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Annual Energy Outlook 2022: Alternative Weather Assumptions

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Executive Summary

Weather is a leading driver of fuel consumption in residential and commercial buildings. Demand for space heating and space cooling can be met by fossil fuels—including natural gas, distillate fuel oil, and propane—and by electricity. This analysis considers the effects that alternative weather assumptions can have on future energy consumption in buildings in the United States. By modifying heating degree days (HDDs) and cooling degree days (CDDs)—indicators of space heating and space cooling energy demand, respectively—relative to the *Annual Energy Outlook 2022* (AEO2022) Reference case, we see how end-use consumption by fuel can vary. We also look at how changing demand for fuels can affect fuel supply and prices. We compare three alternative weather assumptions cases with the AEO2022 Reference case:

- **10-year Historical Trend case (10-yr Trend).** This case projects future HDDs and CDDs based on the most recent decade of historical weather data, rather than three decades of weather data as in the Reference case.
- **Rate Change: Cooler case (Cooler).** This case assumes a one percentage point annual *increase* in HDDs and one percentage point annual *decrease* in CDDs by census division relative to the AEO2022 Reference case for 2023–2050.
- **Rate Change: Warmer case (Warmer).** This case assumes a one percentage point annual *decrease* in HDDs and one percentage point annual *increase* in CDDs by census division relative to the AEO2022 Reference case for 2023–2050.

In the AEO2022 Reference case, delivered residential sector consumption grows 0.2% per year from 2021 to 2050 while commercial sector consumption grows 0.4% per year. Residential consumption grows the most in the Cooler case—0.8% per year—as increasing HDDs drive growing demand for space heating fuels, which outweighs countervailing changes to air conditioning and other end uses at the national level. As a result of changes to energy demand and fuel prices, total U.S. delivered energy consumption in all sectors is 3% higher in 2050 in the Cooler case and 1% lower in 2050 in the Warmer case than the Reference case.

National delivered energy consumption in buildings is about the same in 2050 between the Reference and 10-yr Trend cases as regional variations in warming and cooling offset one another; however, changes to fuel and end-use consumption vary in different regions of the country with different equipment stocks and fuel prices.

Natural gas accounts for the largest share of space heating fuel consumption in buildings. In 2050, residential natural gas consumption is 36% higher in the Cooler case than in the Reference case, compared with 20% lower in the Warmer case, which has lower heating demand. In the commercial sector, natural gas consumption is 14% higher in 2050 in the Cooler case and 11% lower in the Warmer case than in the Reference case.

Rising CDDs in the Warmer case drive increased electricity consumption, mostly as a result of greater demand for space cooling in buildings. Residential and commercial purchased electricity consumption is 5% and 3% higher, respectively, in 2050 than in the Reference case.

In 2050, total U.S. energy-related CO₂ emissions are 4% higher in the Cooler case than the Reference case due to higher CO₂ intensity of fossil fuels consumed. Total U.S. energy-related CO₂ emissions are 4% lower in the Warmer case in 2050 than the Reference case because of lower CO₂ intensity associated of fossil fuels consumed despite increased electricity consumption for space cooling.

Buildings demand for electricity for lighting, appliances, and other non-space heating or cooling end uses (which accounted for 66% of buildings delivered energy consumption in 2021) is not affected by changing weather assumptions in this analysis.

Background

Buildings accounted for 28% of delivered energy¹ consumption in 2021 in the United States, and space heating, cooling, and ventilation accounted for 46% of energy consumed by residential and commercial buildings in 2021, according to EIA's *Annual Energy Outlook 2022* (AEO2022) Reference case. Demand for these services largely depends on the climate at a building's location. The National Oceanic and Atmospheric Administration's (NOAA) most recent decadal degree day data update accounts for [continued historical warming trends](#), showing that this important determinant of energy consumption is subject to uncertainty in the future.

This article presents results from three alternative weather assumption cases relative to the AEO2022 Reference case. We analyze the effects that varying heating degree day (HDD) and cooling degree day (CDD) projections have on buildings end-use energy consumption, utility energy supplies and prices, and energy-related carbon dioxide (CO₂) emissions.

