Energy Impact Study of the 2018 IECC and 2021 IECC Energy Codes for Nebraska

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Executive Summary

The focus of this report is to evaluate the annual residential energy consumption under two energy code conditions. The codes compared are:

- Nebraska's current residential energy code, the 2018 International Energy Conservation Code (IECC), and
- The 2021 International Energy Conservation Code (IECC).

2021 IECC consumes less energy, but construction cost has long payback

The findings of this study indicate that the 2021 International Energy Conservation Code would result in less energy consumption for homes in all areas of the state. The savings in cooling energy and equipment size are substantial. There are also more modest overall savings in heating, lighting, and appliance energy use. One measure, reducing the solar heat gain coefficient (SHGC) of windows, produces large cooling savings and reduces the size of air conditioning equipment, but causes homes to use more heating energy. The overall effect of this change to windows is to use more energy in Nebraska climates.

The largest savings was achieved using a new section of the code (Section 408), which allows users of the code to choose from five different options for increased efficiency. For the purpose of this analysis, we assumed that most builders would choose to locate all heating/cooling equipment and ductwork inside conditioned space. Many new homes are already built in this way, so in those cases both the associated savings and the construction cost would be neutral. However, for homes that are not already doing this, the savings will be realized. The other options are increased heating/cooling equipment efficiency, increased insulation levels, increased hot water equipment efficiency, and increased ventilation system efficiency.

Other changes that contributed to energy savings are increased wall insulation, ceiling insulation, improved ventilation system fan efficiency, and an increase to 100% high-efficacy lighting.

The average energy savings was 9%, and ranged from 5% to 16% for the various house sizes and locations. The average savings in whole-house energy cost was 7.8%. Depending on house size and location, the savings range from $92 to $446 per year, with an average annual savings of $183.

A cost analysis performed for a median sized house showed that overall, the simple payback period for upgrading to the 2021 IECC was approximately 42 years. For homeowners with a 30-year mortgage, the annual cost for mortgage payments and energy were greater with the 2021 IECC than the 2018 IECC.

A few of the individual upgrades in the 2021 IECC did have shorter payback periods. The measures that are projected to pay back in 12 years or less were: increased high efficacy lighting, dimmer switches, and the new section 408 (modeled here with 100% of ductwork inside conditioned space).

Increases in wall and ceiling insulation, while they did account for meaningful energy savings, had payback periods of nearly 100 years. The window upgrade wasn't costly and its cost was offset by

reduction in equipment size, but due to its increased annual energy consumption it didn't contribute positively to overall payback.

Key differences between 2018 and 2021 codes

Key changes in the 2021 IECC include:

1. The glazing U-factor does not change, but the 2021 code adds an upper limit for glazing SHGC (solar heat gain coefficient). Previously, there was no upper limit. The new limit is 0.40. This change applies to both windows and skylights.
2. Minimum ceiling R-value has increased from R-49 to R-60.
3. Minimum wall R-value has increased. The 2018 IECC required at least R-20 (cavity) or 13+5 (cavity + continuous). The 2021 IECC increases the requirement to at least R-20+5 (cavity plus continuous) or 13+10 or 0+15.
4. The minimum percentage of high-efficacy lighting has increased from 90% to 100%. The definition of "high-efficacy lighting" also changes between the codes. The 2018 definition ranged from >40 to >60 lumens per Watt, depending on the Wattage of the lamp. The 2021 definition is increased to >65 lumens per Watt for all lamps or >45 lumens per Watt for all luminaires. Because the market has largely moved toward LEDs, our modeling was performed using LED lighting for both the 2018 and 2021 cases.
5. The 2021 IECC adds a new section 408 that requires an "additional efficiency package". Users of the prescriptive code must choose between one of five additional options. (For our modeling we used option 4 (duct thermal distribution option).
    a. Option 1 – enhanced envelope performance: Use a total building UA that is 5% more efficient than the prescriptive code.
    b. Option 2 – More efficient HVAC: Install systems with the following minimum efficiencies: either 95 AFUE natural gas furnace with 15 SEER air conditioner OR 10 HSPF/16 SEER air source heat pump, OR 3.5 COP ground source heat pump.
    c. Option 3 – Reduced service water heater energy use: Install a water heating system meeting one of the following minimum efficiencies: 0.82 EF gas water heater, 2.0 EF electric heat pump water heater, or 0.4 solar fraction.
    d. Option 4 – more efficient thermal distribution system: locate 100% of ducts, air handlers, hydronic thermal distribution systems, or other thermal distribution systems inside the building thermal envelope.
    e. Option 5 – improved air sealing and efficient ventilation system: Achieve a measured air leakage rate of 3 ACH50 or less and install an ERV or HRV (energy or heat recovery ventilator). The ERV/HRV must have at least 75 percent sensible recovery efficiency, deliver less than 1.1 cfm/Watt, cannot use recirculation for defrost, and ERVs must have greater than 50% latent recovery.

About the Study

The study considers the annual energy consumption of houses constructed according to the 2018 and 2021 IECC energy codes. Energy use was modeled for three cities selected to represent climate variability in the state: Chadron, Norfolk, and Omaha. Energy modeling was performed using

Ekotrope, a commercially available software tool that conforms to RESNET standards[1] for home energy ratings. The RESNET standard is used as the basis for energy-efficient mortgages and is also a primary method used by EPA to determine compliance for the Energy Star® new homes program. It is the most widely accepted means of assessing and comparing home energy performance currently being used in the US.

Four houses were modeled for the study. These include a small ranch style house with 1,453 square feet (sf), a medium ranch style house with 1,852 sf, a medium two-story house with 2,103 sf, and a large two story house at 2,932 sf. Each house was modeled with both 12% and 18% window to wall area ratio. Occupancy and usage patterns were based on national data for average use. Modeling was performed using two different heating/cooling system combinations: (a) a 14 SEER/8.2 HSPF heat pump and (b) a 14 SEER air conditioner with a 95% AFUE gas furnace.

The modeling approach and houses used in this analysis were based on those used for a 2003 study of Nebraska energy codes[2], and follow-up studies performed in 2006, 2009, 2012, 2015, and 2018 based on updated versions of the IECC[3,4,5,6,7]. The first study investigated the life cycle cost impacts of upgrading Nebraska's state energy code from the 1983 Model Energy Code to the 2000 IECC. That study concluded that the new energy code would save buyers of new homes between $50 and $295 per year, depending on the size of the house and where they lived. Statewide, the new code was projected to save homeowners $254,000 the first year, and $59.6 million dollars over the life of houses built before 2018. The 2006 study showed that adoption of the 2006 IECC would not save energy compared with the 2003 IECC for the majority of new homes in Nebraska. The 2009 study showed that the 2009 IECC would provide savings, despite some reductions in required envelope insulation. The 2009 IECC was subsequently adopted by the state. The 2012 IECC and 2015 IECC included many of the changes that are in the 2018 IECC, and produced energy savings in heating and lighting, but were not subsequently adopted by the state. The 2018 IECC showed further savings and was subsequently adopted and is the current code in Nebraska.

About Energy Codes

Energy codes establish minimum insulation requirements for both commercial and residential buildings. Residential codes benefit homeowners by ensuring that newly constructed homes make use of modern techniques and products that make houses energy-efficient. This results in lower energy bills and often improved thermal comfort for the homeowner, and optimal utilization of fossil fuels and nonrenewable resources for communities. Codes also level the playing field for builders by requiring a basic level of quality in areas that homeowners might not see when they are buying a house (for example, the insulation in the walls).

About the Author

Amy Musser holds a Ph.D. degree in Architectural Engineering and an M.S. degree in Mechanical Engineering. She is also a registered professional engineer in the state of Nebraska, and has been conducting research in the fields of building energy and indoor air quality for approximately 25 years. She completed the original Nebraska codes study that investigated the life cycle cost impact of the 2000 IECC for Nebraska while she was a faculty member in the Architectural Engineering Program at the University of Nebraska-Lincoln. She currently holds the position of Principal at Vandemusser Design, LLC, a building energy and air quality consulting firm that she co-founded.

Disclaimer

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Introduction

The objective of this study was to compare the energy impact for Nebraska homeowners under the 2018 International Energy Conservation Code (IECC) and the 2021 IECC. The comparisons were performed with a 14 SEER/8.2 HSPF electric heat pump and a 14 SEER air conditioner with 95% AFUE gas furnace. The study compares the modeled energy use of four houses in three Nebraska climates: Omaha, Norfolk, and Chadron. The four houses are based on those used for previous studies of Nebraska energy codes[2,3,4,5,6,7]. The houses include a ranch style house at the 20th percentile size being constructed in Nebraska, a ranch style house and a two-story house at the median home size, and a two-story house at the 80th percentile size. Each house is investigated with both 12% and 18% window to wall area ratio. Occupancy and appliance loads were modeled based on the RESNET standard[1].

Selection and specification of houses modeled

House size and type

The four houses studied were based on those used for a previous study of the life cycle cost impact of adopting the 2000 IECC in Nebraska[2]. A 2002 survey of Nebraska building code officials conducted as part of that study was used as the basis for selecting four homes for modeling. Their square footages represent homes at the 20th percentile, mean, median, and 80th percentile of Nebraska homes. The actual houses modeled, their square footages, and other characteristics are shown in Table 1.

