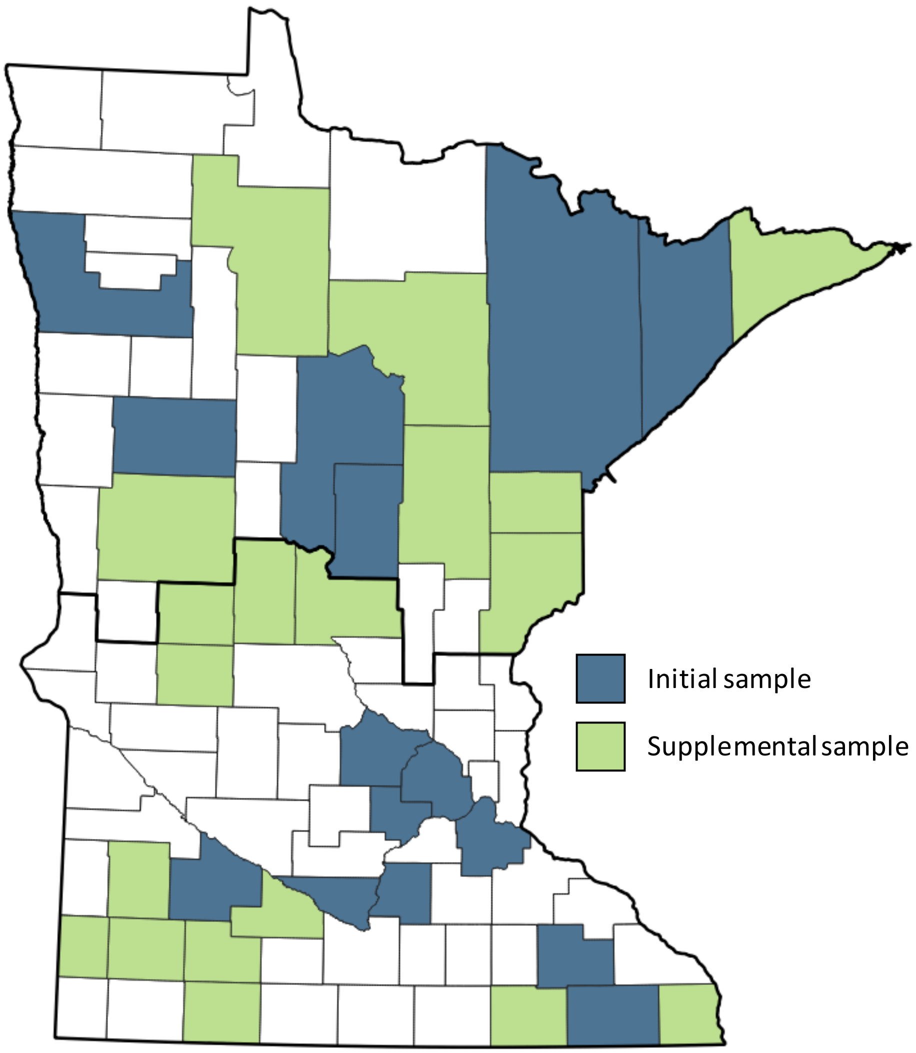
We drew a random sample of 18 counties in this manner. Three counties (Clay, Crow Wing and Hennepin) were sampled twice, so the initial sample yielded 15 unique counties (Figure 47).

---

[31] U.S. Census Bureau's Building Permits Survey (BPS) (https://www.census.gov/construction/bps/)

[32] Minnesota Department of Labor and Industry (http://workplace.doli.state.mn.us/jurisdiction/)

Figure 47. Sampled counties for single-family data collection.



Stakeholder feedback from the project kick-off meeting indicated a high level of interest in construction practices and code enforcement in non-enforcement areas. We therefore sampled more counties in the non-enforcement strata than would have been the case had we desired to make the sample representative of the state overall. (As will be described later in this appendix, case weights are used to correct for this imbalance when calculating statewide statistics.) Our goal was to obtain about equal numbers of homes in enforcement and non-enforcement jurisdictions.

To preserve equal selection probability for individual homes, the appropriate approach with a two-stage PPS sample is to then establish equal completion quotas for each sampled county. We set this target at five homes per county, with the three double-sampled counties having a quota of 10 homes each. This all added up to an overall target of 90 homes for field data collection.

As sometimes occurs with studies of this nature, during implementation, the initial sample of counties proved insufficient to recruit the desired number of homes, especially in terms of meeting the target for homes in non-enforcement jurisdictions. Midway through field data collection, we therefore selected a supplementary pool of 23 counties to add to the initial sample, most of which were majority non-enforcement counties (Figure 47). From a sampling standpoint, the county sample is thus a mix of probability-sampled counties (initial sample) and counties selected with certainty (supplementary sample). This mix is accounted for in later calculation of case weights for each home in the final sample.

Table 77. County recruitment for single-family new construction.

County	Single-family new-construction listings received	At least one telephone recruitment attempted	Postcard sent	Recruited sites
Aitkin	84	14	27	1
Anoka	2,552	212	72	6
Beltrami	201	85	0	6
Brown	101	56	45	0
Carlton	97	37	44	1
Carver	1,255	585	0	10
Cass	21	125	0	1
Clay	186	65	0	2
Crow	1,081	253	0	5
Dakota	1,796	608	0	10
Douglas	214	212	0	0
Fillmore	9	4	0	0
Hennepin	417	553	0	4
Itasca	181	79	0	6
Lake	50	0	22	1
Le Sueur	279	99	165	2
Morrison	209	109	99	2
Nicollet	109	35	0	0
Olmsted	1,420	352	0	4
Otter Tail	30	13	0	0
Pine	180	34	42	4
Redwood	51	0	13	1
Scott	852	361	16	5
St. Louis	754	252	0	5
Stearns	911	0	641	5

County	Single-family new-construction listings received	At least one telephone recruitment attempted	Postcard sent	Recruited sites
Todd	155	62	93	1
Wright	1299	455	0	5

Contacted county but did not receive a listing of new homes: Cook, Cottonwood, Murray, Pipestone, Pope.

Case Weights

Because northern homes and homes in non-enforcement jurisdictions were sampled at a higher rate than they naturally occur in the population, simple averages and other statistics from the study sample will give a potentially misleading impression of the true statewide values. To account for this, we developed case weights to represent how many homes in the overall population are represented by each home in the sample. Simply put, the case weights decrease the influence of subgroups that are over-represented in the sample and increase the influence of subgroups that are under-represented. We used these case weights in all analyses intended to project findings from the study sample to estimates for the full population of Minnesota new homes. The case weights are a mix of probability weights from the sampling process itself, combined with post hoc weights to true up the sample to known population proportions.

The probability case weight for any given home in the study sample is made up of two components: the selection probability for the county in which the home is located (P_{cty}) and the selection probability for the home itself within the total number of new homes in the county (P_{home}). The case weight for the home is then given by:

$$CW_{prob} = (1/ P_{cty})*(1/ P_{home})$$

Here, P_{cty} is either the BPS-based county selection probability for the initial sample of counties or unity for the supplementary sample that was selected with certainty. P_{home} is the number of homes in the sample for the county in question divided by the total number of new single-family homes from the property-tax list received for the county.

These calculations sometimes give rise to extreme weights that introduce instability into results and the calculation of sampling uncertainty. Indeed, the initial case weights calculated for the final sample showed a wide range, with the largest weight being nearly 200 times higher than the smallest case weight. We therefore trimmed extreme weights on both ends to a factor of five around the median weight, which thus reduced the range of weights to a factor of 10 between the largest and smallest weight.

This step helps make the results more stable but comes at the potential cost of introducing some bias into calculated results. However, in this case, the main effect of the procedure was to reduce large case weights for nine homes in two southern enforcement jurisdictions: Olmsted and Wright counties. The bias effect, if any, would thus here be limited to somewhat under-representing homes in those two counties among other southern-zone enforcement jurisdictions.

The second step in the weighting process was to use what are known as *post hoc* (or sometimes just *post*) weights to true up the probability weights to known population proportions. Here we post-weighted the sample in two dimensions: north vs. south climate zone and enforcement vs. non-enforcement jurisdiction. These dimensions are very similar to the strata developed for sampling counties early in the project, but there are some notable differences.

First, enforcement vs. non-enforcement for the post hoc weighting was based on total BPS housing starts by *local* city, township, or county jurisdiction enforcement status. In contrast—and by necessity—the assignment of counties to enforcement/non-enforcement strata in the original sampling relied on classifying entire counties as dominantly enforcement or non-enforcement jurisdictions.

Second, the post hoc case weighting was based on more—and more recent—BPS data than was used for the original sampling plan. The sampling plan relied on 2016 and 2017 data; the post hoc weighting uses 2014 through 2018.

Finally, and perhaps somewhat trivially, because the final study sample ended up including one duplex structure, we included the BPS counts of small multifamily (2-4 unit) housing starts in our population weights. Technically then, the estimates from the study apply to single family and small multifamily new construction, though the latter comprises less than two percent of the total.

To implement the *post hoc* weighting, the probability case weights were adjusted to the five-year, BPS-based estimated population building proportions shown in Table 78. Annual building counts are based on applying the proportions to a round-number value of 13,500 annual housing starts derived from the last two years of BPS data.

Table 78. Annual single-family new construction activity estimates used for final study case weights.

Annual buildings (and % of total)	Enforcement Jurisdictions	Non-enforcement Jurisdictions	Total
South	10,360 (76.74%)	1,220 (9.04%)	11,580 (85.78%)
North	600 (4.44%)	1,320 (9.78%)	1,920 (14.22%)
Total	10,960 (81.18%)	2,540 (18.82%)	13,500 (100.00%)

Note that the post hoc weighting in the analysis presented in this report is dynamic: that is, if one or more cases are missing for a variable of interest, the weights are rescaled to match the above proportions for the non-missing values.

Appendix B: Recruitment Materials

Recruitment Script—Minnesota single-family new homes

Hello, I'm calling from Leede Research on behalf of the State of Minnesota about a study of new homes. I'm not selling anything; I'd just like to talk with an adult member of your household. Are you 18 years or older?

1. Yes
2. No [ask to speak with an adult member of the household, and start script from beginning]

We're recruiting a random sample of new home owners in Minnesota to participate in a research study about the construction of new homes. Participants get a $100 Visa gift card and a free air-leakage test.

(Q1) **Is that something you might be interested in?**

1. *Yes* CONTINUE TO Q1a
2. *No* SKIP TO Q1b
3. *Not sure* SKIP TO Q1c

(Q1a) [Q1= "Yes"] **OK, great! I have a few questions to make sure that you qualify for the study. This will just take a couple of minutes.** [skip to Q2]

(Q1b) [Q1= "No"] **OK, that's fine. To help us with our research study, would you answer a few quick questions about your home before we hang up?**

1. *Yes* SKIP TO Q2
2. *No* **OK, thank you for your time.** [terminate]

(Q1c) [Q1= "Not sure"] **I can give you some more details about the study to help you decide, but first I have a few questions to make sure that you qualify for the study.**

(Q2) **Do you currently live in a single-family home that was built after January 1, 2016?**

1. Yes
2. No **We're interested only in new single-family homes. Thank you for your time.** [terminate]
3. *Not sure* [continue]

(Q3) **Just to be clear, it is a NEW home, right—first occupied by you in 2016, 2017 or 2018?**

1. Yes
2. No **We're interested only in new single-family homes. Thank you for your time.** [terminate]
3. Not sure **OK thank you for your time.** [terminate]

(Q4) **…and your home is a single-family home, not a condo or apartment, right?**

1. Yes (single-family)
2. No (multifamily) **We're interested only in new single-family homes. Thank you for your time.** [terminate]
3. Not sure [clarify that single-family homes are not attached to any other home or structure]

(Q5) **Is your home a mobile home?**

1. *Yes* We're interested only in new single-family homes and not mobile homes. Thank you for your time. [terminate]
2. *No*
3. *Not sure* [clarify that mobile homes (also called manufactured homes) are built in a factory on a permanent steel chassis and towed to their location. This is different than a modular or "prefab" home, which is also built in a factory, but assembled at the site and does not have a permanent steel chassis. Modular homes DO qualify for the study; mobile homes do not.]

(Q6) **Do you own or rent your home?**

1. Own
2. Rent **We're interested is speaking with homeowners only.** T**hank you for your time.** [terminate]

(Q7) **What is the main fuel that you use to heat your house? Is it... [read]**

1. Natural gas
2. Propane or LP
3. Electricity, such as for geothermal heating, a heat pump, or baseboard electricity
4. Wood or pellets
5. Something else
6. [not sure]

[Q1b = "No"] **Thank you for your time. Based on your answers you qualify for the study. Would you reconsider and agree to participate?**

[If no – thank and terminate]

[If yes – Continue to Q8 (begin with second sentence).]

(Q8) **It looks like you qualify for our study. Could I give you a few details about the study, and perhaps schedule a time for a visit?**

1. *Yes* OK, great!
2. *No* OK, thank you for your time. [terminate]
3. *Not sure* OK, let me tell you a little more about it.

If you participate in the study, we'll schedule a time when we'll be in the area—and that works for you—for a technician to come out to look at insulation levels, and record information about your lights and appliances. In some homes they'll also do an air leakage test, a duct leakage test and do a thermal scan, and so will need access to all rooms in the home. The whole visit typically takes about four hours. Someone needs to be home, but you can go about your business during the visit. At the end of the visit, the technician will discuss any notable findings with you, and provide you with a $100 Visa gift card.

(Q9) **Could we schedule a time for a site visit?**

1. *Yes* OK, great! I just need to get some details from you
2. *No* OK, thank you for your time. [terminate]
3. *Not sure* Could I mail or e-mail you some additional information for you to look over before you decide?

(Q9a) **Please give me your name, address, telephone number and e-mail address.**

Name:

Address:

[If provided address does NOT match premise address on record, re-confirm address, and that home is a new, single-family building. Flag for cross-checking against program list.]