Changing space heating and cooling loads drive electricity and fossil fuel consumption in buildings. Residential and commercial energy consumption changes the most in the Cooler case because of increased demand for fossil fuels for space heating. With 32% higher HDDs and 24% lower CDDs in 2050 in the Cooler case than in the Reference case, delivered energy consumption to buildings is 12% higher. In the Warmer case, 25% lower HDDs and 32% higher CDDs lead to 5% lower delivered energy consumption to buildings in 2050 relative to the AEO2022 Reference case.

Methodology

This analysis modifies inputs to the [Residential Demand Module](#) (RDM) and [Commercial Demand Module](#) (CDM) of the National Energy Modeling System (NEMS).² It evaluates alternative weather assumptions that affect energy demand in buildings, as well as the subsequent changes to energy supplies and prices caused by such changes in demand.

Degree days are a measure of how cool or warm a location is over a period of time relative to a base temperature, most commonly specified as 65°F. [Heating degree days](#) (HDDs) and [cooling degree days](#) (CDDs) are used as indicators of space heating and space cooling energy demand, respectively.

For the AEO2022 Reference case, we use 30-year linear trends of historical HDDs and CDDs for projection years 2023–2050 based on state-level degree day data from the National Oceanic and Atmospheric Administration (NOAA), [National Centers for Environmental Information](#), and [Climate Prediction Center](#). Degree days are population-weighted from the state to the census-division level, which helps to account for population migration throughout the United States—predominantly from

¹ The amount of energy supplied to the end-use sectors (residential, commercial, industrial, and transportation), which includes coal, natural gas, petroleum products, renewable energy, and electricity sales to ultimate customers purchased by consumers in the end-use sectors. It excludes electricity generated on-site (such as from rooftop solar panels or combined-heat-and-power systems) and non-marketed renewable energy (solar water heating, ground-source heat pumps, wood from onsite, etc.) produced and consumed entirely within the sector.

² Detailed model documentation for the various modules of NEMS can be found on [EIA's website](#).

heating-dominated to cooling-dominated parts of the country. We have used this methodology since AEO2013.

Case descriptions

The cases considered in this article primarily identify and quantify uncertainties in energy system inputs associated with potential future changes in weather that drive space heating and cooling demand for buildings. These cases focus on the direct impacts that different HDD and CDD assumptions have on building end-use consumption and do not account for any implicit effects that changing weather or climate may have on infrastructure reliability or energy availability. The weather assumptions used in these cases are designed to represent a sensitivity analysis that indicates how changes in heating and cooling demand affect energy consumption, rather than a forecast of likely actual weather or climate trends.

10-year Historical Trend case

Rather than using 30 years of historical HDD and CDD data to project linear trends for 2023 onward, the 10-yr Trend case uses 10 years of state-level historical data (2011–2020). This case more closely illustrates the effects of the most recent decade of historical weather trends, highlighting warming in much of the country and cooling in some areas.

Rate Change: Cooler case

The Cooler case assumes a one percentage point annual *increase* in HDDs and one percentage point annual *decrease* in CDDs by census division relative to the AEO2022 Reference case annual changes for 2023–2050. This case represents the effects of a cooling weather trend. The Cooler case creates a higher and lower range for building space heating and space cooling demand, respectively, than the AEO2022 Reference case.