One difference from the original study is that the four houses were modeled with window to wall area ratios of both 12% and 18%. In the original study, the houses were modeled with the actual window area shown on the building plans. The 2006 study[3] was updated to model the homes with window to wall ratios of 12% and 18% due to the code change eliminating more stringent requirements for homes with larger than a 15% window to wall ratio.

House	Plan area	Style	Ceiling height (range, ft)	Above grade exterior wall area (sf)
20th percentile	1,453 sf	ranch	7.5-10.0	1,530
Surveyed mean	1,852 sf	ranch	7.5-10.0	2,000
Midwest mean	2,103 sf	2 story	7.5-9.0	2,620
80th percentile	2,932 sf	2 story	7.5-12.7	2,540

Table 1. Characteristics of houses modeled.

According to the 2002 survey, 92% of Nebraska houses have basements and 26% of these are finished basements. All four houses were modeled with conditioned basements. The survey also found that when records on the type of heating and cooling systems installed were available, 67% of new homes had gas-fired forced air furnaces and central air conditioning systems. All four homes were modeled using this type of heating/cooling system for both codes, as well as with an all-electric heat pump system.

Occupant and appliance loads

Occupant behavior and heat gains associated with people and their activities influence the energy required for heating and cooling. The RESNET standard assumes a default lighting and appliance load based on the square footage of the home, as well as typical occupant schedules that affect the consumption of this energy and the internal loads in the home. The number of people living in each home under the standard is the number of bedrooms plus one.

Codes

Two energy code conditions and two heating systems were modeled. The codes were the 2018 IECC (International Energy Conservation Code) and the 2021 IECC. Two heating/cooling systems were modeled for each code: a 14 SEER/8.2 HSPF electric heat pump, and a 14 SEER air conditioner with a 95% AFUE furnace.

Key changes in the 2021 IECC include:

1. The glazing U-factor does not change, but the 2021 code adds an upper limit for glazing SHGC (solar heat gain coefficient). Previously, there was no upper limit. The new limit is 0.40. This change applies to both windows and skylights.
2. Minimum ceiling R-value has increased from R-49 to R-60.
3. Minimum wall R-value has increased. The 2018 IECC required at least R-20 (cavity) or 13+5 (cavity + continuous). The 2021 IECC increases the requirement to at least R-20+5 (cavity plus continuous) or 13+10 or 0+15.
4. The minimum percentage of high-efficacy lighting has increased from 90% to 100%. The definition of "high-efficacy lighting" also changes between the codes. The 2018 definition ranged from >40 to >60 lumens per Watt, depending on the Wattage of the lamp. The 2021 definition is increased to >65 lumens per Watt for all lamps or >45 lumens per Watt for all luminaires. Because the market has largely moved toward LEDs, our modeling was performed using LED lighting for both the 2018 and 2021 cases.
5. The 2021 IECC adds a new section 408 that requires an "additional efficiency package". Users of the prescriptive code must choose between one of five additional options. (For our modeling we used option 4 (duct thermal distribution option).
    a. Option 1 – enhanced envelope performance: Use a total building UA that is 5% more efficient than the prescriptive code.
    b. Option 2 – More efficient HVAC: Install systems with the following minimum efficiencies: either 95 AFUE natural gas furnace with 15 SEER air conditioner OR 10 HSPF/16 SEER air source heat pump, OR 3.5 COP ground source heat pump.
    c. Option 3 – Reduced service water heater energy use: Install a water heating system meeting one of the following minimum efficiencies: 0.82 EF gas water heater, 2.0 EF electric heat pump water heater, or 0.4 solar fraction.
    d. Option 4 – more efficient thermal distribution system: locate 100% of ducts, air handlers, hydronic thermal distribution systems, or other thermal distribution systems inside the building thermal envelope.

f. Option 5 – improved air sealing and efficient ventilation system: Achieve a measured air leakage rate of 3 ACH50 or less and install and ERV or HRV (energy or heat recovery ventilator). The ERV/HRV must have at least 75 percent sensible recovery efficiency, deliver less than 1.1 cfm/Watt, cannot use recirculation for defrost, and ERVs must have greater than 50% latent recovery.

There are a few minor changes that should be mentioned as well:

1. There is a minor change to the code for slabs on grade (not modeled in any of the homes in this study). The requirement for both 2018 and 2021 is R-10, but the length is extended from 2 ft wide to 4 ft wide.
2. There are two minor changes related to ductwork. In 2018, supply ducts outside conditioned space required at least R-8 insulation, while return ducts could be insulated to R-6. In 2021, all ducts outside conditioned space require R-8 insulation. Duct testing requirements are unchanged, except that the 2021 IECC requires airtightness testing of ducts located entirely inside conditioned space. (Neither change impacts the 2021 energy simulations in this study due to the handling of Section 408 – see above.)
3. The 2021 IECC has a new requirement in its air leakage section that NEMA OS4 electrical boxes be provided. This will be included in the cost analysis. Use of these boxes should contribute to improved home airtightness, but since the air leakage requirement is 3 ACH50 for both versions of the code, the simulations won't be impacted.
4. By reference to the IRC or IMC, both the 2018 and 2021 IECC requires a whole-house ventilation system using rates specified by ASHRAE Standard 62.2[8]. The ventilation rates required for this standard changed between its 2010 and 2013 versions. We believe that most in Nebraska are still using the 2010 version, so it was used in all simulations for this report. There is a change in minimum cfm/Watt for ventilation systems. For the 2018 IECC, 1.4 cfm/Watt was required; this increased to 2.8 cfm/Watt in 2021. The 2021 IECC also requires flow rates for whole house ventilation to be measured, a change that is included in the cost section of the report.

Table 2 summarizes the required component values for each of the code conditions. The requirements shown below in Table 2 are associated with the "simplified prescriptive track" of each code, which is the easiest and most often used means of code compliance.

Component	2018 IECC (case a)	2018 IECC (case b)	2021 IECC (case a)	2021 IECC (case b)
Heating/cooling system	Heat pump	Furnace+AC	Heat pump	Furnace+AC
Glazing U-factor	0.30	0.30	0.30	0.30
Glazing SHGC	none	none	.40	.40
Opaque door U-factor	0.30	0.30	0.30	0.30
Ceiling R-value (note a)	49	49	60	60
Wall R-value (note b)	20 or 13+5	20 or 13+5	20+5 or 13+10 or 0+15	20+5 or 13+10 or 0+15
Floor R-value (note c)	30	30	30	30
Basement wall R-value (note d)	15ci or 19	15ci or 19	15ci or 19 or 13+5ci	15ci or 19 or 13+5ci
Forced air furnace (AFUE) (note e)	N/A	95%	N/A	95%
AC/heat pump (SEER) (note f)	14.0	14.0	14.0	14.0
Heat pump HSPF	8.2	N/A	8.2	N/A
Programmable thermostat	Yes	Yes	Yes	Yes
% HE lighting (interior)	90	90	100	100
Blower door (ACH50)	3	3	3	3
Mechanical ventilation min. cfm/Watt	1.4	1.4	2.8	2.8
Duct insulation R-value (note g)	8/6/6	8/6/6	8/8/6	8/8/6
Duct leakage to outdoors (base code)	4 cfm/100 sf	4 cfm/100 sf	4 cfm/100 sf	4 cfm/100 sf
Modeled duct leakage to outdoors/location (note h)	2 cfm/100 sf (50% Cond. Space)	2 cfm/100 sf (50% Cond. Space)	0 cfm/100 sf (100% Cond. Space)	0 cfm/100 sf (100% Cond. Space)

Table 3. Component requirements by building code.

Note a: In both codes, R30 may also be used for ceiling areas of up to 20% (max 500 sf) with no attic. Both codes also allow a reduction if uncompressed insulation extends the whole way to the eaves, which was not used in this report.
Note b: The format 13+5 refers to R13 cavity insulation plus R5 continuous insulated sheathing.
Note c: Less than R30 may be used if sufficient to fill the framing cavity; with a minimum of R19.
Note d: the designation "ci" refers to continuous insulation. "15ci or 19" means either R-15 continuous or R-19 in a frame cavity. The change for 2021 simply gives another equivalent option.
Note e: The "prevailing minimum federal efficiency of 78% is required, but 95% is widely installed and was used for the analysis.
Note f: The prevailing minimum federal efficiency is 14 SEER.
Note g: 8/6/6 refers to R-8 supply ducts in attics, R-6 for return ducts in attics, and R-6 for ducts in the conditioned envelope.
Note h: For the 2018 IECC case, the modeled duct leakage to outdoors was half of the code maximum, since 50% of the ducts were assumed to be inside conditioned space. For the 2021 case, the additional efficiency option for Section 408 of the code was selected to be 100% of ducts inside conditioned space, so 0% duct leakage to outdoors was modeled.

For the 2018 IECC, there was no Solar Heat Gain Coefficient (SHGC) requirement for glazing in climate zones 5 and above. For modeling, a default SHGC of 0.66 was used. This represents double glazed clear fenestration with operable metal frames or fixed nonmetal frames.