Phone:

Email:

(Q9b) **What is the total square footage of your home?**

1. Record number _______
2. Don't know

Schedule date and time for visit

[if scheduled] **I'll send you some additional information about the study so you know what to expect, and we'll contact you a day or two before the visit to confirm the appointment.** [if no email provided in Q9a] **Could I get an e-mail address for that?** [record e-mail address]

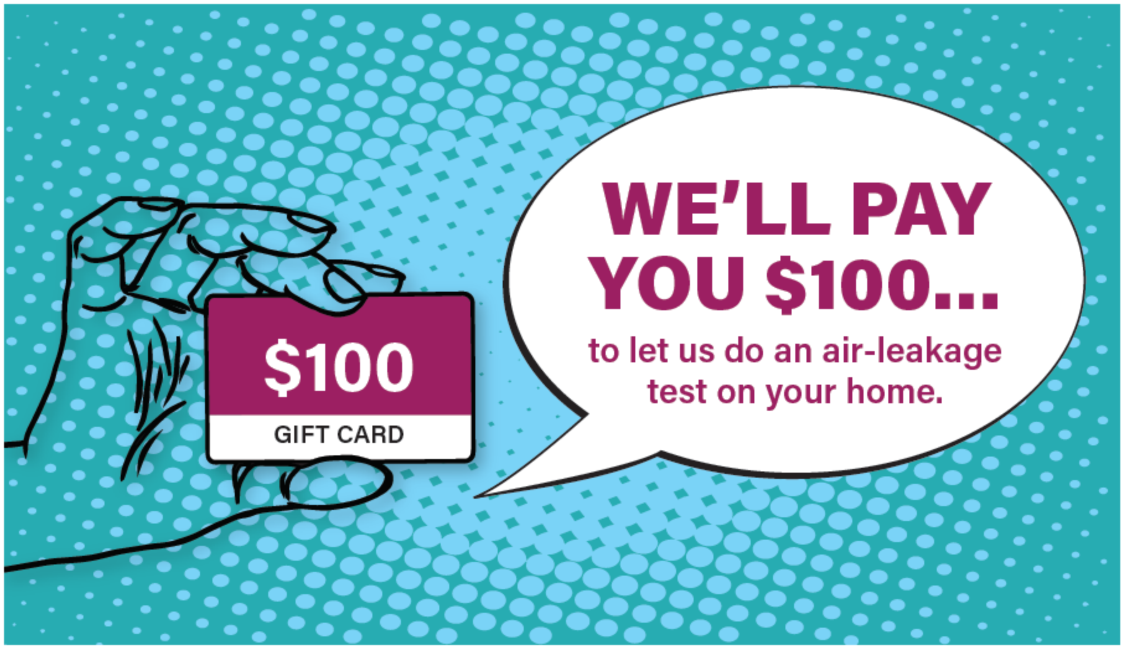
[if email provided in Q9a] **I'd just like to confirm your e-mail address. Is it** [insert email address from Q9a].

[if still unsure] **I'll send you some additional information about the study so you know what to expect, and call back in a few days to talk it over again.**

[if no email provided in Q9a] **Could I get an e-mail address for that?** [record e-mail address]

[if email provided in Q9a] **I'd just like to confirm your e-mail address. Is it** [insert email address from Q9a].

Thank you for your time!



slipstream

Slipstream, a non-profit research company, **is looking for participants for a study of the energy characteristics of new homes. If your home qualifies,** we'll schedule a time for our researcher to visit your home and you'll get a $100 gift card.

WANT TO PARTICIPATE?

Call 1.800.969.9322 and ask about the Minnesota New Homes Energy Research Study. Or go online for more information: **slipstreaminc.org/energystudy**

If you qualify, the study site visit includes having our researcher:

- Ask you a few questions about your thermostat settings and other home energy uses
- Measure the square footage of your home
- Record information on insulation levels, lighting and appliances
- Conduct an air-leakage (blower door) test

The study is funded by the Minnesota Department of Commerce Conservation Applied Research and Development program. Please contact Lindsay Anderson at the Minnesota Department of Commerce, Division of Energy Resources, **651.539.1771** or **Lindsay.anderson@state.mn.us** if you have questions about why the study is being conducted.

COMMERCE DEPARTMENT
DIVISION OF ENERGY RESOURCES

Slipstream
431 Charmany Drive
Madison, WI 53719

slipstream	mn COMMERCE DEPARTMENT ENERGY RESOURCES

Minnesota New Homes Research Study

What to expect from the site visit?

A representative from Slipstream, the research firm hired by the Minnesota Department of Commerce, Divisionof Energy Resources, to complete this study, will contact you to confirm the appointment the day before the scheduled visit. On the day of the visit, the technician will first ask you a few questions about your thermostat settings and other aspects of how you operate your home. He or she will then measure the square footage of your home and walk through the home to record information about insulation levels and lighting and appliance characteristics. If conditions are amenable, the technician will use an infrared camera to look for areas of missing or ineffective insulation.

The visit will also involve conducting an air-leakage test on your home. During this test, the technician will temporarily mount a device called a blower-door in one of your home's exterior doors to pressurize your hometo measure its leakage rate.

At the completion of the testing, the technician will discuss any notable findings with you, and provide you witha $100 Visa gift card as a thank you.

Some important things to know about the site visit are:

- The technician will need access to all rooms in your home in order to gather the information for thestudy.
- For homes with forced-air heating and cooling, it is important that the grills and registers be accessibleduring the visit for testing duct leakage.
- If you have a wood or pellet fireplace or stove, it is important that it NOT be in use at the time of thevisit, as this will prevent the technician from doing an air leakage test.
- The technician will need access to your home's attic in order to assess insulation levels.

If you have a set of construction plans for your home, it will be helpful to have those available at the time of the visit.

Frequently Asked Questions

How long will the visit take?
Most of the time, we can complete the visit in four hours, but it could take an hour or so more if your home is large or has complicated geometry.

Does someone need to be home for the site visit?
Yes, we need access to your home so that we can do our testing, and record information about appliances. You are free to go about your business while our technician collects this information.

What kind of gift card will I get?
We'll provide a $100 Visa card that is good anywhere that credit and debit cards are accepted.

What information will you collect?
We will look at insulation levels, window characteristics, and details of your heating, cooling and water heating equipment. We'll also do an air leakage test, a ventilation test and scan your home with an infrared camera. Finally, we'll look at the types of lighting that you have in your home, and ask you a few questions about how you operate your appliances.

Will I get a report?
Our technician will inform you of any noteworthy findings at the completion of the visit. We will not provide a written report on your home.

Will my information be kept confidential?
Yes, any personal information that could be used to identify you will be removed before we share data files with others, or the results of the study are made public.

How did you get my name and number?
County assessor's offices provided us with property tax data for homes constructed in 2016, 2017 and 2018. We're contacting a random sample of customers in 15 counties on behalf of the Minnesota Department of Commerce, Division of Energy Resources.

How will this information be used?
The study will be used to assess current construction practices for new homes in Minnesota.

How many homes are you visiting?
We are visiting a total of 100 homes across Minnesota.

Who is paying for the study?
The study is funded by the Minnesota Department of Commerce, Division of Energy Resources.

Who is Slipstream?
Slipstream was hired by the Minnesota Department of Commerce, Division of Energy Resources through a competitive request-for-proposals process to complete this research study.

How can I be sure the study is legitimate?
You may contact Lindsay Anderson at the Minnesota Department of Commerce, Division of Energy Resources, 651-539-1771 or Lindsay.anderson@state.mn.us if you have any questions about why the study is being conducted and how it will be used.

Who do I call if I need to reschedule or have more detailed questions?
Please contact Melanie Lord at 608.210.7134 or mlord@slipstreaminc.org

Email text from recruiter

Dear {Participant Name},

Thank you for agreeing to participate in the Minnesota New Homes Research Study. We have scheduled a technician to visit your home at {site address} in {City} on {date} at {time}. A representative from Slipstream, the research firm hired to complete the study will be in touch with you to confirm your appointment and provide you with additional information on what to expect during the site visit.

If you have questions or need to reschedule this appointment, please contact Melanie Lord at mlord@slipstreaminc.org or 608-210-7134. Please find additional information attached.

Email text from Slipstream

Hello {Participant Name},

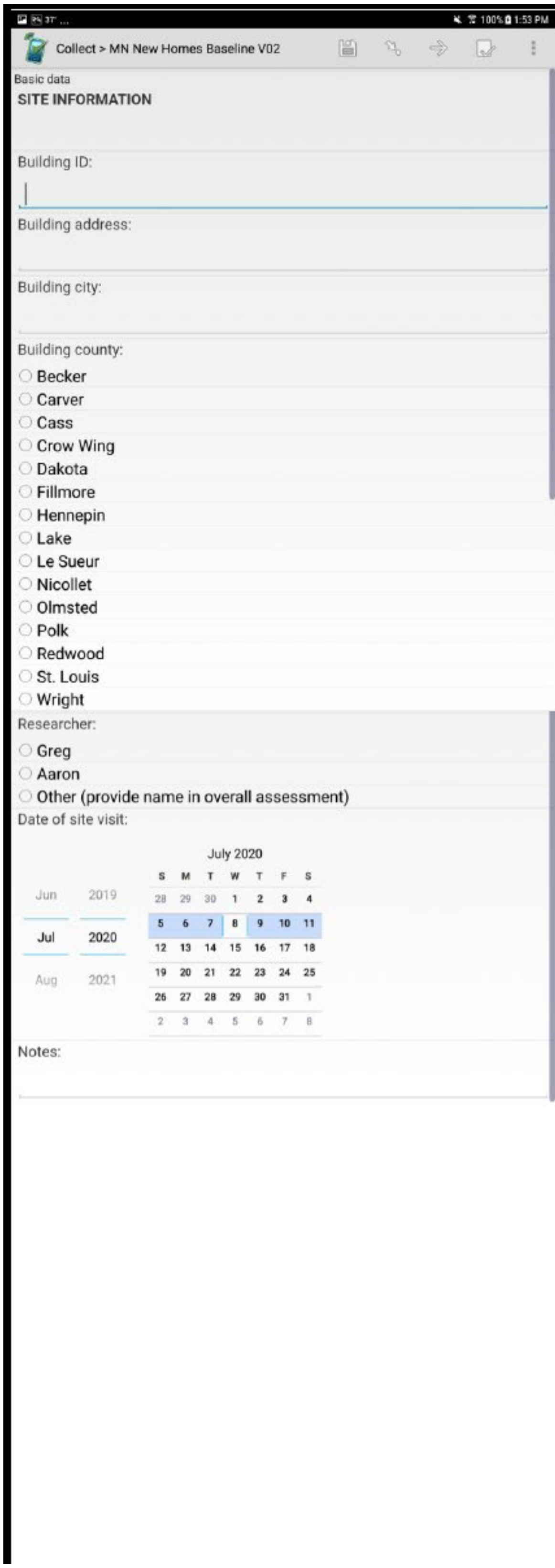
Thank you for agreeing to participate in the Minnesota new homes research study that is being conducted by Slipstream on behalf of the Minnesota Dept. of Commerce, Division of Energy Resources. Aaron Riendeau, field researcher for Slipstream, will be at your home on {date} at {time} to collect information on your home. If you have any questions or concerns, please feel free to contact me: Melanie Lord, 608-210-7134 or mlord@slipstreaminc.org.

When Aaron has collected the information needed, he'll discuss any notable findings with you and provide you with a $100 gift card.

Just as a reminder:

1. The technician will need access to all rooms in your home in order to gather the information for the study.
2. For homes with forced-air heating and cooling, it is important that the grills and registers be accessible during the visit for testing duct leakage.
3. The technician will need access to your home's attic in order to assess insulation levels.
4. If you have a wood or pellet fireplace or stove, it is important that it NOT be in use at the time of the visit, as this will prevent the technician from doing an air leakage test.
5. If you have a set of construction plans for your home, it will be helpful to have those available at the time of the visit.