Rate Change: Warmer case

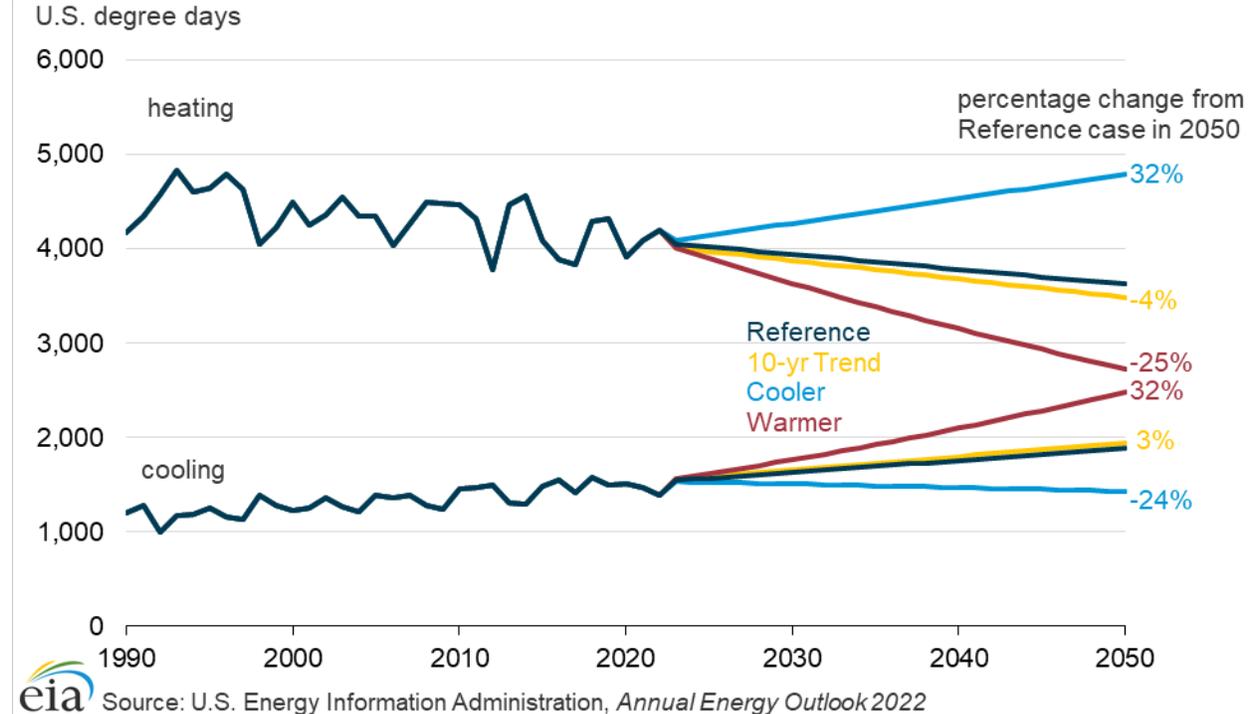
Opposite of the Cooler case, the Warmer case assumes a one percentage point annual *decrease* in HDDs and one percentage point annual *increase* in CDDs by census division relative to the AEO2022 Reference case annual changes for 2023–2050. This case represents the effects of a warming weather trend. The Warmer case is meant to create a lower and higher range for building space heating and space cooling demand, respectively, than the AEO2022 Reference case.

Degree day projections

In the AEO2022 Reference case, we project HDDs to be 11% lower, and we project CDDs to be 28% higher in 2050 compared with 2021 based on a 30-year historical trend of weather data (Figure 1). HDDs decrease 0.4% per year, and CDDs increase 0.9% per year on average from 2021 to 2050. Similarly, HDDs decrease 0.5% per year, and CDDs increase 1.0% per year on average from 2021 to 2050 in the 10-yr Trend case. By 2050, HDDs are 15% lower, and CDDs are 32% higher compared with 2021.

As assumed changes in degree days in the Cooler and Warmer cases deviate one percentage point annually at the U.S. census-division level relative to their Reference case trends, national average HDDs grow 0.6% per year, and CDDs decrease 0.1% per year from 2021 to 2050 in the Cooler case. Conversely, HDDs decrease 1.4% per year, and CDDs grow 1.8% per year from 2021 to 2050 in the Warmer case.

Figure 1. U.S. degree day projections, Reference case and alternative weather assumption cases (1990–2050)



Results

This section discusses effects on building energy demand, energy supply, and energy-related CO₂ emissions relative to the AEO2022 Reference case and between cases.

Building energy demand

In the *Annual Energy Outlook 2022* (AEO2022) Reference case, nearly half of the energy buildings consumed in 2021 was for space conditioning. Space heating, cooling, and ventilation accounted for 55% of residential and 35% of commercial delivered energy consumption in 2021. The results of the alternative weather cases show that altering projected weather assumptions affects end-use consumption for space heating in different ways than for space cooling.