Neither of the codes modeled places a limit on window to wall ratio. Both codes also allow lower R values to be used for ceilings and floors if the insulation fills the framing cavity. In this analysis, we assumed that the builder did *not* make use of this exemption for floors. The exception was allowed for a small section of vaulted ceiling (5% of the total roof area) in the largest of the home plans, where a vaulted ceiling was modeled as R-30 for both codes.

The houses in this study had only small areas of framed, insulated floor, which was limited primarily to framed floors over garages. Modeling was performed with basement insulation in cavity walls, with R-19 used for both codes.

The code does have minor changes to on-grade slab insulation (a change from 2 ft to 4 ft required) and crawlspace wall insulation (an additional compliance option was added). These conditions don't impact the models in this study since neither envelope component is present in these homes.

Climates

Three cities were chosen to represent the climate variation in Nebraska. The National Oceanic and Atmospheric Administration (NOAA) publishes a list of annual degree days that includes approximately 140 cities and towns in the state of Nebraska. The heating degree days (65°F base) in the state range from 5,552 to 7,862. Table 3 summarizes the selected cities and their actual numbers of degree days. Numbers of degree days for other code jurisdictions not shown can be found in Table A1 in the appendix to this report. Note that the state's second largest city, Lincoln, has nearly the same climate as Omaha (6,119 vs. 6,153 degree days).

City	Annual heating degree days
Omaha	6,153
Norfolk	6,766
Chadron	7,021

Table 3. Selected Nebraska cities and climates.

The climate zone map for Nebraska is unchanged between the 2018 and 2021 IECC, both of which place the entire state of Nebraska in a single climate zone (5). Variations in actual heating degree days and cooling degree hours throughout the state will cause different cities to respond to code changes in slightly different ways.

Component Selection

Since variations in the way that some components are selected and installed can impact thermal performance, and because certain products are available only in discrete increments of R-value, it was necessary to specify some components in detail.

Windows

All code conditions are modeled with a window having exactly the prescribed U-factor. For the 2018 IECC the solar heat gain coefficient (SHGC) was modeled as 0.66. For the 2021 IECC the SHGC was modeled having the prescribed SHGC. For reference, U-factors in the range of 0.30-0.35 can typically be achieved using a double-glazed vinyl window with ½ inch argon fill and low-e coating.

Windows were modeled at 12% or 18% window to wall ratio, with 25% of the window area placed in each compass direction (N, S, E, and W) and no overhang.

Exterior wall insulation

In the model, the R-value of cavity insulation is adjusted to account for the effects of wood studs and other framing members. For this analysis, a framing factor of 0.23 was used; this means that the wood construction makes up 23% of the wall surface area.

The 2018 IECC requires R-20 cavity insulation or R-13 cavity insulation with R-5 rigid insulation on the exterior. Typically, fiberglass batts are currently available in R-19 and R-21 increments. Cellulose insulation is typically R-21 when used in a 2x6 wall, and spray foams are now available that can be applied in various thicknesses to achieve R-values of 20 or more in a 2x6 cavity. Based on the code requirement for R-20, it is likely that most 2x6 walls will actually have installed R-21 cavity insulation. The overall U-factor for this assembly is 0.058. The U-factor for an assembly with exactly R-20 cavity insulation is 0.060. If the 13+5 method is used, a 2x4 stud wall with R-5 exterior insulation achieves a U-value of 0.058. However, accounting for sheathing on 25% of the exterior, the resulting U-value is 0.060. Because all of these scenarios are very close to one another, the 2018 IECC was modeled with an R-20 cavity insulation in a 2x6 wall, with an overall U-value of 0.60.

The increased wall insulation for the 2021 IECC will require builders using the prescriptive path to add continuous exterior insulation. This could be done using a 2x6 wall with R-5 exterior insulation or a 2x4 wall with R-10 exterior insulation. For the modeling, it was assumed that many builders might go back to a 2x4 wall to save cost, so the 2021 IECC cases were modeled with a 2x4 wall, R-13 cavity insulation, and R-10 continuous exterior insulation. The U-factor for this combination is 0.041.

Basement wall insulation

This analysis was performed with the assumption that the basements are conditioned, which requires that basement walls be insulated. For all of the code conditions, R-19 insulation was placed in a 2x6 framed cavity on the interior of the basement wall. Framing was modeled as 16” o.c. wood framing.

Ceiling insulation

Most of the ceiling area for the four house plans is beneath attics. Where attics are present, blown-in fiberglass insulation is used in the correct thickness to meet the R-value requirement. Framing is modeled with a 2x12 structural member at the attic floor and an 11% framing factor.

One floor plan also contains a small amount of cathedral ceiling (about 5% of the overall roof area) directly beneath a sloped roof supported by 2x10 joists. R-30 fiberglass batts were used in these locations. Table 4 summarizes the roof/ceiling insulation combinations that were used to meet the codes.

R-value ($^oFft^2hr/Btu$)	Insulation location	Insulation type
30	Cathedral ceiling	9" R30 fiberglass batts
49	Attic floor	19.6" blown-in fiberglass insulation (R2.5 per inch)
60	Attic floor	24" blown-in fiberglass insulation (R2.5 per inch)

Table 4. Roof and ceiling insulation combinations used to meet code requirements.

Floor insulation

Insulation requirements for framed floors over unconditioned space were met using an R-30 fiberglass batt in a minimum 2x10 floor cavity, with a framing factor of 13%. Note that when the depth of floor insulation is less than that of the framing cavity, the insulation must be installed next to the floor above in order to function properly.

Exterior doors

The U-factor requirement for opaque doors is equal to the U-factor requirement for windows under both codes, and the opaque portions of doors were modeled having this specified U-factor. The requirement for a 0.30 or lower U-factor will likely require that a fiberglass or metal insulated door be used. These typically achieve U-factors of 0.20 or better.

Infiltration

Both the 2018 and 2021 IECC require airtightness testing with a blower door, and homes must achieve the stringent requirement of 3 ACH50 or less. Both also have an air sealing checklist that is substantially unchanged in 2021. Modeling was done with this tested air leakage.

Whole-house ventilation

The 2018 and 2021 IECC refer to the IRC or IMC (specified without date). These both require a system using the flow rates specified by ASHRAE Standard 62.2 (assumed 2010 version)[8].

All cases were modeled with whole-house ventilation systems. The rate is based on finished floor area and number of bedrooms. To calculate the rate for each of the modeled homes, 50% of the basement floor area was assumed to be finished, and there were no bedrooms in the basement. The whole-house mechanical ventilation systems were assumed to be continuously operating exhaust-only. For the 2018 IECC cases, the fan efficiency is 1.4 cfm/Watt. Fan efficiency increases to 2.8 cfm/Watt for the 2021 IECC. Table 5 shows the ventilation flow rates and fan Watts modeled for each home in the study.

Main floor area (sf)	# of bedrooms	Whole house ventilation airflow (cfm)	Fan power (W) 2018 IECC	Fan power (W) 2021 IECC
1453	3	52	37	19
1852	3	58	41	21
2103	4	69	49	25
2932	4	82	59	29

Table 5. Whole house ventilation inputs.

Thermostat settings

The RESNET standard was used to determine thermostat setpoints (68°F winter/78°F summer) and energy savings associated with the programmable thermostat.

Ducts

Ducts for the 2018 IECC cases were modeled with an R-value of 8 for supply ducts outside conditioned space and an R-value of 6 for all other ducts. The homes were modeled so that each has 50% of its ducts located in attics and/or floors over garages as appropriate to each home's design.

The 2018 cases were modeled with 2% duct leakage to outdoors. 2% was chosen because many homes in Nebraska have some or all of their duct systems located inside conditioned space. For this reason, we felt that even though the maximum duct leakage allowed by the code is 4% to the outdoors, many homes in the state will actually test better as a result of the requirement. We also felt that the requirement would create incentive for builders to place ducts inside conditioned space. Thus, 2% leakage to the outside is a better estimate of the actual condition likely to be present under the 2018 IECC, and is consistent with how modeling was performed in our previous reports.

The 2021 IECC cases were modeled with the air handler and 100% of ducts located inside conditioned space, based on our selection of Option (4) in the new Section 408 (Additional efficiency packages). We chose to select option 4 because we felt that it was one of the lower-cost and most straightforward options available and would therefore be a popular choice with builders. In a few test-run simulations with one of the homes its energy savings was about the middle of the 5 options, which also made it an attractive choice.

HVAC system sizing

HVAC system sizing can affect the simulated energy consumption of a home, particularly as oversized cooling systems can be penalized for short-cycling inefficiencies. Both version of the code require that HVAC contractors utilize a Manual J calculation (or approved alternative) to size heating and cooling equipment. This ensures that the installed equipment will have enough capacity to meet the load, but it is also important to avoid oversizing because short cycling of space conditioning equipment can be inefficient and provides inadequate dehumidification in the summer. Another benefit of properly sizing equipment is that homeowners may see a cost savings if the increased insulation and airtightness requirements of the new code allow smaller equipment to be installed.

For each case, air conditioners and heat pumps were sized in ½ ton increments. Manual S requires that single stage heat pumps and air conditioners be sized between 100-130% of the Manual J load calculation. For the simulations, the largest ½ ton increment size that fell within 100-130% of the total cooling load was used. Many of the 2021 code cases required a ½ ton smaller air conditioner/heat pump than the 2018 cases.