Appendix C: Data Collection Instruments



Collect > MN New Homes Baseline V02

Basic data

SITE INFORMATION

Building ID:

Building address:

Building city:

Building county:
- Becker
- Carver
- Cass
- Crow Wing
- Dakota
- Fillmore
- Hennepin
- Lake
- Le Sueur
- Nicollet
- Olmsted
- Polk
- Redwood
- St. Louis
- Wright

Researcher:
- Greg
- Aaron
- Other (provide name in overall assessment)

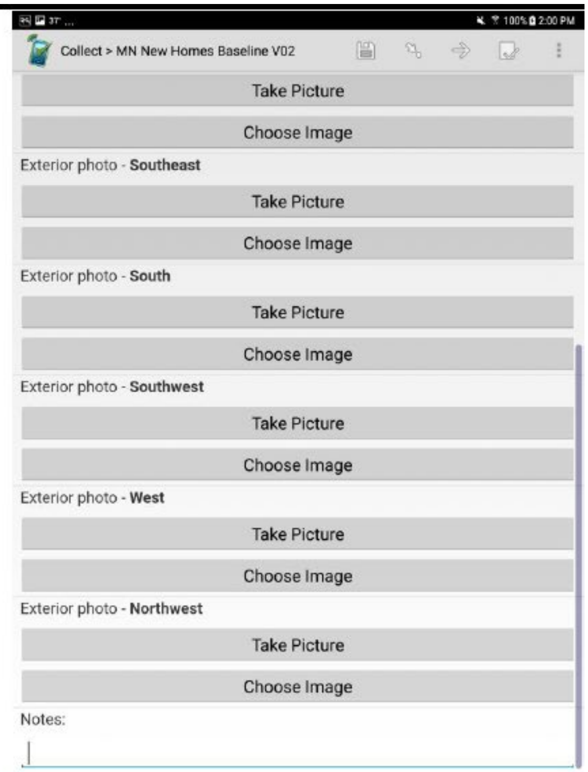
Date of site visit:

July 2020

S	M	T	W	T	F	S
28	29	30	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	1
2	3	4	5	6	7	8

Jun 2019 / Jul 2020 / Aug 2021

Notes:



Collect > MN New Homes Baseline V02

Take Picture

Choose Image

Exterior photo - **Southeast**

Take Picture

Choose Image

Exterior photo - **South**

Take Picture

Choose Image

Exterior photo - **Southwest**

Take Picture

Choose Image

Exterior photo - **West**

Take Picture

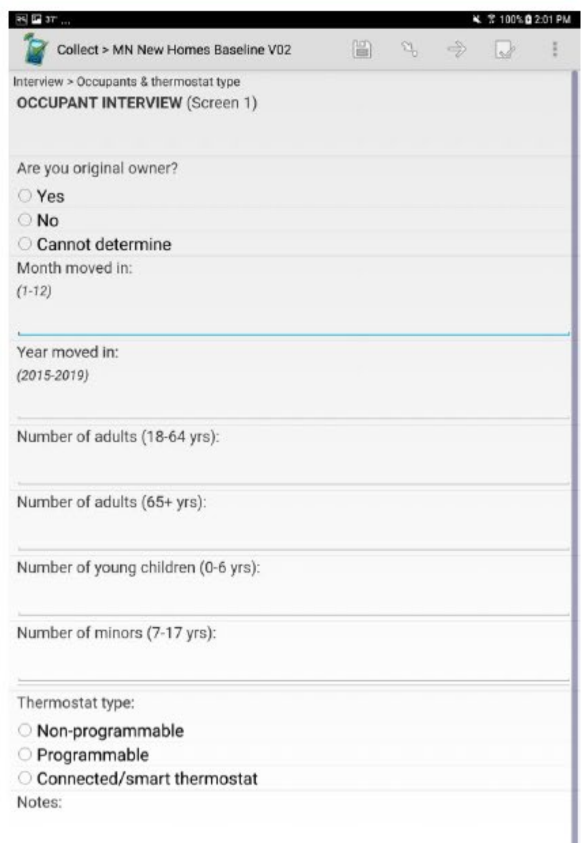
Choose Image

Exterior photo - **Northwest**

Take Picture

Choose Image

Notes:



Collect > MN New Homes Baseline V02

Interview > Occupants & thermostat type

OCCUPANT INTERVIEW (Screen 1)

Are you original owner?
- Yes
- No
- Cannot determine

Month moved in:
(1-12)

Year moved in:
(2015-2019)

Number of adults (18-64 yrs):

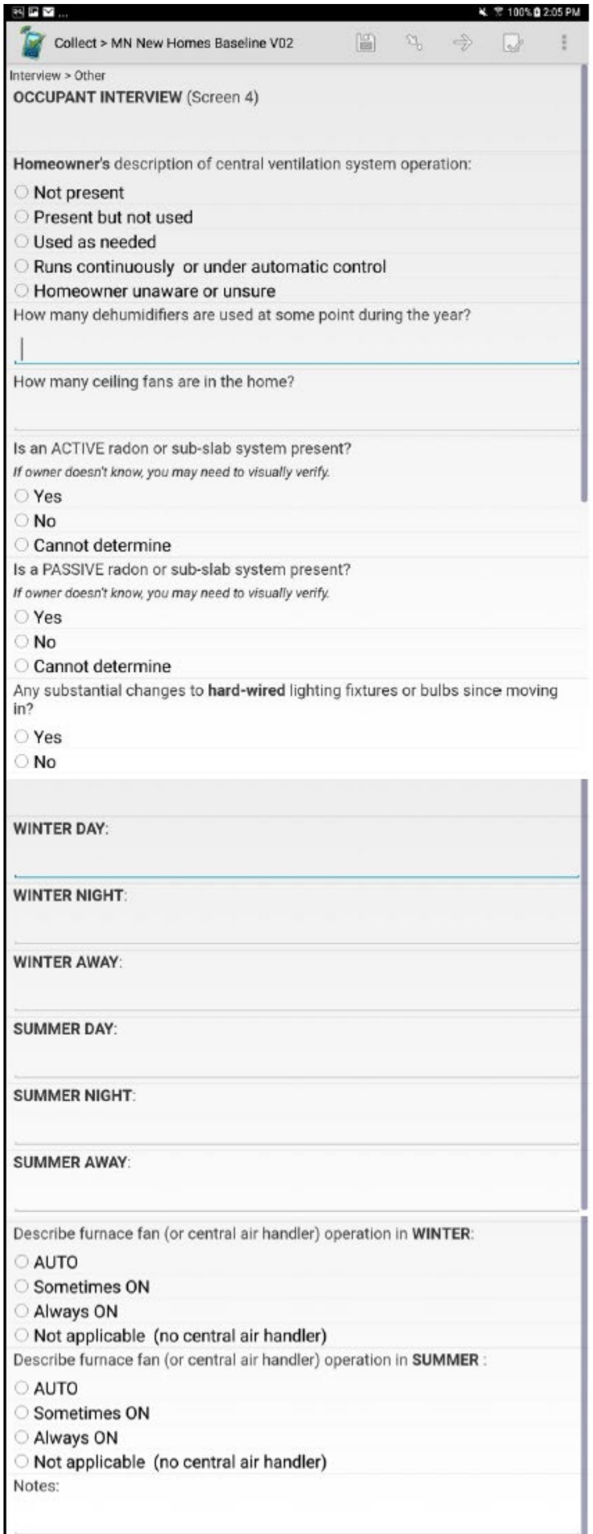
Number of adults (65+ yrs):

Number of young children (0-6 yrs):

Number of minors (7-17 yrs):

Thermostat type:
- Non-programmable
- Programmable
- Connected/smart thermostat

Notes:



Collect > MN New Homes Baseline V02

Interview > Other

OCCUPANT INTERVIEW (Screen 4)

Homeowner's description of central ventilation system operation:

- ○ Not present
- ○ Present but not used
- ○ Used as needed
- ○ Runs continuously or under automatic control
- ○ Homeowner unaware or unsure

How many dehumidifiers are used at some point during the year?

How many ceiling fans are in the home?

Is an ACTIVE radon or sub-slab system present?

If owner doesn't know, you may need to visually verify.

- ○ Yes
- ○ No
- ○ Cannot determine

Is a PASSIVE radon or sub-slab system present?

If owner doesn't know, you may need to visually verify.

- ○ Yes
- ○ No
- ○ Cannot determine

Any substantial changes to **hard-wired** lighting fixtures or bulbs since moving in?

- ○ Yes
- ○ No

WINTER DAY:

WINTER NIGHT:

WINTER AWAY:

SUMMER DAY:

SUMMER NIGHT:

SUMMER AWAY:

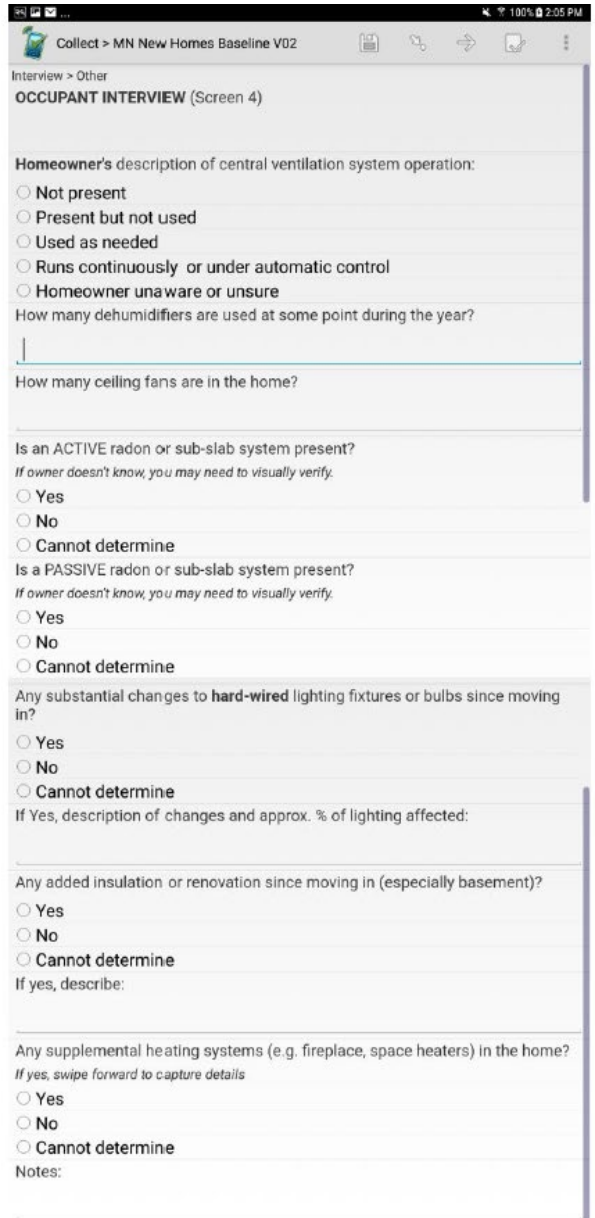
Describe furnace fan (or central air handler) operation in **WINTER**:

- ○ AUTO
- ○ Sometimes ON
- ○ Always ON
- ○ Not applicable (no central air handler)

Describe furnace fan (or central air handler) operation in **SUMMER** :

- ○ AUTO
- ○ Sometimes ON
- ○ Always ON
- ○ Not applicable (no central air handler)

Notes:



Collect > MN New Homes Baseline V02

Interview > Other

OCCUPANT INTERVIEW (Screen 4)

Homeowner's description of central ventilation system operation:

- ○ Not present
- ○ Present but not used
- ○ Used as needed
- ○ Runs continuously or under automatic control
- ○ Homeowner unaware or unsure

How many dehumidifiers are used at some point during the year?

How many ceiling fans are in the home?

Is an ACTIVE radon or sub-slab system present?

If owner doesn't know, you may need to visually verify.

- ○ Yes
- ○ No
- ○ Cannot determine

Is a PASSIVE radon or sub-slab system present?

If owner doesn't know, you may need to visually verify.

- ○ Yes
- ○ No
- ○ Cannot determine

Any substantial changes to **hard-wired** lighting fixtures or bulbs since moving in?

- ○ Yes
- ○ No
- ○ Cannot determine

If Yes, description of changes and approx. % of lighting affected:

Any added insulation or renovation since moving in (especially basement)?

- ○ Yes
- ○ No
- ○ Cannot determine

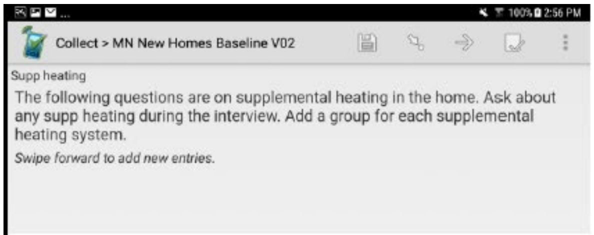
If yes, describe:

Any supplemental heating systems (e.g. fireplace, space heaters) in the home?

If yes, swipe forward to capture details

- ○ Yes
- ○ No
- ○ Cannot determine

Notes:

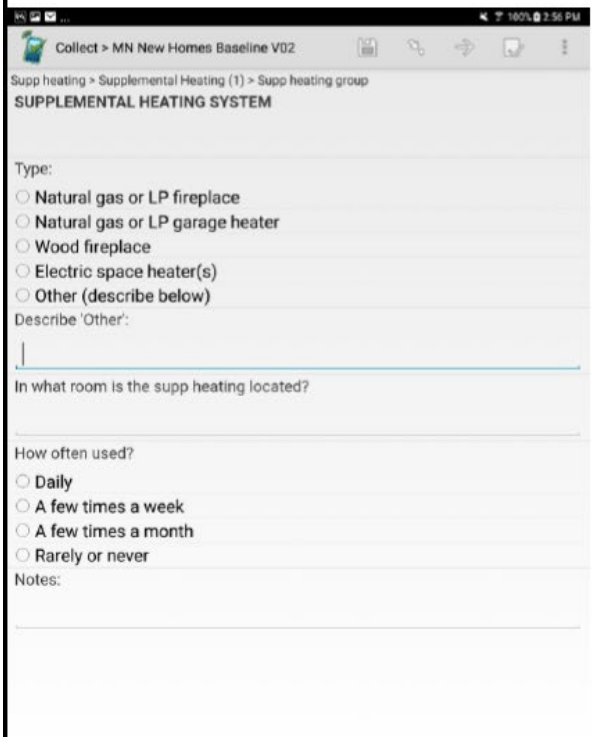


Collect > MN New Homes Baseline V02

Supp heating

The following questions are on supplemental heating in the home. Ask about any supp heating during the interview. Add a group for each supplemental heating system.

Swipe forward to add new entries.



Collect > MN New Homes Baseline V02

Supp heating > Supplemental Heating (1) > Supp heating group

SUPPLEMENTAL HEATING SYSTEM

Type:

- Natural gas or LP fireplace
- Natural gas or LP garage heater
- Wood fireplace
- Electric space heater(s)
- Other (describe below)

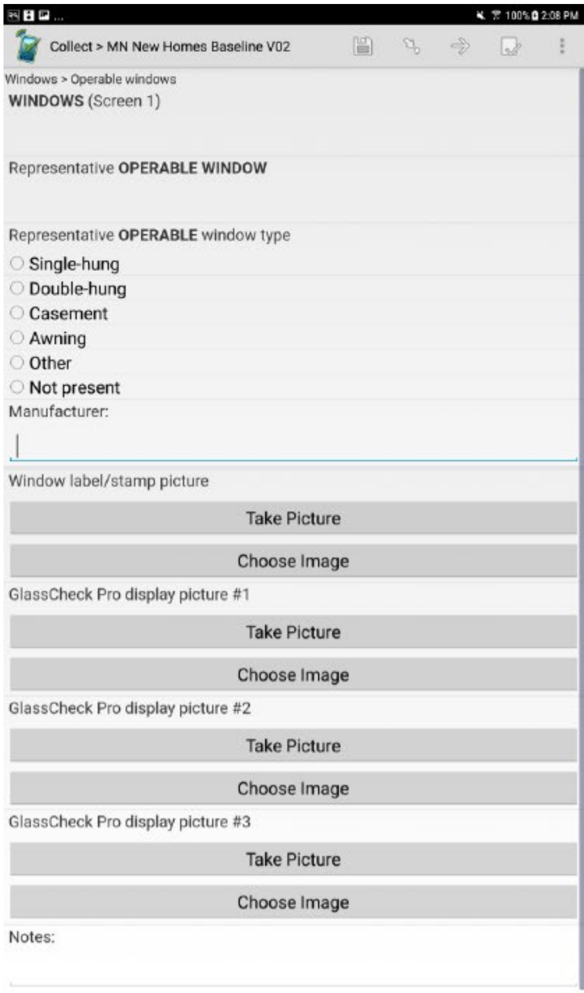
Describe 'Other':

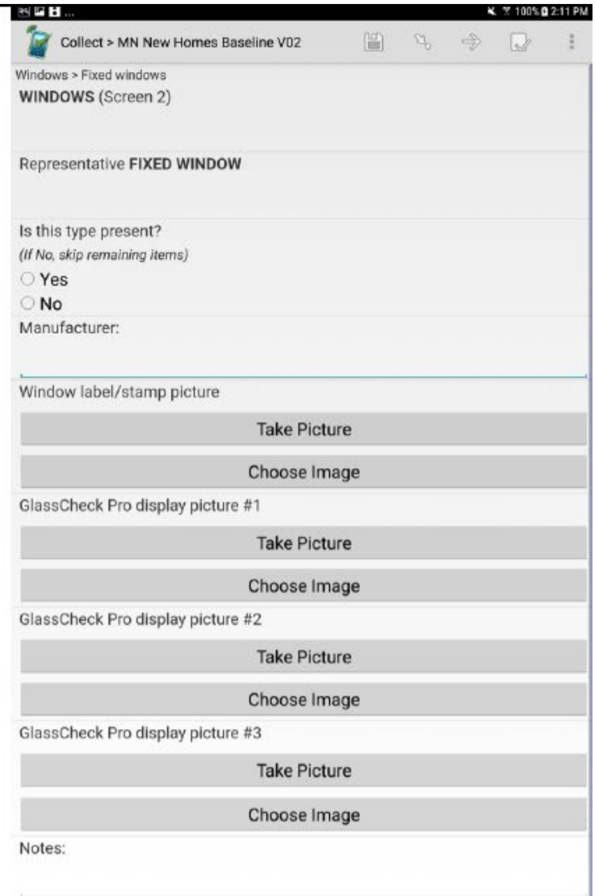
In what room is the supp heating located?

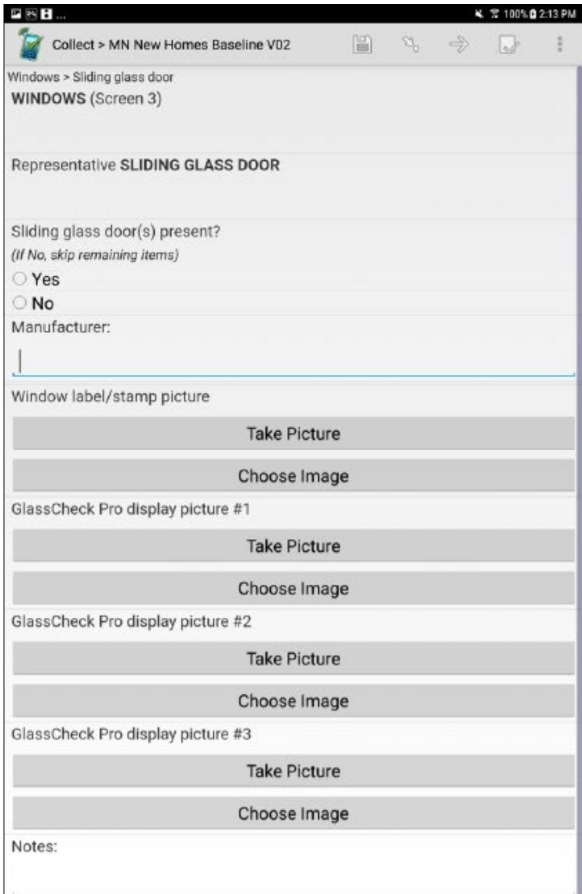
How often used?

- Daily
- A few times a week
- A few times a month
- Rarely or never

Notes:


Collect > MN New Homes Baseline V02
Windows > Operable windows
WINDOWS (Screen 1)
Representative OPERABLE WINDOW
Representative OPERABLE window type
Single-hung
Double-hung
Casement
Awning
Other
Not present
Manufacturer:
Window label/stamp picture
Take Picture
Choose Image
GlassCheck Pro display picture #1
Take Picture
Choose Image
GlassCheck Pro display picture #2
Take Picture
Choose Image
GlassCheck Pro display picture #3
Take Picture
Choose Image
Notes:


Collect > MN New Homes Baseline V02
Windows > Fixed windows
WINDOWS (Screen 2)
Representative FIXED WINDOW
Is this type present?
(If No, skip remaining items)
Yes
No
Manufacturer:
Window label/stamp picture
Take Picture
Choose Image
GlassCheck Pro display picture #1
Take Picture
Choose Image
GlassCheck Pro display picture #2
Take Picture
Choose Image
GlassCheck Pro display picture #3
Take Picture
Choose Image
Notes:


Collect > MN New Homes Baseline V02
Windows > Sliding glass door
WINDOWS (Screen 3)
Representative SLIDING GLASS DOOR
Sliding glass door(s) present?
(If No, skip remaining items)
Yes
No
Manufacturer:
Window label/stamp picture
Take Picture
Choose Image
GlassCheck Pro display picture #1
Take Picture
Choose Image
GlassCheck Pro display picture #2
Take Picture
Choose Image
GlassCheck Pro display picture #3
Take Picture
Choose Image
Notes:


Collect > MN New Homes Baseline V02
Windows > Foundation windows
WINDOWS (Screen 4)
Representative FOUNDATION WINDOW
Foundation window(s) present?
(If No, skip remaining items)
Yes
No
Representative window type
Fixed
Double-hung
Casement
Awning
Other
Not present
Manufacturer:
Window label/stamp picture
Take Picture
Choose Image
GlassCheck Pro display picture #1
Take Picture
Choose Image
GlassCheck Pro display picture #2
Take Picture
Choose Image
GlassCheck Pro display picture #3
Take Picture
Choose Image
Notes:

Collect > MN New Homes Baseline V02

Interior foundation photo

INTERIOR FOUNDATION PHOTO

Interior foundation and framing/insulation picture

Take Picture

Choose Image

(Optional) additional picture

Take Picture

Choose Image

Notes:

Collect > MN New Homes Baseline V02

Heating system 1

HEATING SYSTEM 1

Area(s) served:

Whole house

Type:

- Furnace
- Boiler
- Free-standing stove
- Other (describe below)

Describe 'Other':

Fuel:

- Natural Gas
- Electricity
- Propane
- Fuel oil
- Other (describe in notes)

Manufacturer:

Model:

AHRI reference number

Fill out later

Distance picture of heating system

Take Picture

Choose Image

Picture of heating system **nameplate**

Make sure information is legible

Take Picture

Choose Image

If furnace, picture of the **control board**

Make sure DIP switch positions are visible

Take Picture

Choose Image

(Optional) additional picture

Take Picture

Choose Image

Filter type:

- 1" mesh
- 1" pleated
- 4" pleated
- Electronic
- Other (describe in notes)
- No filter present

Filter condition:

- Clean
- Dirty
- Clogged
- No filter present
- Unable to observe

Filter MERV rating:

(if printed on filter)

Is this heating system zoned?

- Yes
- No
- Cannot determine

If yes, describe zoning:

Leave blank if not zoned

Humidifier attached to this heating system?

- Yes
- No
- Cannot determine

Any ducts in unconditioned spaces?

- Yes
- No
- Cannot determine

If yes, decribe:

% supply in unconditioned spaces?

% return in unconditioned spaces?

Notes:

Collect > MN New Homes Baseline V02

Heating system 2

HEATING SYSTEM 2

Area(s) served:

(Not present)

Type:

- ○ Furnace
- ○ Boiler
- ○ Free-standing stove
- ○ Other (describe below)

Describe 'Other':

Fuel:

- ○ Natural Gas
- ○ Electricity
- ○ Propane
- ○ Fuel oil
- ○ Other (describe in notes)

Manufacturer:

Model:

AHRI reference number

Fill out later

Distance picture of heating system

Take Picture

Choose Image

Picture of heating system **nameplate**

Make sure information is legible

Take Picture

Choose Image

If furnace, picture of the **control board**

Make sure DIP switch positions are visible

Take Picture

Choose Image

(Optional) additional picture

Take Picture

Choose Image

Filter type:

- ○ 1" mesh
- ○ 1" pleated
- ○ 4" pleated
- ○ Electronic
- ○ Other (describe in notes)
- ○ No filter present

Filter condition:

- ○ Clean
- ○ Dirty
- ○ Clogged
- ○ No filter present
- ○ Unable to observe

Filter MERV rating:

(If printed on filter)

Is this heating system zoned?

- ○ Yes
- ○ No
- ○ Cannot determine

If yes, describe zoning:

Leave blank if not zoned

Humidifier attached to this heating system?

- ○ Yes
- ○ No
- ○ Cannot determine

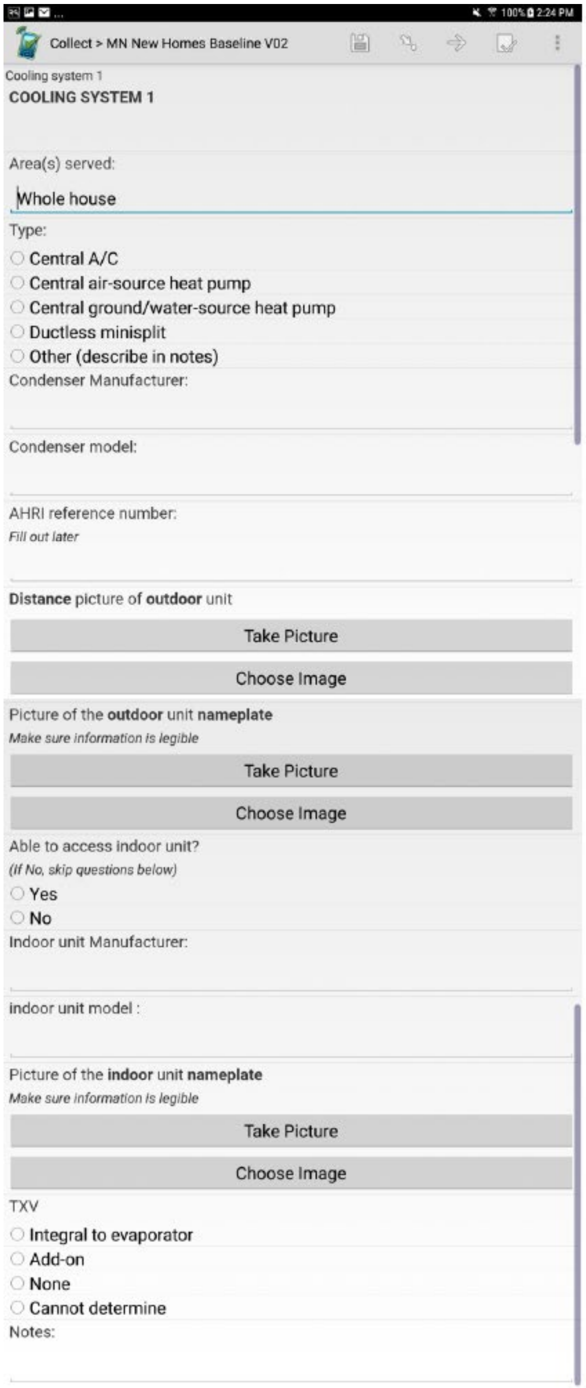
Any ducts in unconditioned spaces?

- ○ Yes
- ○ No
- ○ Cannot determine

If yes, decribe:

% return in unconditioned spaces?

Notes:



Collect > MN New Homes Baseline V02

Cooling system 1

COOLING SYSTEM 1

Area(s) served:

Whole house

Type:

- Central A/C
- Central air-source heat pump
- Central ground/water-source heat pump
- Ductless minisplit
- Other (describe in notes)

Condenser Manufacturer:

Condenser model:

AHRI reference number:

Fill out later

Distance picture of **outdoor** unit

Take Picture

Choose Image

Picture of the **outdoor** unit **nameplate**

Make sure information is legible

Take Picture

Choose Image

Able to access indoor unit?