Lighting

The Ekotrope software allows lighting to be modeled as a defined percentage of incandescent, fluorescent, and LED lamps. All high efficacy lighting for both codes was modeled as LED, since the market has substantially moved in that direction. The 2018 IECC was modeled with 90% LED lamps and 10% incandescent lamps for indoors. The 2021 IECC was modeled with 100% LED lamps indoors. The model also allows lighting type to be specified for outdoor and garage lighting. Since

both codes are silent on outdoor/garage lighting, these were modeled as incandescent to allow future simulations to accommodate an upgrade to LED if this occurs.

Water heating

Both codes were modeled with R-3 pipe insulation and standard-efficiency fixtures. Both code conditions were modeled with a 50 gallon electric water heater having an efficiency factor of 0.92 and located inside conditioned space. Recirculation systems and domestic hot water heat recovery were not used. The distance from the water heater to the furthest fixture was set to software default length, which is based on the size of the home.

Results

Annual energy simulations were performed for the four houses under the four code and HVAC conditions to determine their annual energy consumption. Comparison of the results shows that the 2021 IECC requires less overall energy than the 2018 cases for all houses and climates. All of the homes showed savings. The savings were larger for homes with less glazing and in the homes heated with heat pumps.

Energy use

Table 6 shows the annual cooling-related electricity consumption of each house under each code condition. The furnace efficiency does not impact cooling energy, so the (a – heat pump) and (b - furnace) cases of each code are identical for the 2021 IECC. The small difference with the 2018 IECC appears to have something to do with how duct leakage energy use is calculated and the fact that the furnace/AC case was modeled with an ECM fan while the heat pump case was run with a less efficient PSC fan. Cooling savings are substantial and are mostly due to the decrease in window SHGC (solar heat gain coefficient). The percent savings ranged from 30 to 41%, with an average of 36%.

To show the impact of each change on cooling, a step-wise analysis was performed using the 1453 sf home in Chadron with 18% glazing and gas heating. This shows that in addition to the large savings from the change to windows, there are also moderate savings related to the increase in high-efficacy lighting and the movement of ductwork into conditioned space. The savings related to increased insulation are small. The change in ventilation system cfm/Watt is assigned to appliance energy savings, and doesn't impact heating or cooling since there is no heat recovery and the volume of ventilation air stays the same. Note that the incremental change in energy use for each item is dependent on the order in which the items are added, but the process is a helpful way to demonstrate the effects of each change.

Code-based change	Cooling kWh	Change (kWh)
Begin with 2018 IECC	1443.4	
Decrease window SHGC to 0.40	979.9	-463.5
Increase wall insulation from R-19 to R13+10	972.4	-7.4
Increase ceiling insulation from R-49 to R-60	967.8	-4.6
Increase ventilation cfm/Watt to 2.8	967.8	-0
Increase to 100% high-efficacy lighting	947.6	-20.2
Move ducts into conditioned space/no outdoor leakage	873.2	-74.4
Reduce AC size from 2.5 tons to 1.5 tons	873.2	-0
End with 2021 IECC	873.2	-570.2 (total change)

Code	City	Window/ wall ratio	1,453 sf ranch	1,852 sf ranch	2,103 sf 2 story	2,932 sf 2 story
2018 IECC (a)	Omaha	12%	1448.1	1740.5	2030.7	2552.9
2018 IECC (b)	Omaha	12%	1470.4	1774.4	2069.8	2617.3
2021 IECC (a)	Omaha	12%	1006.2	1180.4	1351.7	1680.3
2021 IECC (b)	Omaha	12%	1006.2	1180.4	1351.7	1680.3
2018 IECC (a)	Omaha	18%	1843.0	2234.0	2671.2	3305.0
2018 IECC (b)	Omaha	18%	1871.4	2277.5	2722.6	3378.2
2021 IECC (a)	Omaha	18%	1212.0	1433.4	1676.4	2074.7
2021 IECC (b)	Omaha	18%	1212.0	1433.4	1676.4	2074.7
2018 IECC (a)	Norfolk	12%	1260.9	1518.2	1810.0	2227.8
2018 IECC (b)	Norfolk	12%	1280.4	1547.9	1844.9	2284.1
2021 IECC (a)	Norfolk	12%	838.2	982.9	1153.0	1396.2
2021 IECC (b)	Norfolk	12%	838.2	982.9	1153.0	1396.2
2018 IECC (a)	Norfolk	18%	1661.1	2018.5	2451.5	2994.1
2018 IECC (b)	Norfolk	18%	1686.8	2057.9	2498.8	3060.6
2021 IECC (a)	Norfolk	18%	1040.5	1232.2	1472.1	1782.4
2021 IECC (b)	Norfolk	18%	1040.5	1232.2	1472.1	1782.4
2018 IECC (a)	Chadron	12%	1063.1	1281.3	1536.5	1878.2
2018 IECC (b)	Chadron	12%	1079.3	1306	1565.8	1925.2
2021 IECC (a)	Chadron	12%	698.0	819.2	964.1	1162.5
2021 IECC (b)	Chadron	12%	698.0	819.2	964.1	1162.5
2018 IECC (a)	Chadron	18%	1421.7	1728.6	2114.3	2549.6
2018 IECC (b)	Chadron	18%	1443.4	1761.9	2148.9	2599.5
2021 IECC (a)	Chadron	18%	873.2	1034.6	1241.1	1496.1
2021 IECC (b)	Chadron	18%	873.2	1034.6	1241.1	1496.1

Table 6. Annual cooling electricity consumption (kWh).

Table 7 shows annual heating electricity consumption. Forced air furnaces require some energy to operate the fan, so some electricity is required for heating even when a gas furnace is used. However, this is a small portion of overall heating energy use. In a few of the gas furnace cases, the 2021 code used more electricity to operate the fan because smaller system sizes resulted in longer run times.

For the cases (a) using heat pumps, the heating electricity use for the 2021 IECC ranged from 6 to 21% lower than the 2018 IECC, which an average savings of 13%. Heating percent savings were larger for homes with less glazing. This is because the lower window SHGC (solar heat gain coefficient) required by the 2021 IECC reduces heat gains in the winter.

Code	City	Window/ wall ratio	1,453 sf ranch	1,852 sf ranch	2,103 sf 2 story	2,932 sf 2 story
2018 IECC (a)	Omaha	12%	8312.5	10256.8	10231.4	17141.1
2018 IECC (b)	Omaha	12%	300.4	329.7	329.0	492.9
2021 IECC (a)	Omaha	12%	7276.2	8720.4	8787.9	13677.5
2021 IECC (b)	Omaha	12%	272.5	326.6	329.1	465.1
2018 IECC (a)	Omaha	18%	8221.0	10143.8	10153.7	16943.6
2018 IECC (b)	Omaha	18%	297.1	326.1	326.5	487.2
2021 IECC (a)	Omaha	18%	7516.2	9015.3	9178.2	14139.5
2021 IECC (b)	Omaha	18%	281.5	337.6	343.7	480.8
2018 IECC (a)	Norfolk	12%	10456.4	12987.6	12850.6	21781.8
2018 IECC (b)	Norfolk	12%	368.9	407.0	402.8	607.6
2021 IECC (a)	Norfolk	12%	9076.3	10926.3	10937.0	17093.5
2021 IECC (b)	Norfolk	12%	332.9	400.7	401.1	569.3
2018 IECC (a)	Norfolk	18%	10325.2	12821.6	12727.5	21501.1
2018 IECC (b)	Norfolk	18%	364.3	401.8	399.0	599.8
2021 IECC (a)	Norfolk	18%	9352.9	11268.9	11386.8	17629.0
2021 IECC (b)	Norfolk	18%	343.0	413.3	417.6	587.1
2018 IECC (a)	Chadron	12%	8272.3	10198.7	9969.4	17017.7
2018 IECC (b)	Chadron	12%	300.7	329.5	322.3	490.9
2021 IECC (a)	Chadron	12%	7362.8	8809.0	8756.2	13769.6
2021 IECC (b)	Chadron	12%	277.8	332.4	330.4	471.8
2018 IECC (a)	Chadron	18%	7984.1	9835	9639	16166.1
2018 IECC (b)	Chadron	18%	290.2	317.7	311.6	473.5
2021 IECC (a)	Chadron	18%	7518.4	9002.8	9027.7	14075.4
2021 IECC (b)	Chadron	18%	283.7	339.7	340.6	482.3

Table 7. Annual heating electricity consumption (kWh).

Table 8 shows gas consumption for the various cases in therms per year. In all cases, the 2021 IECC has lower gas consumption. The reduction in gas consumed ranged from 1% to 11%, with an average of 7%. As with the electrically heated homes, a larger percent reduction in heating energy was obtained in the homes with less glazing, due to the effect of lower SHGC windows allowing less solar heat into the homes in winter.

The step-wise calculation (again using the 1453 sf Chadron home with 18% glazing and gas heating) shows that the code changes in the 2021 IECC are a mix of measures that both increase and reduce heating energy use. The window change causes the largest increase in heating energy use, but the change to 100% high-efficacy lighting also increases it slightly. These costs are offset by the savings in cooling and appliance energy.