(If No, skip questions below)

- Yes
- No

Indoor unit Manufacturer:

indoor unit model :

Picture of the **indoor** unit **nameplate**

Make sure information is legible

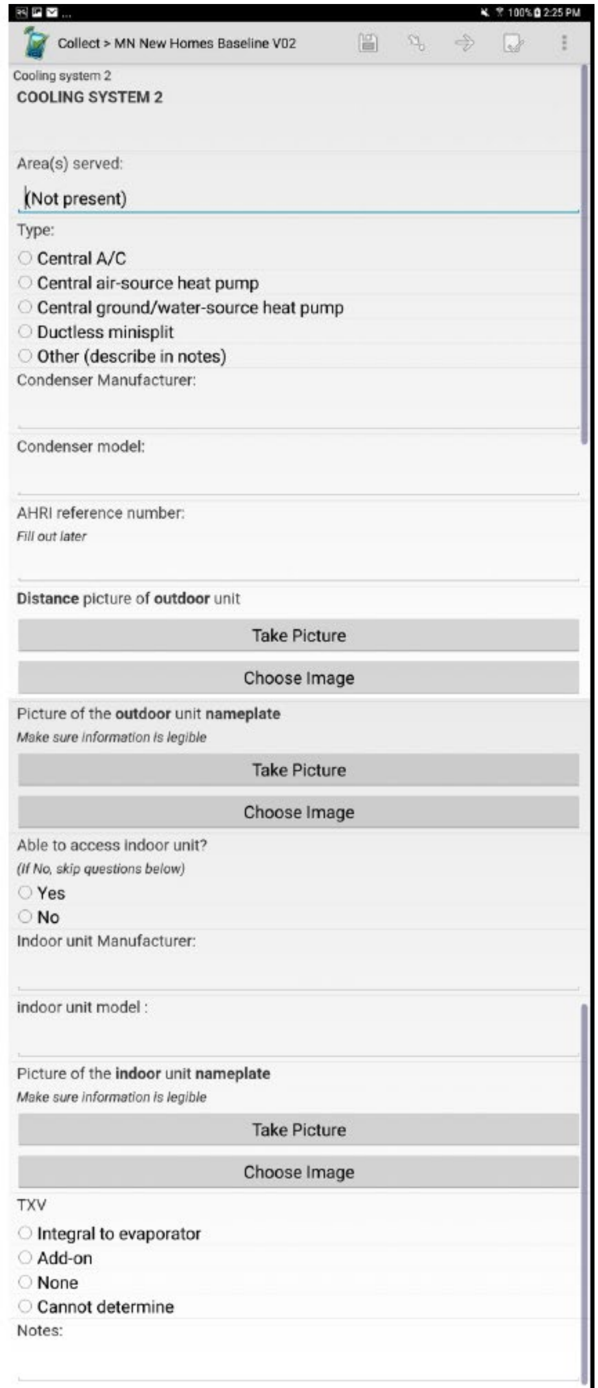
Take Picture

Choose Image

TXV

- Integral to evaporator
- Add-on
- None
- Cannot determine

Notes:



Collect > MN New Homes Baseline V02

Cooling system 2

COOLING SYSTEM 2

Area(s) served:

(Not present)

Type:

- Central A/C
- Central air-source heat pump
- Central ground/water-source heat pump
- Ductless minisplit
- Other (describe in notes)

Condenser Manufacturer:

Condenser model:

AHRI reference number:

Fill out later

Distance picture of **outdoor** unit

Take Picture

Choose Image

Picture of the **outdoor** unit **nameplate**

Make sure information is legible

Take Picture

Choose Image

Able to access indoor unit?

(If No, skip questions below)

- Yes
- No

Indoor unit Manufacturer:

indoor unit model :

Picture of the **indoor** unit **nameplate**

Make sure information is legible

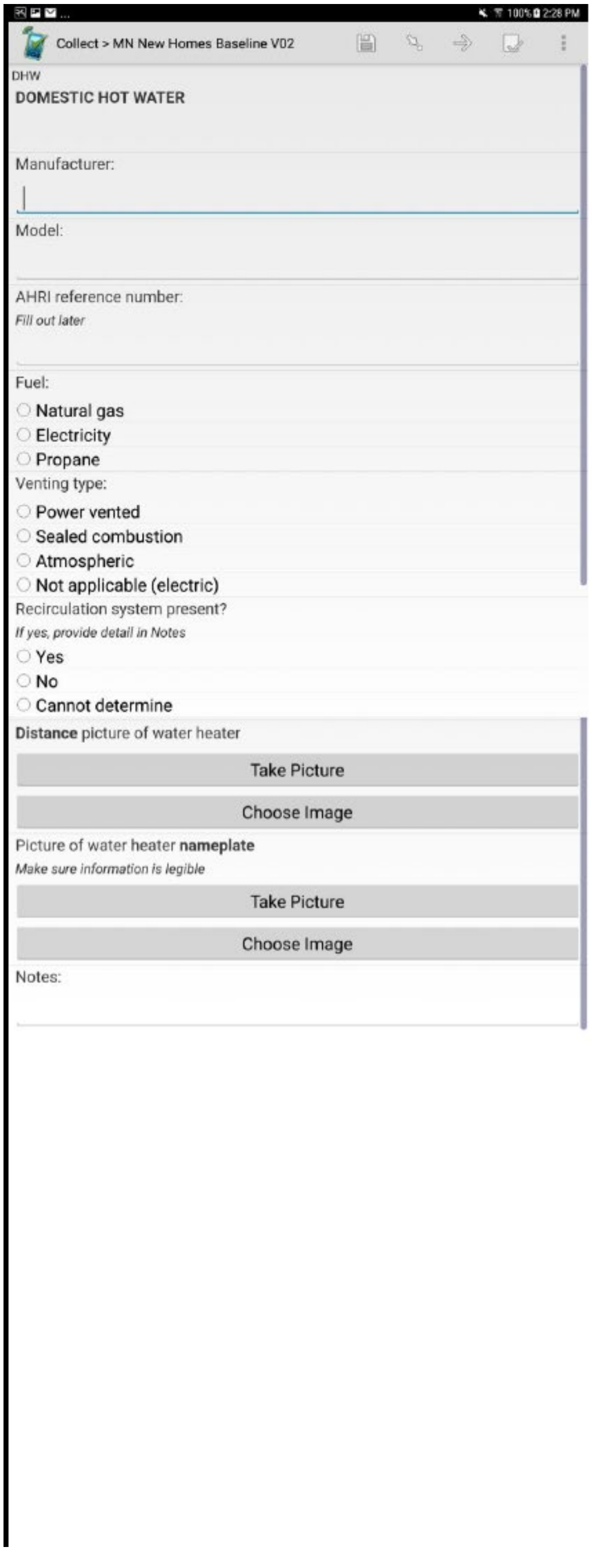
Take Picture

Choose Image

TXV

- Integral to evaporator
- Add-on
- None
- Cannot determine

Notes:



Collect > MN New Homes Baseline V02

DHW

DOMESTIC HOT WATER

Manufacturer:

Model:

AHRI reference number:

Fill out later

Fuel:

- Natural gas
- Electricity
- Propane

Venting type:

- Power vented
- Sealed combustion
- Atmospheric
- Not applicable (electric)

Recirculation system present?

If yes, provide detail in Notes

- Yes
- No
- Cannot determine

Distance picture of water heater

Take Picture

Choose Image

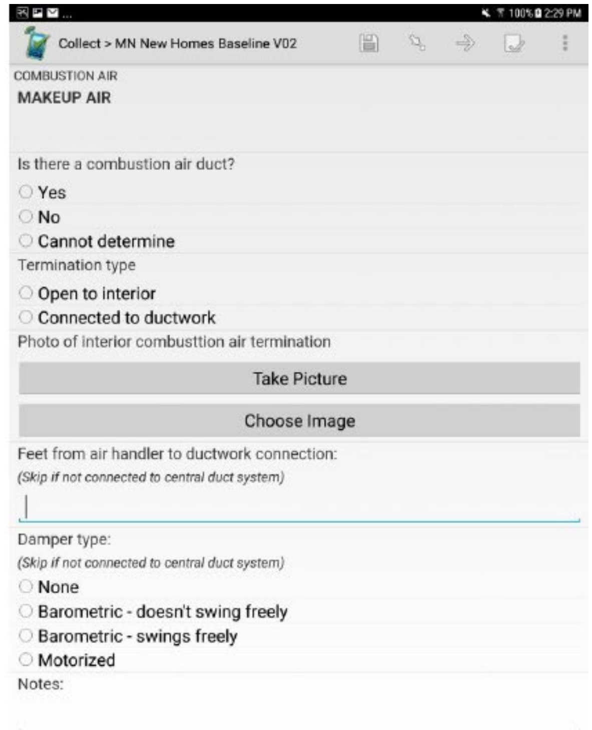
Picture of water heater **nameplate**

Make sure information is legible

Take Picture

Choose Image

Notes:



Collect > MN New Homes Baseline V02

COMBUSTION AIR

MAKEUP AIR

Is there a combustion air duct?

- Yes
- No
- Cannot determine

Termination type

- Open to interior
- Connected to ductwork

Photo of interior combusttion air termination

Take Picture

Choose Image

Feet from air handler to ductwork connection:

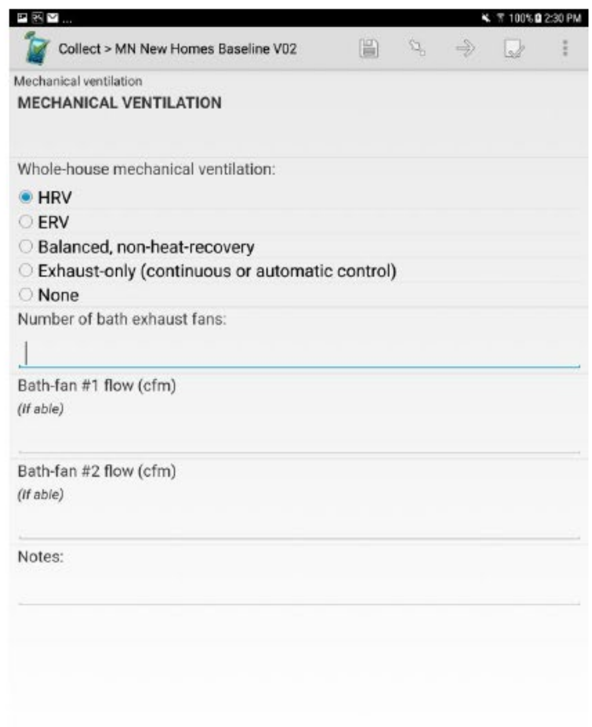
(Skip if not connected to central duct system)

Damper type:

(Skip if not connected to central duct system)

- None
- Barometric - doesn't swing freely
- Barometric - swings freely
- Motorized

Notes:



Collect > MN New Homes Baseline V02

Mechanical ventilation

MECHANICAL VENTILATION

Whole-house mechanical ventilation:

- HRV
- ERV
- Balanced, non-heat-recovery
- Exhaust-only (continuous or automatic control)
- None

Number of bath exhaust fans:

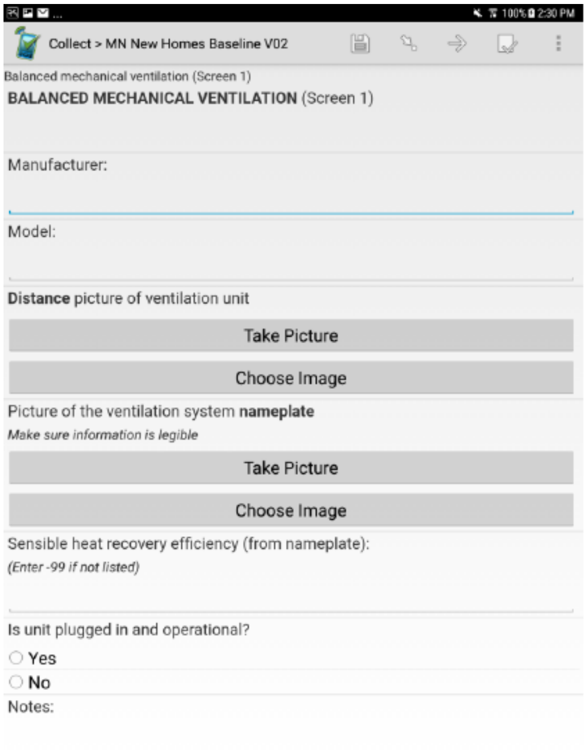
Bath-fan #1 flow (cfm)

(If able)

Bath-fan #2 flow (cfm)

(If able)

Notes:



Collect > MN New Homes Baseline V02

Balanced mechanical ventilation (Screen 1)

BALANCED MECHANICAL VENTILATION (Screen 1)

Manufacturer:

Model:

Distance picture of ventilation unit

Take Picture

Choose Image

Picture of the ventilation system **nameplate**

Make sure information is legible

Take Picture

Choose Image

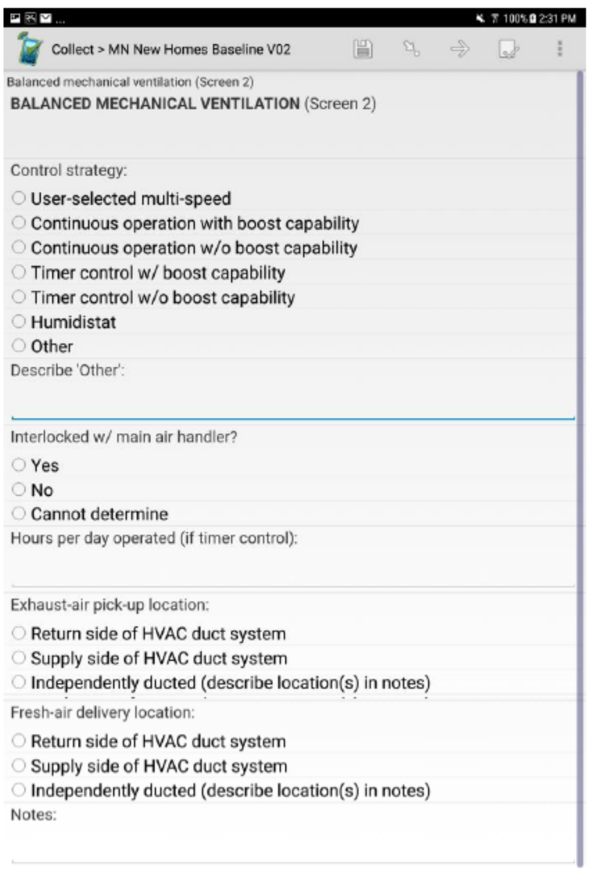
Sensible heat recovery efficiency (from nameplate):

(Enter -99 if not listed)

Is unit plugged in and operational?

- Yes
- No

Notes:



Collect > MN New Homes Baseline V02

Balanced mechanical ventilation (Screen 2)

BALANCED MECHANICAL VENTILATION (Screen 2)

Control strategy:

- User-selected multi-speed
- Continuous operation with boost capability
- Continuous operation w/o boost capability
- Timer control w/ boost capability
- Timer control w/o boost capability
- Humidistat
- Other

Describe 'Other':

Interlocked w/ main air handler?