The biggest heating savings occur due to the increased insulation for walls and ceilings as well as moving ductwork into conditioned space.

Code-based change	Heating Therms	Change (Therms)
Begin with 2018 IECC	446.8	
Decrease window SHGC to 0.40	526.7	+79.9
Increase wall insulation from R-19 to R13+10	488.5	-38.2
Increase ceiling insulation from R-49 to R-60	476.7	-11.8
Increase ventilation cfm/Watt to 2.8	476.7	-0
Increase to 100% high-efficacy lighting	482.2	+5.5
Move ducts into conditioned space/no outdoor leakage	436.7	-45.5
Reduce AC size from 2.5 tons to 1.5 tons	436.7	-0
End with 2021 IECC	436.7	-10.1 (total change)

Code	City	Window/ wall ratio	1,453 sf ranch	1,852 sf ranch	2,103 sf 2 story	2,932 sf 2 story
2018 IECC (a)	Omaha	12%	0	0	0	0
2018 IECC (b)	Omaha	12%	462.5	559	557.8	880.2
2021 IECC (a)	Omaha	12%	0	0	0	0
2021 IECC (b)	Omaha	12%	419.5	502.8	506.7	788.6
2018 IECC (a)	Omaha	18%	0	0	0	0
2018 IECC (b)	Omaha	18%	457.4	552.8	553.6	870.1
2021 IECC (a)	Omaha	18%	0	0	0	0
2021 IECC (b)	Omaha	18%	433.4	519.8	529.2	815.2
2018 IECC (a)	Norfolk	12%	0	0	0	0
2018 IECC (b)	Norfolk	12%	568	690	682.9	1085.1
2021 IECC (a)	Norfolk	12%	0	0	0	0
2021 IECC (b)	Norfolk	12%	512.5	616.9	617.5	965.2
2018 IECC (a)	Norfolk	18%	0	0	0	0
2018 IECC (b)	Norfolk	18%	560.9	681.2	676.4	1071.1
2021 IECC (a)	Norfolk	18%	0	0	0	0
2021 IECC (b)	Norfolk	18%	528.1	636.3	642.9	995.4
2018 IECC (a)	Chadron	12%	0	0	0	0
2018 IECC (b)	Chadron	12%	463	558.6	546.4	876.6
2021 IECC (a)	Chadron	12%	0	0	0	0
2021 IECC (b)	Chadron	12%	427.7	511.7	508.6	799.9
2018 IECC (a)	Chadron	18%	0	0	0	0
2018 IECC (b)	Chadron	18%	446.8	538.7	528.3	845.5
2021 IECC (a)	Chadron	18%	0	0	0	0
2021 IECC (b)	Chadron	18%	436.7	523	524.4	817.6

Table 8. Annual heating gas consumption (therm).

Table 9 shows the annual electricity consumption for lighting and appliances. Since this does not depend on city or glazing percentage, it is simply shown for each code and each house size. This value is influenced by the change to 100% high-efficacy lamps and the improved efficiency of the mechanical ventilation fan. Overall, the savings in lighting/appliance energy is between 5-6%.

Code	1,453 sf ranch	1,852 sf ranch	2,103 sf 2 story	2,932 sf 2 story
2018 IECC	7237.7	8243.2	8084.8	10704.6
2021 IECC	6850.9	7788.7	7622.8	10063.1

Table 9. Annual electricity consumption for lights and appliances (kWh)

Table 10 shows annual whole-house energy consumption in MMBtu/year. This includes heating and cooling, domestic water heating, and lights and appliances. In all cases, the 2021 IECC used less total energy than the 2018 IECC. The percent savings are larger for homes with less glazing and those that are heated using heat pumps. The savings range from 5% (the 2103 sf house with 18% glazing and gas heating in Chadron) to 16% (the 2932 sf house with 12% glazing and electric heating in Norfolk). The average overall energy savings was 9%.

Code	City	Window/ wall ratio	1,453 sf ranch	1,852 sf ranch	2,103 sf 2 story	2,932 sf 2 story
2018 IECC (a)	Omaha	12%	68.65	79.71	82.01	116.32
2018 IECC (b)	Omaha	12%	87.62	101.84	104.12	147.74
2021 IECC (a)	Omaha	12%	62.28	71.01	73.19	99.33
2021 IECC (b)	Omaha	12%	80.33	92.64	94.99	133.09
2018 IECC (a)	Omaha	18%	69.68	81.01	83.93	118.21
2018 IECC (b)	Omaha	18%	88.47	102.93	105.92	149.3
2021 IECC (a)	Omaha	18%	63.8	72.88	75.63	102.25
2021 IECC (b)	Omaha	18%	82.45	95.24	98.39	137.16
2018 IECC (a)	Norfolk	12%	76.01	88.96	91.02	131.87
2018 IECC (b)	Norfolk	12%	98.45	115.12	116.94	168.3
2021 IECC (a)	Norfolk	12%	68.54	78.55	80.67	110.84
2021 IECC (b)	Norfolk	12%	89.95	104.32	106.46	150.96
2018 IECC (a)	Norfolk	18%	76.93	90.1	92.78	133.52
2018 IECC (b)	Norfolk	18%	99.11	115.96	118.51	169.53
2021 IECC (a)	Norfolk	18%	70.17	80.57	83.29	113.98
2021 IECC (b)	Norfolk	18%	92.23	107.15	110.15	155.36
2018 IECC (a)	Chadron	12%	67.81	78.56	80.16	114.32
2018 IECC (b)	Chadron	12%	86.95	100.82	101.97	145.74
2021 IECC (a)	Chadron	12%	62.14	70.69	72.49	98.61
2021 IECC (b)	Chadron	12%	80.73	92.93	94.6	133.21
2018 IECC (a)	Chadron	18%	68.04	78.84	81	113.7
2018 IECC (b)	Chadron	18%	86.54	100.34	102.11	144.87
2021 IECC (a)	Chadron	18%	63.27	72.08	74.36	100.79
2021 IECC (b)	Chadron	18%	82.25	94.81	97.15	136.16

Table 10. Annual whole house energy consumption (MMBtu/year).

To understand the relative impact of each change on the overall energy use in Table 10, the Chadron 18% glass, 1453 sf home with gas heating can also be used. This house design had a reduction of 5% in total energy use, which is among the smaller savings of the cases.

Code based change	Energy use MMBtu/yr	Change (MMBtu/year)
Begin with 2018 IECC	86.5	
Decrease window SHGC to 0.40	93.1	+6.6
Increase wall insulation from R-19 to R13+10	89.2	-3.9
Increase ceiling insulation from R-49 to R-60	88.0	-1.2
Increase ventilation cfm/Watt to 2.8	87.4	-0.6
Increase to 100% high-efficacy lighting	87.1	-0.3
Move ducts into conditioned space/no outdoor leakage	82.2	-4.9
Reduce AC size from 2.5 tons to 1.5 tons	82.2	-0
End with 2021 IECC	82.2	-4.3 (total change)

The order in which the changes are implemented in the above analysis does slightly impact the magnitude of each change. For this home, the window change caused a net increase in energy use (since the penalty on heating was larger than the savings on cooling). However, the size of the air conditioner for the home was reduced by one ton, which is an initial cost savings to the owner.

For comparison, the Norfolk 2932 sf home with 12% glazing and heat pump experienced an increase of 4.6 MMBtu/year (about +3.5%) attributed to the change in window SHGC. The size of the air conditioner/heat pump in this case was also reduced by 1 ton. This particular change is an overall energy penalty in all cases, since Nebraska homes spend more hours heating than cooling. However, it does result in lower construction cost, due to smaller cooling equipment.

The largest energy savings step is due to moving all ductwork into conditioned space and eliminating outdoor duct leakage. The next largest savings is due to the increased wall insulation. All of the other code changes produce savings but of a smaller magnitude.

Table 11 shows energy cost in dollars per year for each of the cases. Adopting the 2021 IECC saves consumers between 5% and 14% depending on the city. The average is 7.8% savings. The percent savings in energy cost and energy consumption are not exactly the same because different fuels (gas and electricity) have different costs and because each fuel has a fixed customer charge. Depending on house size and location, the savings range from $92 to $446 per year, with an average annual savings of $183.

Code	City	Window/ wall ratio	1,453 sf ranch	1,852 sf ranch	2,103 sf 2 story	2,932 sf 2 story
2018 IECC (a)	Omaha	12%	1830	2031	2082	2681
2018 IECC (b)	Omaha	12%	1967	2154	2207	2707
2021 IECC (a)	Omaha	12%	1705	1865	1911	2371
2021 IECC (b)	Omaha	12%	1854	2017	2066	2500
2018 IECC (a)	Omaha	18%	1861	2070	2136	2739
2018 IECC (b)	Omaha	18%	2001	2195	2262	2769
2021 IECC (a)	Omaha	18%	1738	1905	1962	2433
2021 IECC (b)	Omaha	18%	1886	2056	2115	2559
2018 IECC (a)	Norfolk	12%	1993	2267	2319	3170
2018 IECC (b)	Norfolk	12%	2018	2226	2281	2876
2021 IECC (a)	Norfolk	12%	1829	2042	2092	2724
2021 IECC (b)	Norfolk	12%	1898	2077	2126	2642
2018 IECC (a)	Norfolk	18%	2021	2303	2370	3222
2018 IECC (b)	Norfolk	18%	2049	2265	2335	2935
2021 IECC (a)	Norfolk	18%	1867	2018	2152	2796
2021 IECC (b)	Norfolk	18%	1930	2117	2178	2704
2018 IECC (a)	Chadron	12%	1831	2062	2104	2823
2018 IECC (b)	Chadron	12%	1913	2096	2143	2674
2021 IECC (a)	Chadron	12%	1703	1887	1931	2483
2021 IECC (b)	Chadron	12%	1816	1975	2020	2485
2018 IECC (a)	Chadron	18%	1845	2080	2136	2829
2018 IECC (b)	Chadron	18%	1932	2121	2179	2709
2021 IECC (a)	Chadron	18%	1731	1921	1976	2536
2021 IECC (b)	Chadron	18%	1840	2006	2060	2533

Table 11. Annual whole house energy cost ($/year).

Conclusions

The findings of this study indicate that the 2021 International Energy Conservation Code would result in less energy consumption for homes in all areas of the state. Most of the savings is related to increased wall insulation and the new code section 408 (modeled here as ductwork 100% inside conditioned space). The one portion of the 2021 code that does not save energy or energy cost in Nebraska is the adoption of an upper limit on window SHGC (solar heat gain coefficient), which saves cooling energy but increases heating energy. However, this change does allow smaller cooling equipment to be installed, which is an initial cost savings.

The average energy savings was 9%, and ranged from 5% to 16% for the various house sizes and locations. The average savings in whole-house energy cost was 7.8%. Depending on house size and location, the savings range from $92 to $446 per year, with an average annual savings of $183.

Cost analysis

This section discusses construction cost impacts associated with upgrading the Nebraska State Energy Code from the current 2018 International Energy Conservation Code (IECC) to the 2021 IECC. The item-by-item differences between the 2018 and 21 codes and the cost impact of each are discussed below.

Cost data

Cost estimates were obtained from these sources:

- *Residential Costs with RS Means data– 2023*, 42nd annual edition; Gordian. (Costs from Means are based on Omaha as a location. The cost factors for other locations in the state are lower than Omaha. Unless noted otherwise, costs obtained from RS Means include materials, labor, equipment, overhead and profit to represent what an installing contractor will charge a customer.)
- *EPA report: "Cost & Savings estimates: Energy Star Certified Homes, Version 3.1 (Rev. 09)* Dec. 20, 2018 available online at: https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Version%203.1%20Cost%20%20Savings%20Summary.pdf. This report provides an estimate of the incremental cost to build an Energy Star version 3 certified home compared to the 2012 IECC code.
- *Home Depot web site* – provides online pricing available to customers nationwide. Online pricing often mirrors pricing available in national chain home improvement stores. Pricing for this report was obtained using "Central Omaha" as the store location, in December 2022.
- *Contractor quote from Rexell USA (a national supply house for electrical contractors)*: Pricing for this report was obtained in December 2022. This source was used to obtain pricing for airtight and regular electrical boxes, as well as dimmer switches.

Cost and savings examples are shown for the 1852 sf three-bedroom home with 18% window to wall ratio and 95% AFUE furnace, located in Omaha. The savings example in the energy section of the report was for the smallest home plan in the study, but for this report, a median sized home plan was used. The energy cost savings by line item for this house are as shown below:

Code based change	Energy cost $/yr	Change ($/year)
Begin with 2018 IECC	2195	
Decrease window SHGC to 0.40	2200	+5
Increase wall insulation from R-19 to R13+10	2162	-38
Increase ceiling insulation from R-49 to R-60	2150	-12
Increase ventilation cfm/Watt to 2.8	2137	-13
Increase to 100% high-efficacy lighting	2117	-20
Move ducts into conditioned space/no outdoor leakage	2056	-61
Reduce AC size from 2.5 tons to 2 tons	2056	-0
End with 2021 IECC	2056	-139 (total change)

In addition, there are three changes in the 2021 IECC that don't directly correlate to a modeled energy savings that are included in the cost report. These include: (1) ventilation fans are required to be tested and meet the specified airflow, (2) NEMA OS4 electrical boxes are required for electrical and

communication boxes in the exterior envelope, and (3) dimmer switches are required in all rooms except baths, halls, and exterior fixtures.

Implementing the package of code upgrades in the 2021 IECC (including insulation, lighting, duct tightness, and window SHGC) also results in a ½ ton reduction in air conditioner size and a nominal 20 kBtu/hr reduction in furnace size. Although window SHGC increases the overall energy use and cost, it is the main reason for the decrease in air conditioner size. The installation cost savings associated with this reduction can be applied to the overall code upgrade. The 1852 sf home that is used for the cost examples in this report saw a reduction from a 2.5 ton to 2.0 ton air conditioner and a reduction from a nominal 60 kBtu/hr furnace to a nominal 40 kBtu/hr furnace. RS means shows a cost reduction for the evaporator coil, furnace, and condensing unit of $216 total.

Windows, doors, and skylights:
The U-factor for windows, skylights, and opaque doors is unchanged between the ***2018 and 2021 IECC.*** The ***2018 IECC*** has no maximum fenestration SHGC (solar heat gain coefficient). The maximum fenestration SHGC in the ***2021 IECC*** is 0.40. This change in SHGC applies to both windows and skylights.
Net change: The 2022 IECC requires that windows and skylights utilize glass with a lower SHGC.
Cost example-windows: The energy study considered homes with both 12% and 18% window to wall ratio. The 1852 sf home used in that study has 240 sf of glazing for 12% window to wall ratio and 360 sf of glazing for 18% window to wall ratio.

It is difficult to obtain cost data for decreasing window SHGC from 0.66 to 0.40. Consumer sites are unfortunately not configured to allow easy consumer comparison of thermal performance variables in the same window. RS means does show costs for window units with “double insulated glass” and “low-e glass” but the cost difference varies among window types and is sometimes zero. The Energy Star report doesn’t include any similar cases, since none of their cases have SHGC greater than 0.40. However, the methods section of the Energy Star report describes the 2-part method that they used to determine window costs. First they used a regression equation derived from NREL research. However, they found that the NREL equation gave them higher costs than they observed using market data for the Energy Star windows program. Based on that experience, they developed factors that they used to reduce the costs obtained using the NREL equation. Unfortunately those factors are not completely described by the report. For this calculation we used the NREL equation, which may overestimate cost. It is notable that in that equation, reductions in U-value add far more to cost than reductions in SHGC. This aligns with our professional observation that changing the window SHGC in the range of 0.30 and higher typically has a minimal impact on cost.

The regression equation used in the Energy Star report is:
Window Cost/sf = [SHGC x (-0.688)] + [U-value x (-96.33)] +54.5
Using this equation, a reduction in window SHGC from 0.66 to 0.40 would result in a cost of $0.17 per sf. This would produce a cost increase of $40.80 for the 12% window to wall ratio case and $61.20 for the 18% window to wall case.

Since the low-e coatings used to decrease SHGC in skylights and glazed doors is similar to that used for windows, I would expect similar cost impacts. Many products with SHGC less than 0.40 are already available in the marketplace. In the case of doors, which have a higher ratio of frame to

glazing, it can actually be difficult to find products with SHGC higher than 0.40 that also meet the U-value requirements of the code.

The energy study did not include skylights.

Savings: For the 1852 sf case with 18% window to wall ratio, the change to lower SHGC glazing increased energy cost by $5 per year. However, it did contribute to the smaller air conditioner size required for this house.

Exterior wall insulation:
The ***2018 IECC*** requires either R-20 insulation in wood frame cavity walls or R-5 continuous exterior insulation with R-13 cavity insulation. Costs for this scenario are based on a 2x6 wall with either blown cellulose (R-21) or blown fiberglass (R-22) cavity insulation (costs for these two insulation options were identical in RS Means), as we anticipate that most builders would prefer to use a 2x6 wall over installing continuous rigid insulation. Blown insulation was chosen because RS Means does not provide costs for an R-21 fiberglass batt.
The ***2022 IECC*** requires that wood frame walls be insulated with one of three options: (1) R-20 cavity and R-5 continuous exterior, (2) R-13 cavity with R-10 continuous exterior, or (3) R-15 continuous exterior. Costs for this scenario are based on a 2x4 wall with R-13 fiberglass cavity insulation and R-10 rigid exterior board insulation. This is based on the assumption that if builders have to install continuous rigid insulation, they are likely to drop back to a 2x4 wall as the cheaper option.
Net change: Since the 2022 IECC requires continuous rigid exterior insulation, we anticipate that the lowest cost solution would be to use a 2x4 wall. Fiberglass batts are available in high density type (R-15 or R-21) and low density type (R-13 or R-19). The 2x4 with R-13 option would be less expensive both due to the smaller framing members and the ability to install low-density fiberglass batts, which are less expensive.
Cost example: The 1852 sf example home has 2000 sf exterior wall area.
Costs for the 2018 case include framing for a 2x6 wall assembly ($7.875 per sf) and 5.5 inches of blown cellulose or fiberglass insulation installed in a wall ($1.386 per sf for either type). Total cost for framing and insulation is $18,522.
Costs for the 2021 case include framing for a 2x4 wall assembly ($6.588 per sf), R-13 fiberglass batts ($0.864/sf), and 2 inch thick extruded polystyrene R-10.8 rigid exterior insulation ($3.645 per sf). Total cost for framing and insulation is $22,194.
The 2021 IECC results in a cost increase of $3,672 for increased wall insulation.
Savings: The cost analysis shows energy savings of $38 per year when upgrading to the 2021 IECC.