- Yes
- No
- Cannot determine

Hours per day operated (if timer control):

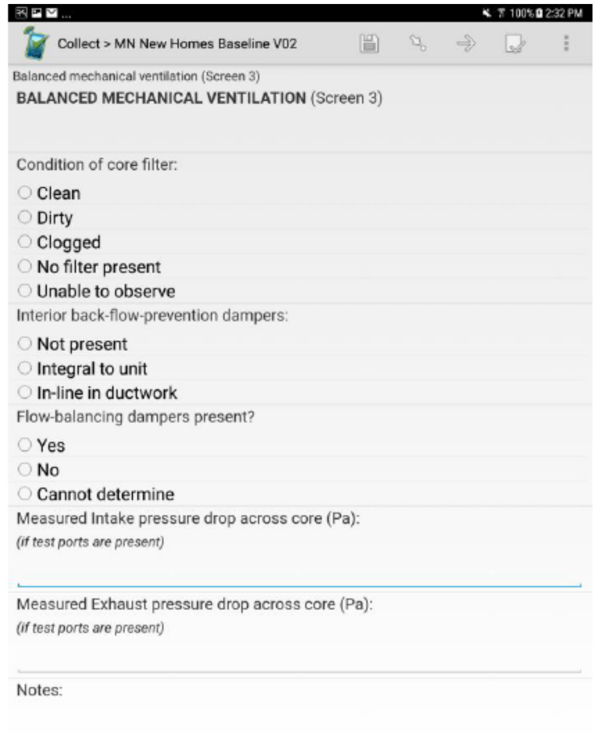
Exhaust-air pick-up location:

- Return side of HVAC duct system
- Supply side of HVAC duct system
- Independently ducted (describe location(s) in notes)

Fresh-air delivery location:

- Return side of HVAC duct system
- Supply side of HVAC duct system
- Independently ducted (describe location(s) in notes)

Notes:



Collect > MN New Homes Baseline V02

Balanced mechanical ventilation (Screen 3)

BALANCED MECHANICAL VENTILATION (Screen 3)

Condition of core filter:

- Clean
- Dirty
- Clogged
- No filter present
- Unable to observe

Interior back-flow-prevention dampers:

- Not present
- Integral to unit
- In-line in ductwork

Flow-balancing dampers present?

- Yes
- No
- Cannot determine

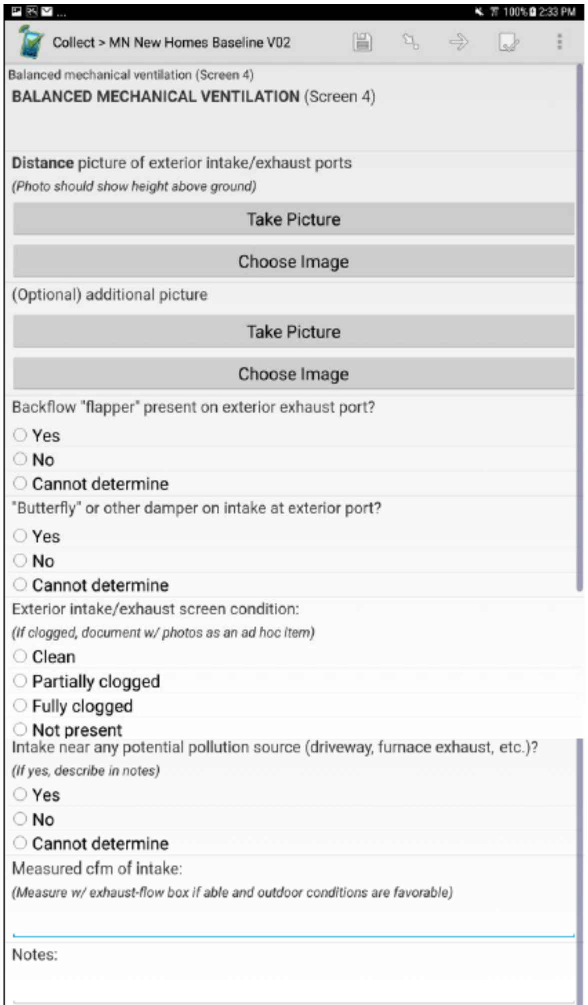
Measured Intake pressure drop across core (Pa):

(if test ports are present)

Measured Exhaust pressure drop across core (Pa):

(if test ports are present)

Notes:



Collect > MN New Homes Baseline V02

Balanced mechanical ventilation (Screen 4)

BALANCED MECHANICAL VENTILATION (Screen 4)

Distance picture of exterior intake/exhaust ports

(Photo should show height above ground)

Take Picture

Choose Image

(Optional) additional picture

Take Picture

Choose Image

Backflow "flapper" present on exterior exhaust port?

- Yes
- No
- Cannot determine

"Butterfly" or other damper on intake at exterior port?

- Yes
- No
- Cannot determine

Exterior intake/exhaust screen condition:

(If clogged, document w/ photos as an ad hoc item)

- Clean
- Partially clogged
- Fully clogged
- Not present

Intake near any potential pollution source (driveway, furnace exhaust, etc.)?

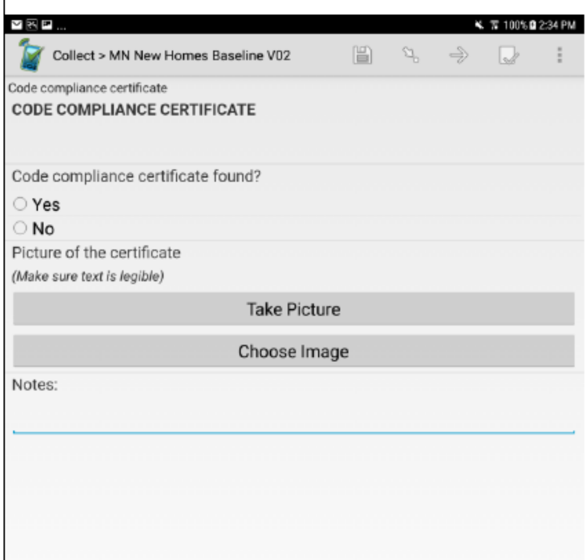
(If yes, describe in notes)

- Yes
- No
- Cannot determine

Measured cfm of intake:

(Measure w/ exhaust-flow box if able and outdoor conditions are favorable)

Notes:



Collect > MN New Homes Baseline V02

Code compliance certificate

CODE COMPLIANCE CERTIFICATE

Code compliance certificate found?

- Yes
- No

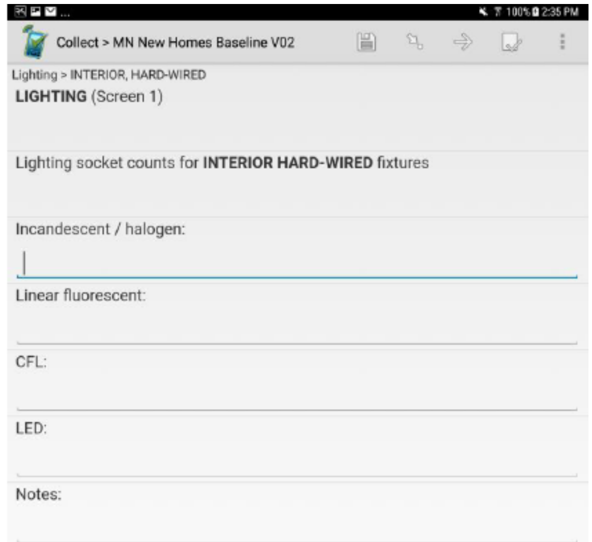
Picture of the certificate

(Make sure text is legible)

Take Picture

Choose Image

Notes:



Collect > MN New Homes Baseline V02

Lighting > INTERIOR, HARD-WIRED

LIGHTING (Screen 1)

Lighting socket counts for **INTERIOR HARD-WIRED** fixtures

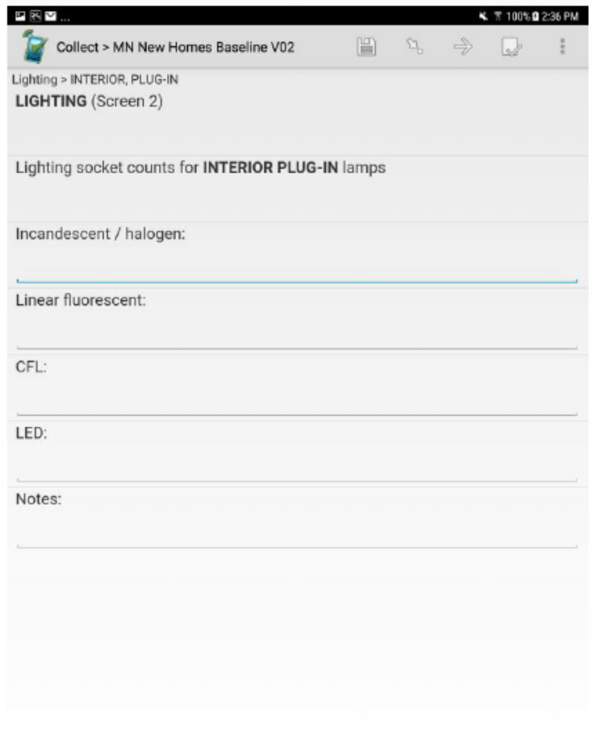
Incandescent / halogen:

Linear fluorescent:

CFL:

LED:

Notes:



Collect > MN New Homes Baseline V02

Lighting > INTERIOR, PLUG-IN

LIGHTING (Screen 2)

Lighting socket counts for **INTERIOR PLUG-IN** lamps

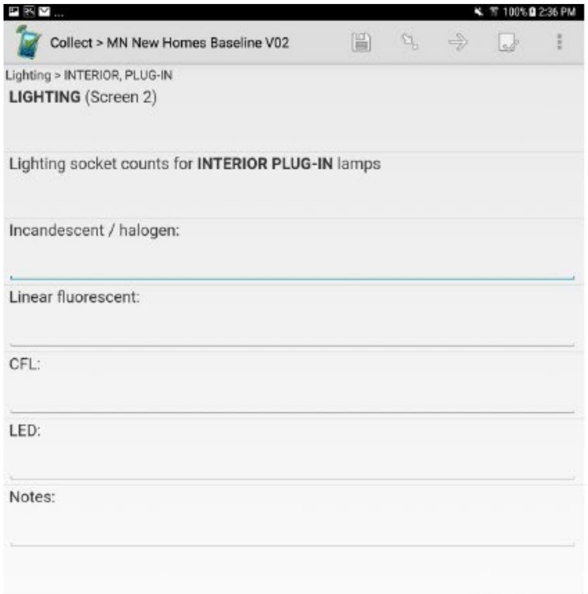
Incandescent / halogen:

Linear fluorescent:

CFL:

LED:

Notes:



Collect > MN New Homes Baseline V02

Lighting > INTERIOR, PLUG-IN

LIGHTING (Screen 2)

Lighting socket counts for **INTERIOR PLUG-IN** lamps

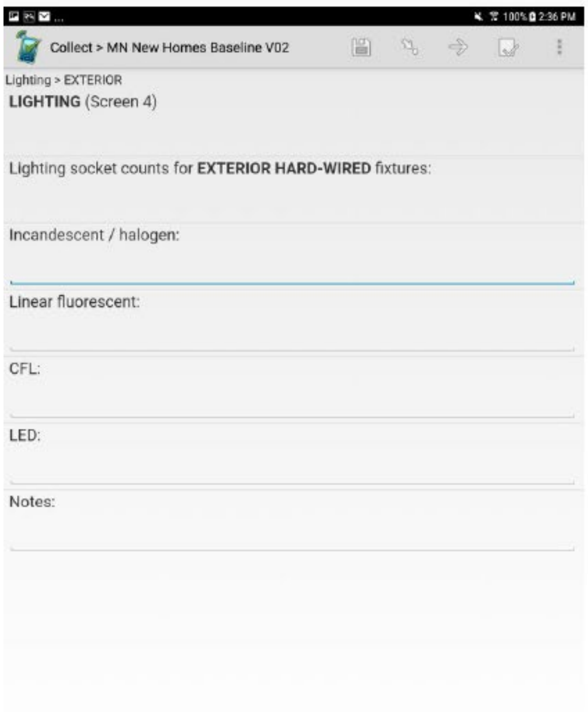
Incandescent / halogen:

Linear fluorescent:

CFL:

LED:

Notes:



Collect > MN New Homes Baseline V02

Lighting > EXTERIOR

LIGHTING (Screen 4)

Lighting socket counts for **EXTERIOR HARD-WIRED** fixtures:

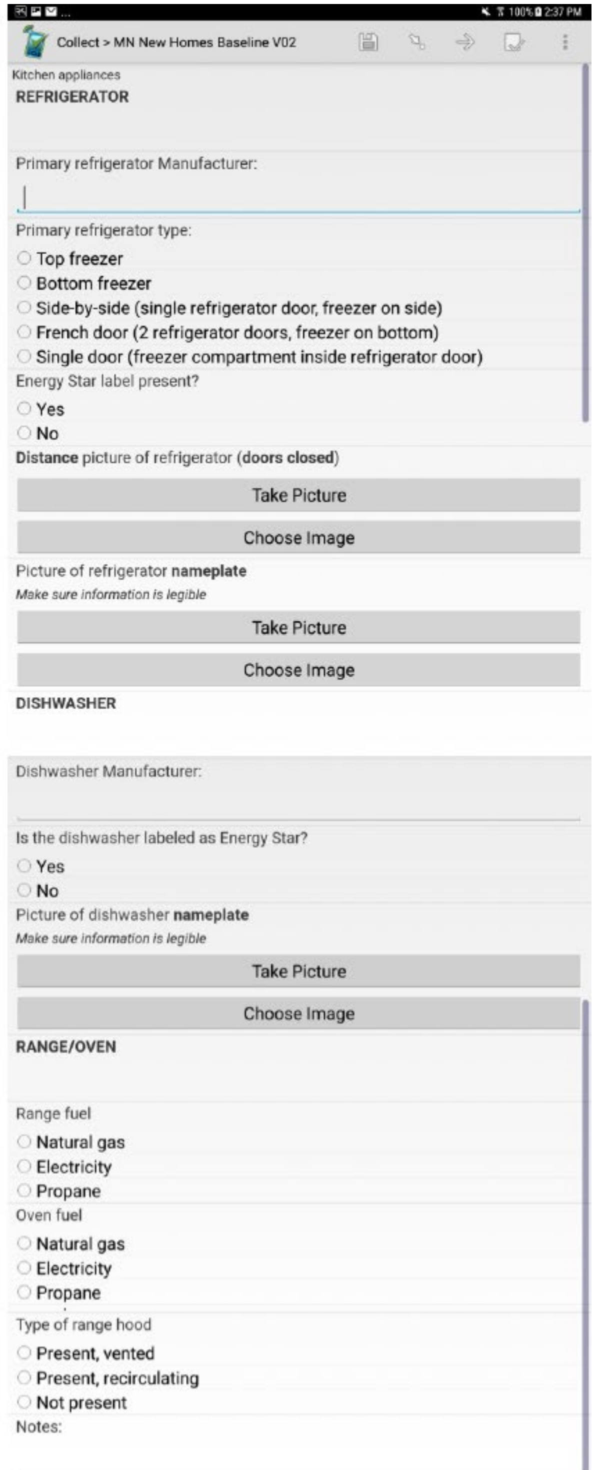
Incandescent / halogen:

Linear fluorescent:

CFL:

LED:

Notes:



Collect > MN New Homes Baseline V02

Kitchen appliances

REFRIGERATOR

Primary refrigerator Manufacturer:

Primary refrigerator type:

- Top freezer
- Bottom freezer
- Side-by-side (single refrigerator door, freezer on side)
- French door (2 refrigerator doors, freezer on bottom)
- Single door (freezer compartment inside refrigerator door)

Energy Star label present?

- Yes
- No

Distance picture of refrigerator (**doors closed**)

Take Picture

Choose Image

Picture of refrigerator **nameplate**

Make sure information is legible

Take Picture

Choose Image

DISHWASHER

Dishwasher Manufacturer:

Is the dishwasher labeled as Energy Star?

- Yes
- No

Picture of dishwasher **nameplate**

Make sure information is legible

Take Picture

Choose Image

RANGE/OVEN

Range fuel

- Natural gas
- Electricity
- Propane

Oven fuel

- Natural gas
- Electricity
- Propane

Type of range hood

- Present, vented
- Present, recirculating
- Not present

Notes:

Collect > MN New Homes Baseline V02

Secondary refrigerators/freezers

Are there any secondary refrigerators or freezers?

- ○ Yes
- ○ No

Collect > MN New Homes Baseline V02

Secondary refrigerators/freezers > Supplemental refrigeration (1) > Supp refrigeration group

SECONDARY REFRIGERATOR/FREEZER

Type of unit:

- ○ Top freezer refrigerator
- ○ Bottom freezer refrigerator
- ○ Side-by-side refrigerator (freezer on side)
- ○ French door refrigerator (freezer on bottom)
- ○ Single door refrigerator (freezer compartment inside refrigerator door)
- ○ Compact refrigerator
- ○ Beverage refrigerator
- ○ Chest freezer
- ○ Upright freezer

Location:

- ○ Kitchen
- ○ Basement
- ○ Enclosed porch
- ○ Garage
- ○ Other conditioned space
- ○ Other unconditioned space

Energy Star label present?

- ○ Yes
- ○ No

Distance picture of unit (**doors open, showing contents**)

[Take Picture]

[Choose Image]

Picture of refrigerator/freezer **nameplate**

Make sure information is legible

[Take Picture]

[Choose Image]

Notes:

Collect > MN New Homes Baseline V02

Laundry appliances

CLOTHES WASHER

Clothes washer Manufacturer:

Distance picture of the clothes washer

[Take Picture]

[Choose Image]

Picture of the clothes washer **nameplate**

Make sure information is legible

[Take Picture]

[Choose Image]

Energy Star label present for clothes washer?

- ○ Yes
- ○ No

CLOTHES DRYER

Clothes dryer Manufacturer:

Clothes dryer fuel:

- ○ Natural gas
- ○ Electricity
- ○ Propane

Distance picture of clothes dryer

[Take Picture]

[Choose Image]

Picture of clothes dryer **nameplate**

Make sure information is legible

[Take Picture]

[Choose Image]

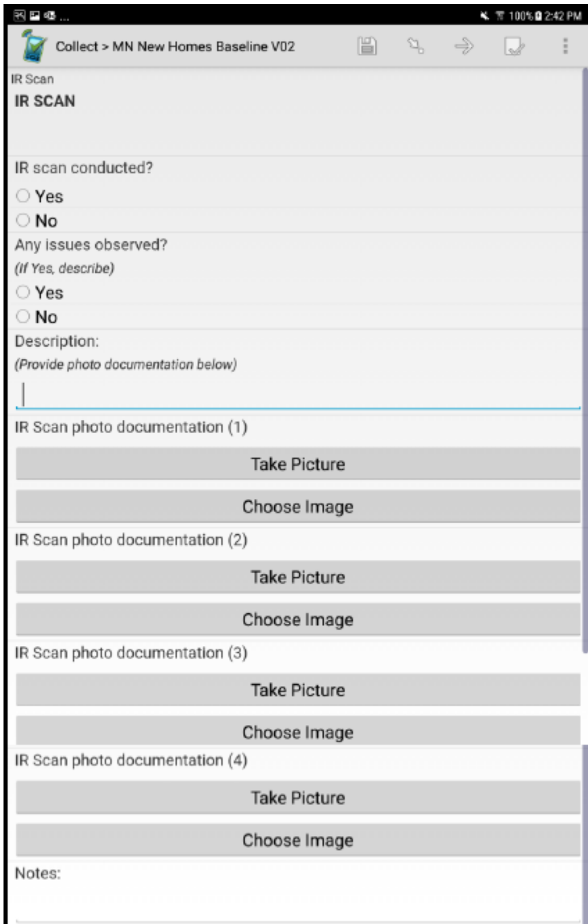
Energy Star label present for clothes dryer?

- ○ Yes
- ○ No

Does the clothes dryer vent to the outside?

- ○ Yes
- ○ No

Notes:


Collect > MN New Homes Baseline V02

IR Scan

IR SCAN

IR scan conducted?

○ Yes
○ No

Any issues observed?
(If Yes, describe)

○ Yes
○ No

Description:
(Provide photo documentation below)

IR Scan photo documentation (1)

Take Picture

Choose Image

IR Scan photo documentation (2)

Take Picture

Choose Image

IR Scan photo documentation (3)

Take Picture

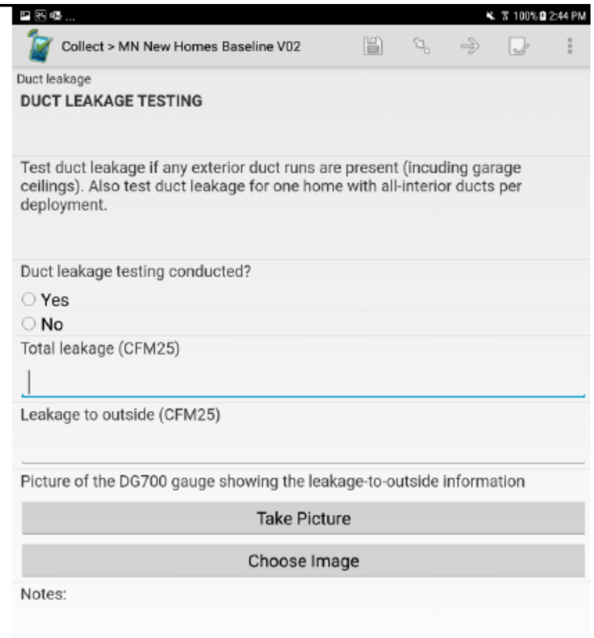
Choose Image

IR Scan photo documentation (4)

Take Picture

Choose Image

Notes:


Collect > MN New Homes Baseline V02

Duct leakage

DUCT LEAKAGE TESTING

Test duct leakage if any exterior duct runs are present (incuding garage ceilings). Also test duct leakage for one home with all-interior ducts per deployment.

Duct leakage testing conducted?

○ Yes
○ No

Total leakage (CFM25)

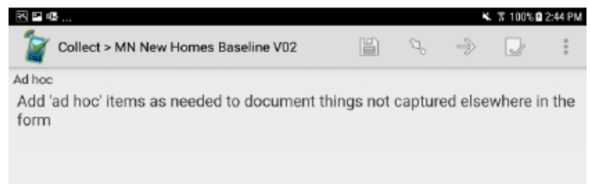
Leakage to outside (CFM25)

Picture of the DG700 gauge showing the leakage-to-outside information

Take Picture

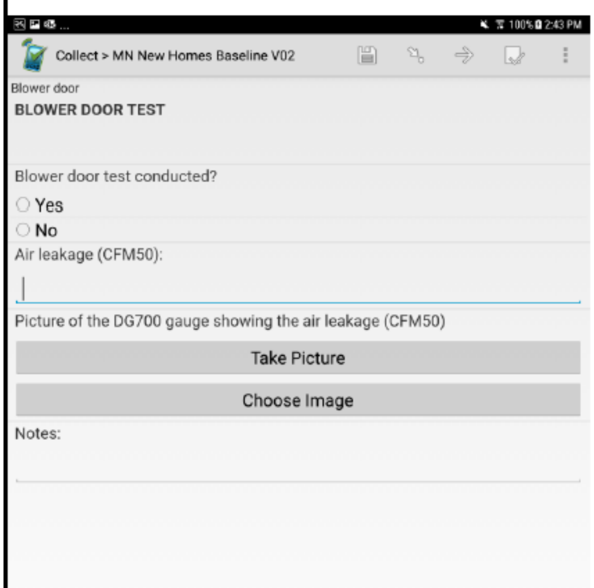
Choose Image

Notes:


Collect > MN New Homes Baseline V02

Ad hoc

Add 'ad hoc' items as needed to document things not captured elsewhere in the form


Collect > MN New Homes Baseline V02

Blower door

BLOWER DOOR TEST

Blower door test conducted?

○ Yes
○ No

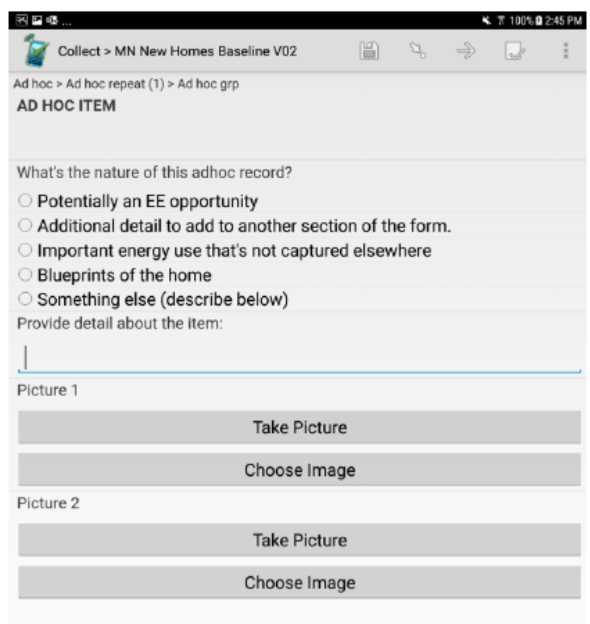
Air leakage (CFM50):

Picture of the DG700 gauge showing the air leakage (CFM50)

Take Picture

Choose Image

Notes:


Collect > MN New Homes Baseline V02

Ad hoc > Ad hoc repeat (1) > Ad hoc grp

AD HOC ITEM

What's the nature of this adhoc record?

○ Potentially an EE opportunity
○ Additional detail to add to another section of the form.
○ Important energy use that's not captured elsewhere
○ Blueprints of the home
○ Something else (describe below)

Provide detail about the item:

Picture 1

Take Picture

Choose Image

Picture 2

Take Picture

Choose Image

Collect > MN New Homes Baseline V02

Gift card and signatures

GIFT CARD AND SIGNATURES

Collect > MN New Homes Baseline V02

Gift card and signatures

Name of gift card recipient:

The name you fill in here will appear on the signature screen

Xxxx Yyyy

Collect > MN New Homes Baseline V02

Gift card and signatures

My signature below confirms that I, **Xxxx Yyyy**, have received a $100 gift card as a thank-you for participating in the Minnesota Residential Energy Baseline and Market Characterization Study.

Gather Signature

Collect > MN New Homes Baseline V02

Gift card and signatures

My signature below confirms that I, **Xxxx Yyyy**, give the Minnesota Residential Energy Baseline and Market Characterization Study team **permission to use any photos taken during this site visit**. I understand that these pictures may be published in public reports or presentations, but that **my name and address will be kept confidential**. I also give permission for my electric and/or natural gas utility to provide information about whether my home has been certified under a utility new-construction or renovation incentive program.

Gather Signature

Collect > MN New Homes Baseline V02

Key item review

KEY ITEM REVIEW

Key items will appear if they were skipped earlier in the form. **Complete before leaving the site**.