Ceiling insulation:
The ***2018 IECC*** requires R-49 insulation in ceilings. R-49 insulation can be accomplished with blown-in insulation or with a combination of batts and blown-in insulation.
The ***2021 IECC*** requires R-60 insulation in ceilings. This can be accomplished with blown-in insulation or with a combination of batts and blown-in insulation.
Net change: The 2021 IECC will require an additional R-11 insulation to be installed in attics.
Cost example: The 1852 sf ranch home has 1852 sf ceiling area. RS Means cost data for blown fiberglass attic insulation (installed) only goes up to R-49 ($2.979 per sf). However, the incremental cost to achieve R-60 insulation can be inferred from the incremental cost increase using RS Means data to increase from R-38 ($2.340 per sf) to R-49, which is also an R-11 difference.

Using this method based on an incremental cost increase of $0.639 per sf, the total cost of ceiling insulation is $5517 for the 2018 IECC and $6700 for the 2021 IECC, a cost increase of $1183.
Savings: The cost analysis shows energy savings of $12 per year when upgrading to the 2021 IECC.

Whole house ventilation system efficiency (CFM/Watt):
Both the ***2018 IECC*** and the ***2021 IECC*** refer to the IRC or IMC, which both require a system using the flow rates specified by ASHRAE Standard 62.2 (assumed 2010 version).
The ***2018 IECC*** required a minimum fan efficiency of 1.4 CFM/Watt.
The ***2021 IECC*** requires a minimum fan efficiency of 2.8 CFM/Watt.
This requirement is most commonly implemented by contractors using a quiet, continuous run bath fan. To meet ASHRAE Standard 62.2, the fan must have a sound rating less than 1 sone.
Net change: The installed fan will need to be more efficient than before, but most fans in the marketplace already meet the new 2021 requirement.
The HVI (Home Ventilating Institute) directory lists bath fans that are tested for sone rating, rated flow, and cfm/watt. That directory currently includes 2286 bathroom fans that list both sone rating and CFM/Watt. Of these 1526 fans are rated at 1 sone or less and could be used for whole-house ventilation. Of these 1526 available fans, 97.5% are rated at more than 2.8 CFM/Watt and could meet the new requirement. Most of the fans that are rated less than 2.8 CFM/Watt are also rated at 50 cfm or less, so they would not be capable of providing the correct amount of ventilation in any but the smallest homes.
Cost example: On the Home Depot web site the least expensive 80 and 100 cfm fans under 1 sone both provide more than 2.8 CFM/Watt. Therefore, we consider the upgrade cost to be negligible.
Energy Cost: The cost analysis shows energy savings of $13 per year when upgrading to the 2021 IECC.

Energy efficient lighting:
The ***2018 IECC*** requires that high-efficacy lighting be used for 90% of installed indoor lamps (light bulbs). Today, this requirement is most frequently met using LED lamps.
The ***2021 IECC*** increases the requirement to 100% high-efficacy indoor lamps. There is also a minor change to the definition of high-efficacy, however standard LED lamps meet the definition of high-efficacy for both versions of the code.
Net change: The 2021 code would require that an additional 10% of the lighting be installed as high-efficacy.
Cost example: The drawings from which the models were developed show 17 total interior light fixtures: 4 in bathrooms, 2 in hallways, 1 in a closet, and 10 in other rooms (bedrooms, living, kitchen, foyer, laundry, etc.). We assume 1 lamp in the bath, hallway, and closet fixtures and 2 lamps in the other fixtures for a total of 27 lamps in the home.
RSMeans does not list cost data for lamps. Costs for lamps were obtained from the Home Depot web site for a the lowest cost "top selling" multi-pack (16-48 lamps) of each type, with a light output equivalent to a 60 Watt incandescent. We found that incandescent lamps were available for $1.09 each, non-dimmable LEDs were $1.50 each, and dimmable LEDs were $2.41 each.
Based on these costs, the incremental cost to switch 3 lamps from incandescent to dimmable LED is $3.96.
Savings: The cost analysis shows energy savings of $20 per year when upgrading to the 2021 IECC.

Ducts located inside conditioned space:
The ***2018 IECC*** has requirements for duct leakage that can be met/demonstrated in one of four ways: (1) Postconstruction duct blaster testing demonstrating leakage to outdoors of less than 4 cfm/100 sf of conditioned floor area; (2) Rough-in duct blaster testing demonstrating total duct leakage less than 4 cfm/100 sf of conditioned floor area performed with the air handler installed; (3) Rough-in duct blaster testing demonstrating total duct leakage less than 3 cfm/100 sf of conditioned floor area performed without the air handler installed; or (4) no testing is required if the air handler and all ducts are located inside conditioned space. For the energy modeling portion of this study, it was assumed that the 2018 code case had 2 cfm/100 sf duct leakage to outdoors at final since it is common for part of the system to be located inside the conditioned envelope.
The 2021 IECC has similar requirements, but it also requires an additional efficiency measure one of which can be to bring all ducts inside conditioned space. This measure was selected for the modeling portion of the study, so it is also included in the cost study. The 2021 IECC requires ducts located in conditioned space to be tested, so the testing cost would remain the same between the 2 code cases.
Net change: Many homes in Nebraska have all or part of the HVAC system located inside conditioned space. If this is already the case, would be no cost increase associated with this requirement. This is why we chose ducts inside conditioned space as the optional efficiency upgrade measure for the 2021 IECC. For the 2021 case, we assume that all of the system and its ductwork are inside conditioned space.
Cost example: The Energy Star report shows a cost of $0.39 per conditioned square foot to locate ductwork inside conditioned space. Assuming the ducts for the basement square footage are already in conditioned space (consistent with the fact that we have previously only taken credit for half the code-allowed exterior duct leakage), the cost impact can be attributed to the 1852 sf main level only for the prototype house. The cost to implement this measure would be $722.28.
Savings: The cost analysis shows a savings of $61 per year when upgrading to the 2021 IECC by moving all ducts inside the conditioned envelope.

Tested whole house ventilation fan:
The ***2021 IECC*** introduces a new requirement that requires the whole-house ventilation fan flow rate to be tested. Testing requires either a flow hood (for exhaust fans or other types of systems with accessible inlets/outlets) or a pressure gauge (for certain types of ERV/HRV units) and can typically be performed in less than 10 minutes.
Net change: The change simply requires that a system already required by the code be operating as intended. It is possible that a builder might opt to install a slightly larger fan to ensure that the testing is more likely to pass. This could be an additional cost in addition to the cost of the testing.
Cost example: A HERS rater can test the system if one is involved with the project. If not, most HVAC installation companies own the equipment required and could add this testing to their equipment startup procedure. The Energy Star cost report estimates the cost of testing to be $11 (based on a prevailing wage of $55 per hour).
Upgrading a popular low-cost 1.0 sone bath fan on the Home Depot web site from 80 CFM to 100 CFM flow rating results in a cost increase from $104.44 to $116.62, for an additional cost of $12.18.
Cost/savings is neutral: The inclusion of this requirement in the code is based on health and safety and not energy savings. As such, no savings was calculated in the energy study. Fixing a bath fan that was found to not be working properly when tested could also have the benefit of preventing future moisture problems, in addition to improving ventilation.

NEMA OS4 electrical boxes

The ***2018 IECC*** did not have requirements related to NEMA OS4 electrical/communication boxes.

The ***2021 IECC*** requires that electrical and communication outlet boxes located in the building exterior envelope be tested and rated in accordance with NEMA OS 4. These boxes are designed to be more airtight than typical boxes.

Net change: The 2021 IECC requires an upgraded electrical/communication box when these are located on the building exterior.

Cost example: The plans for this prototype house show 27 total electrical/switch boxes located on exterior walls. Of these, 22 are single gang, four are 2-gang, and one is 3-gang.

Costs from Rexel for Allied Molded brand electrical boxes are as follows:

- Single gang airtight: $6.06 each
- Single gang regular: $0.93 each
- 2-gang airtight: $12.26 each
- 2-gang regular: $3.22 each
- 3-gang airtight: $12.66 each
- 3-gang regular: $3.88 each

In total, the cost to upgrade the 27 boxes in this house to airtight boxes is $157.80.

Savings: Savings were not calculated for this change. While the change is expected to contribute to overall house airtightness, it is difficult to quantify that savings. Since there is no change in overall airtightness required by the two codes, a reduction in airtightness cannot be guaranteed, so it was not calculated.

Dimmer switches

The ***2018 IECC*** does not require dimmer switches on indoor lighting.

The ***2021 IECC*** requires dimmer switches on indoor lighting fixtures except those that serve bathrooms and hallways.

Net change: The 2021 IECC will require dimmer switches to be installed for most interior light fixtures. This will also require that slightly more expensive dimmable LED lamps be provided.

Cost example: In a previous step, we explained that this example home has 27 indoor lamps. Six of these are in bathrooms and hallways and are exempted from the dimmer requirement. The cost of upgrading 3 of the remaining lamps to dimmable LEDs was included in the previous step. This leaves 18 lamps that would need to be upgraded from non-dimmable LEDs to dimmable LEDs to meet the 2021 IECC. Based on an incremental cost of $0.91 from the previous step, this results in an additional cost of $16.38 for the dimmable lamps.

The is also a cost for the dimmer switches themselves. This home design has 11 total fixtures that require dimmer switches. Costs for dimmer switches can vary widely, and not all dimmers are compatible with all dimmable lamps. The least expensive universal dimmer switch available from Rexel was a $23.08 toggle dimmer from Ariadni. A non-dimmable single toggle switch is available from Leviton for $0.84. Based on these costs, the total cost to upgrade 11 switches would be $244.64. The total cost increase for both dimmable lamps and dimmer switches to meet the 2021 IECC would be $261.02.

Savings: Cost savings associated with this code change was not calculated because it depends on the homeowner's usage of the dimming feature, which is not a standardized feature in home energy rating or the Ekotrope software. The calculation shows that once 100% LED lighting is installed indoors, the indoor lighting annual cost is $76 per year. If the use of dimmers achieved a 30% savings, the annual savings would be approximately $23.

Summary:
The table below summarizes expected construction costs and annual energy cost savings for the 1,852 sf ranch-style house.

Code Change	Construction Cost Change	Associated Annual Energy Impact	Simple payback, years	Notes
Glazing (reduced SHGC)	+$61.20	+$5	N/A	Costs and savings shown are for 18% window to wall area.
Exterior wall insulation	+$3672	-$38	97	
Ceiling insulation	+$1183	-$12	99	
Increase whole house ventilation CFM/Watt	+0$	-$13	Immediate	97.5% of capable fans in the marketplace already meet new requirement.
High efficacy lighting	+$3.96	-$20	0.2	
Ducts located in conditioned space	+$722.28	-$61	12	
Testing/upsizing of whole house ventilation fan	+$23	Not applicable	N/A	*Considered a health and safety upgrade**.
NEMA OS4 electrical boxes	+$157.80	Not calculated	N/A	Contributes to airtightness, but individual impact not calculated.
Dimmer switches and dimmable lamps	+$261.02	Estimated -$23	11 (est.)	Savings depends on homeowner usage. Estimate is based on 30% annual savings for indoor lighting.
Reduction in air conditioner and furnace size	-216$	$0	N/A	Savings obtained when other measures are employed.
Estimated total	$5868	-$139 (savings)	42	

**These costs can impact the future health and safety of the homeowners and is a factor in ownership cost, but this study does not quantify those related benefits.*

The table above provides cost estimates and savings for an example 1852 sf home constructed in Omaha that has 18% window to wall ratio, a conditioned basement, and is heated/cooled with a 95% AFUE gas furna14 SEER air conditioner. The data show a total estimated increase in construction cost for the home of approximately $5868 if the 2021 IECC is adopted, in whole, as the Nebraska Energy Code, providing a simple payback in energy savings of approximately 42 years (with no "payback" value assigned to the health and safety item).

Since most homes are financed on a 30 year mortgage and energy costs increase each year, it is useful to compare the annual savings with the impact on mortgage rates. With a 7% mortgage

interest rate, the additional annual mortgage payment for $5868 in construction cost is $468. With an annual energy cost savings of $139, homeowners with a mortgage would experience a net annual cost increase of $329 with the adoption of the 2021 IECC.

REFERENCES

[1] 2022 Mortgage Industry National Home Energy Rating Systems Standards – Continuous Maintenance Version. Residential Energy Services Network, Inc. Oceanside, CA http://resnet.us/

[2]Musser 2003. "Life Cycle Cost Analysis of the 2000 International Energy Conservation Code for Nebraska"

[3]Musser 2006. "Energy Impact Study of the 2003 IECC, 2006 IECC, and 2006 IRC Energy Codes for Nebraska:"

[4]Musser 2009. Energy Impact Study of the 2003 IECC and 2009 IECC Energy Codes for Nebraska."

[5]Musser 2012. "Energy Impact Study of the 2003 IECC and 2012 IECC Energy Codes for Nebraska."

[6]Musser 2015. "Energy Impact Study of the 2003 IECC and 2015 IECC Energy Codes for Nebraska."

[7]Musser 2018. "Energy Impact Study of the 2009 IECC and 2018 IECC Energy Codes for Nebraska."

[8]ASHRAE Standard 62.2-2010. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Atlanta, GA, American Society of Heating, Refrigerating, and Air Conditioning Engineers.

Appendix A

Heating degree days by code jurisdiction

Jurisdiction	HDD	Modeled City	Jurisdiction	HDD	Modeled City
Albion	7087	Chadron	Louisville	6292	Omaha
Alliance	6823	Norfolk	McCook	5967	None
Alma	6203	Omaha	Mead	6570	Norfolk
Ashland	6379	Omaha	Milford	5779	None
Auburn	5765	None	Minden	6398	Omaha
Beatrice	6151	Omaha	Nebraska City	6023	Omaha
Bellevue	6153	Omaha	Norfolk	6766	Norfolk
Blair	6455	Omaha	North Platte	6766	Norfolk
Bloomfield	7057	Chadron	Ogallala	6672	Norfolk
Cass County	6292	Omaha	Omaha	6153	Omaha
Central City	5834	None	O'Neill	7246	Chadron
Ceresco	6613	Norfolk	Palmyra	6337	Omaha
Chadron	7021	Chadron	Papillion	6153	Omaha
Columbus	6411	Omaha	Plainview	6485	Omaha
Cozad	6303	Omaha	Plattsmouth	6153	Omaha
Crete	5811	None	Ralston	6153	Omaha
Dakota City	6600	Norfolk	Sarpy County	6153	Omaha
David City	6237	Omaha	Saunders County	6613	Norfolk
Douglas County	6153	Omaha	Scottsbluff	6742	Norfolk
Elkhorn	6153	Omaha	Seward	5779	None
Falls City	5795	None	Seward County	5779	None
Fremont	6444	Omaha	Sidney	7092	Chadron
Gering	6742	Norfolk	South Sioux City	6600	Norfolk
Grand Island	6385	Omaha	Superior	5552	None
Gretna	6379	Omaha	Sutton	6347	Omaha
Hall County	6385	Omaha	Tekamah	6564	Norfolk
Hastings	6211	Omaha	Valley	6570	Norfolk
Holdrege	6482	Omaha	Wahoo	6570	Norfolk
Kearney	6652	Norfolk	Washington Cty.	6455	Omaha
Keith County	6672	Norfolk	Waverly	6119	Omaha
LaVista	6153	Omaha	Wayne	7143	Chadron
Lancaster County	6119	Omaha	Wymore	6151	Omaha
Lexington	6303	Omaha	York	6338	Omaha
Lincoln	6119	Omaha	Yutan	6570	Norfolk

Table A1. Modeled city representing Nebraska code jurisdictions.

Appendix B

Glossary of Abbreviations used in this report

ACH50: Air changes per hour at 50 Pascals pressure difference. This is a tested measure of whole-house airtightness that is commonly used to benchmark whole-house airtightness.

AFUE: Annual fuel utilization efficiency. Used to quantify and compare the efficiency of gas furnaces. A higher value indicates better efficiency, with 100% being the theoretical maximum.

ASHRAE: American Society of Heating, Refrigerating, and Air Conditioning Engineers, a global society dedicated to advancing the arts and sciences of HVAC.

cfm: cubic feet per minute, a measure of airflow

EPA: Environmental Protection Agency, an agency of the US federal government.

HVAC: Heating, Ventilating, and Air Conditioning

IECC: International Energy Conservation Code

NOAA: National Oceanic and Atmospheric Administration, an agency of the US federal government.

R-value: measures how well a product prevents heat from moving through the building exterior. A high R-value means that the material has a high resistance to heat flow and is considered a good insulator. R-value is the mathematical inverse of U-factor.

Ekotrope: A whole-house energy modeling tool used to perform this study.

RESNET: Residential Energy Services Network (www.resnet.us) This organization maintains the RESNET standards, a commonly used method of rating the energy performance of homes.

SEER: Seasonal energy efficiency ratio. Used to quantify and compare the efficiency of air conditioners (and heat pumps in cooling mode). A higher value indicates a more efficient unit. Currently available units range from 13 to approximately 20 SEER.

sf: square feet

SHGC: Solar heat gain coefficient. A number between 0 and 1 that expresses the portion of incident solar energy that passes through a window, including frame effects. The lower the value, the more solar heat is blocked from entering the home via the window.

U-factor: measures how well a product prevents heat from moving through the building exterior. A low U-factor means that the material has a high resistance to heat flow and is considered a good insulator. U-factor is the mathematical inverse of R-value.