Building ID

Exterior photo - North

Take Picture

Choose Image

Exterior photo - East

Take Picture

Choose Image

Exterior photo - South

Take Picture

Choose Image

Exterior photo - West

Take Picture

Choose Image

Htg system 1: Take a picture of the **nameplate**

Make sure information is legible

Take Picture

Choose Image

Clg system 1: Take a picture of the **nameplate**

Make sure information is legible

Take Picture

Choose Image

Clg system 1: Take a picture of the evaporator **nameplate**

Make sure information is legible

Take Picture

Choose Image

Take a picture of the DHW **nameplate**

Make sure information is legible

Take Picture

Choose Image

Take a picture of the balanced ventilation system **nameplate**

Make sure information is legible

Take Picture

Choose Image

Take a picture of the code-compliance certificate

Take Picture

Choose Image

Record the air leakage CFM50

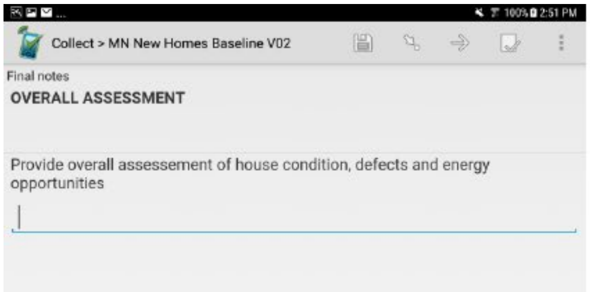
Record the duct leakage to outside CFM25

My signature below confirms that I, **Xxxx Yyyy**, have received a $100 gift card as a thank-you for participating in the Minnesota Residential Energy Baseline and Market Characterization Study.

Gather Signature

My signature below confirms that I, **Xxxx Yyyy**, give the Minnesota Residential Energy Baseline and Market Characterization Study team **permission to use any photos taken during this site visit**. I understand that these pictures may be published in public reports or presentations, but that **my name and address will be kept confidential**. I also give permission for my electric and/or natural gas utility to provide information about whether my home has been certified under a utility new-construction or renovation incentive program.

Gather Signature

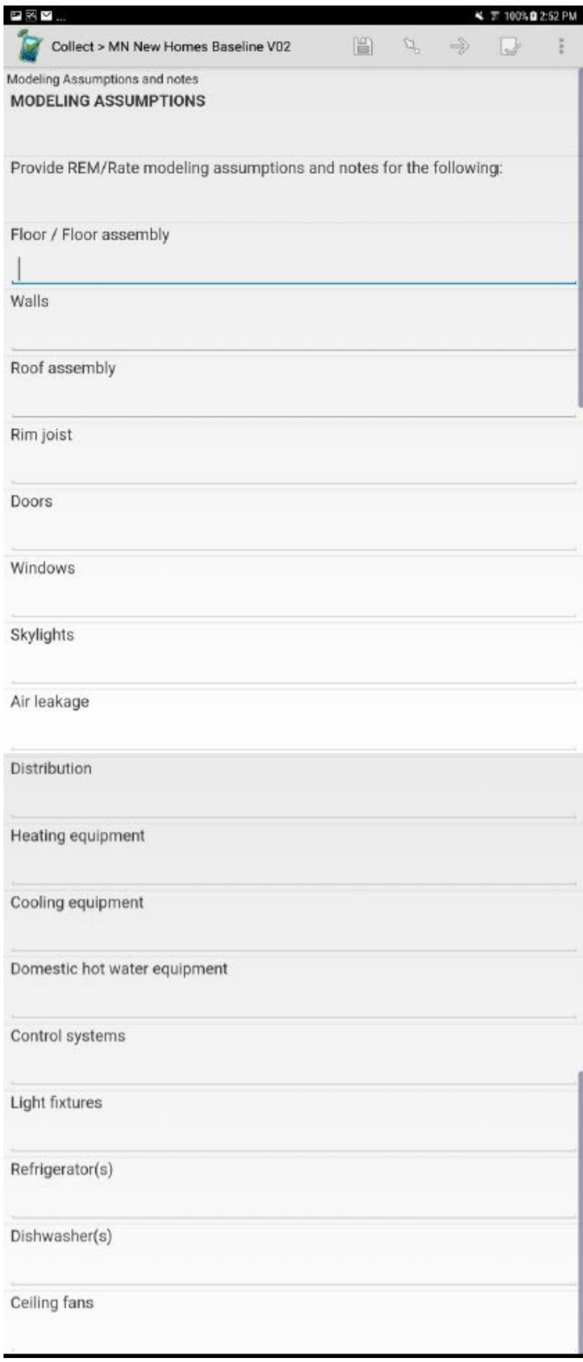


Collect > MN New Homes Baseline V02

Final notes

OVERALL ASSESSMENT

Provide overall assessement of house condition, defects and energy opportunities



Collect > MN New Homes Baseline V02

Modeling Assumptions and notes

MODELING ASSUMPTIONS

Provide REM/Rate modeling assumptions and notes for the following:

Floor / Floor assembly

Walls

Roof assembly

Rim joist

Doors

Windows

Skylights

Air leakage

Distribution

Heating equipment

Cooling equipment

Domestic hot water equipment

Control systems

Light fixtures

Refrigerator(s)

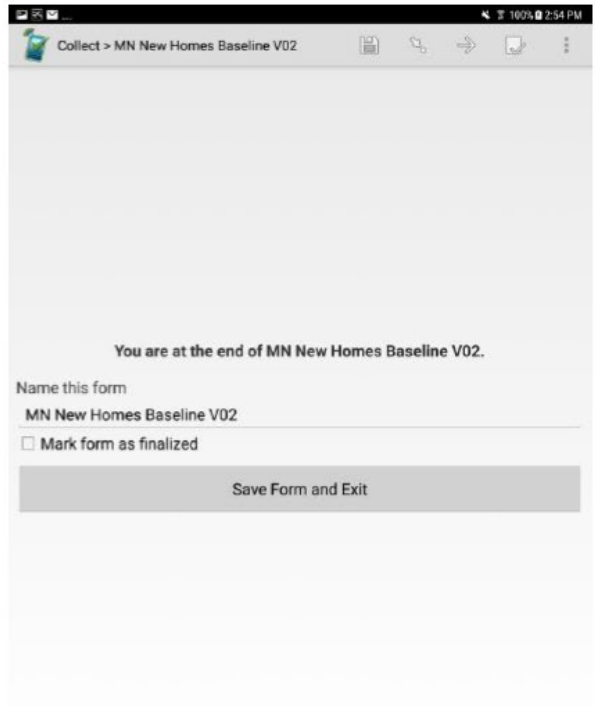
Dishwasher(s)

Ceiling fans

Mechnical ventilation system(s)

On-site power generation

Additional assumptions



Collect > MN New Homes Baseline V02

You are at the end of MN New Homes Baseline V02.

Name this form

MN New Homes Baseline V02

☐ Mark form as finalized

Save Form and Exit

Appendix D: Utility Rates

This appendix provides details about utility rates used in the analysis. For electricity and natural gas, we estimated statewide average costs that are weighted across utilities and utility types according to our geographic analysis of new-home construction. Electricity rates are further broken down by season and presence (has electric heat) and type of electric heat (i.e., strip, heat pump).

Electricity

For electricity, we looked up the published monthly customer charges and seasonal energy charges for utilities that represent the top 70 to 90 percent of new-home construction within each of the three utility types according to our geographic analysis (Table 79).

Table 79. Base electric rates (weighted average).

Utility type	Monthly customer charge	Summer (Jun-Sep) energy charge (per kWh)	Winter (Oct-May) energy charge (per kWh)
Investor-owned[a]	$9.85	$0.1028	$0.0888
Cooperative[b]	$17.90	$0.1272	$0.1168
Municipal[c]	$14.83	$0.1103	$0.1127

[a]Weighted average of Xcel (89.5%), Minnesota Power (7.3%) and Otter Tail Power (3.1%)

[b]Weighted average of Connexus (31.1%), Dakota Electric (19.1%), Wright-Hennepin (13.9%), Minnesota Valley Elec (10.9%), East Central Electric (9.5%), Lake Country Power (8.1%), Crow Wing Elec Coop (7.3%) and Stearns Coop (5.1%)

[c]Weighted average of Rochester (37.7%), Moorhead (11.6%), Elk River (10.5%), Chaska (9.8%), Anoka (5.8%), Shakopee (5.0%), New Prague (4.8%), Delano (4.2%), Alexandria (3.8%), Kasson (3.5%) and Owatonna (3.2%)

We then made percentage adjustments to these base rates to account for taxes, franchise fees, riders and other adders to base rates. These assumed adjustments were: +10 percent for investor-owned utilities, +7 percent for cooperative utilities and +2 percent for municipal utilities.

We also assumed slightly lower rates for homes with electric space heating in investor-owned and cooperative utility service areas, because electricity is not taxable in Minnesota during the winter for homes that are primarily heating with electricity. And we further adjusted winter electric rates for customers of IOU and cooperative utilities with dual-fuel heat pumps, as these utilities frequently offer discounted power for this type of heating.

Final (rounded) electric rates used in the analysis are shown in Table 80.

Table 80. Final adjusted electric rates used for analysis.

Utility type	Monthly customer charge	Summer (Jun-Sep) energy charge (per kWh)	Winter (Oct-May) energy charge, non-electric heat (per kWh)	Winter (Oct-May) energy charge, electric heat (per kWh)	Winter (Oct-May) energy charge, dual-fuel heat (per kWh)
Investor-owned	$11	$0.115	$0.100	$0.095	$0.050
Cooperative	$19	$0.135	$0.125	$0.120	$0.065
Municipal	$15	$0.115	$0.115	$0.115	$0.115

Natural Gas

For natural gas, our geographic analysis indicated that the three large investor-owned utilities serve about 95 percent of all new homes with natural gas service. Rates for these are publicly available, but a significant proportion of customer bills are subject to regular purchased-gas adjustments that pass the utilities' cost of gas directly through to consumers. Therefore, we used Energy Information Administration (EIA) published data on total annual residential sales volume, revenue and number of customers for 2016 through 2018 for each utility to derive average usage and cost per customer, then adjusted these for current published monthly customer charges to get an adjusted average cost per therm. We weighted customer charges and calculated per-therm charges across the utilities (at 55.9 percent for Centerpoint Energy, 29.1 percent for Xcel Energy and 15.0 percent for Minnesota Energy Resources) and estimate a statewide average natural rate for new homes of $10 per month in customer charges and 67 cents per therm in energy charges.

Propane

We averaged weekly heating-season propane prices for Minnesota (available from EIA) over the last three heating seasons (2017/18, 2018/19 and 2019/20) to derive an average price for propane of $1.62 per gallon.

Wood

For the two homes in the study that used wood as a primary heating source, we assumed a cost of $375 per cord (128 ft^3) with a total heating value of 20 MMBtu per cord. This yields a cost of $18.75 per million Btu.

Appendix E: Prescriptive-Code Modeling Details

This appendix describes certain details related to modeling prescriptive energy code minimum values, mainly concerning modeling of insulation levels.

Table 81 provides details about how various building components were set up in REM/Rate for modeling prescriptive-code insulation levels. Table 82 shows the resulting component assembly U-values that were used for comparison to as-built conditions and compares these to values specified in Minnesota code for the U-factor alternative, which is also the reference source for performance-path modeling. In some cases, the calculated U-values for prescriptive-code modeling differ from the code specifications for performance-path modeling: we used the prescriptive-code based values for the study.

Table 81. Modeled minimum prescriptive-code components.

Component	Prescriptive code insulation requirement	Modeled configuration
Above-grade walls	R-20 (Zone 6), R-21 (Zone 7)	2x6 construction, 16-inch on-center, 0.23 framing factor (default), R-20 or R-21 cavity insulation (Grade 1), no continuous insulation
Ceilings	R-49	2x4 truss construction, 24-inch on-center, 0.0688 framing factor (default), R-11 cavity insulation and R-38 continuous insulation (Grade 1), 0.5-inch gypsum thickness
Foundation walls	R-15	8-inch concrete, full-height R-10 exterior continuous insulation, full-height R-5 interior continuous insulation (Grade 1)
Slabs (on-grade or heated)	R-10 perimeter to 3.5 feet (Zone 6), 5 feet (Zone 7)	R10 perimeter insulation (Grade 1), to 3.5 or 5 feet, no under-slab insulation
Frame floor	R-30 (Zone 6), R-38 (Zone 7)	2x12 construction, 16-inch on-center, 9 inches of R-30 or 11.5 inches of R-38 cavity insulation (Grade 1), no continuous insulation, hardwood flooring

Table 82. Code performance-path and modeled U-values with equivalent R-values.

Component and prescriptive-code R-value	Code Table 402.1.3 U-value	Code Table 402.1.3 equiv. R-value	REM/Rate modeled U-value	REM/Rate modeled equiv. R-value
Above-grade walls, R-20 (Zone 6)	0.048	20.8	0.060	16.7
Above-grade walls, R-21 (Zone 7)	0.048	20.8	0.058	17.2
Ceilings, R-49	0.026	38.5	0.020	50.0
Foundation walls	0.050	20.0	0.0605	16.5
Frame floor, R-30 (Zone 6)	0.033	30.3	0.036	27.8
Frame floor, R-38 (Zone 7)	0.028	35.7	0.029	34.5

In addition to insulation modeling described above, for modeling prescriptive-code minimums, we:

- Set air-leakage to 3.0 ACH50, retaining the shelter class as modeled for the as-built condition
- Set all window U-values to 0.32, retaining the SHGC value used for the as-built condition
- Set all ducts outside the thermal envelope to R-8 insulation
- Set lighting to 75% LED
- For duct leakage —
  - If there were no ducts outside the thermal envelope, retained the duct leakage values for the as-built condition
  - If any ducts were outside the thermal envelope, set total duct leakage to 0.04 CFM25 per square foot of conditioned floor area and assumed that 20% of total duct leakage was leakage to outside.
- Configured mechanical ventilation to meet the home's required continuous ventilation rate using the as-built ventilation equipment, with air handler electricity included in mechanical ventilation if an interlock was required due to the as-built ducting arrangement. Air-handler watts set to 1 Watt per 10 kBtuh of furnace input firing rate, derated by 15% to account for coincident air-handler operation during the heating and cooling seasons.

All other modeling parameters were left in the as-built condition for modeling the prescriptive-code minimum condition for the home.