Sector-level consumption by fuel type

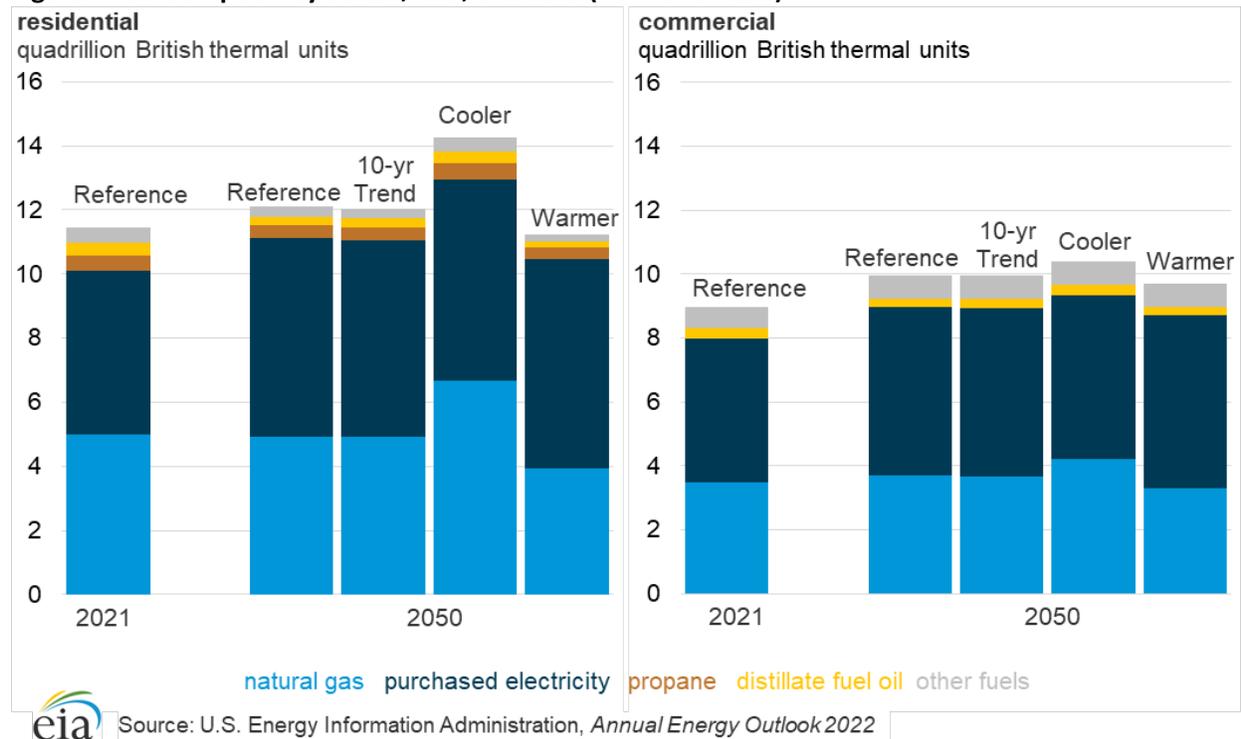
In the AEO2022 Reference case, delivered residential sector energy consumption grows 0.2% per year from 2021 to 2050 while commercial sector consumption grows 0.4% per year. Residential consumption grows most in the Cooler case—0.8% per year—because increasing HDDs drive growing demand for space heating fuels.

As further explained in the [regional results](#), natural gas accounts for the largest share of space heating fuel consumption in both residential and commercial buildings. In the AEO2022 Reference case, natural gas consumption through 2050 grows by 2%, from 8.5 quads to 8.6 quads, with increases in commercial consumption offsetting decreases in residential consumption. In 2050, residential natural gas consumption is 36% higher in the Cooler case than in the Reference case, compared with 20% lower in

the Warmer case, which has decreasing HDDs (Figure 2). In the commercial sector, natural gas consumption is 14% higher in the Cooler case and 11% lower in the Warmer case in 2050 than in the Reference case.

The residential sector consumed about twice as much natural gas for space heating as the commercial sector in 2021, and residential sector natural gas consumption changes more than in the commercial sector as a result of the weather assumptions. This difference in demand contributes to divergent projections for natural gas prices between the two sectors. For both the residential and commercial sectors, the 10-yr Trend case shows negligible differences at the national level compared with the Reference case.

Figure 2. Consumption by sector, fuel, and case (2021 and 2050)



In the Warmer case, residential purchased electricity consumption is 5% higher, and commercial purchased electricity consumption is 3% higher in 2050 than in the Reference case. Rising CDDs drive increased electricity consumption mostly because of greater demand for space cooling in buildings.

The rate at which purchased electricity consumption changes as a result of alternative weather assumptions is slower than the rate of change for delivered natural gas, propane, and distillate fuel oil, in part, because of differences in efficiency in space conditioning equipment.³ Space heating equipment, such as furnaces and boilers, burns fuel to generate heat and so has direct thermal losses associated with combustion. Conversely, air conditioners and heat pumps do not generate heat, but rather, [move](#)

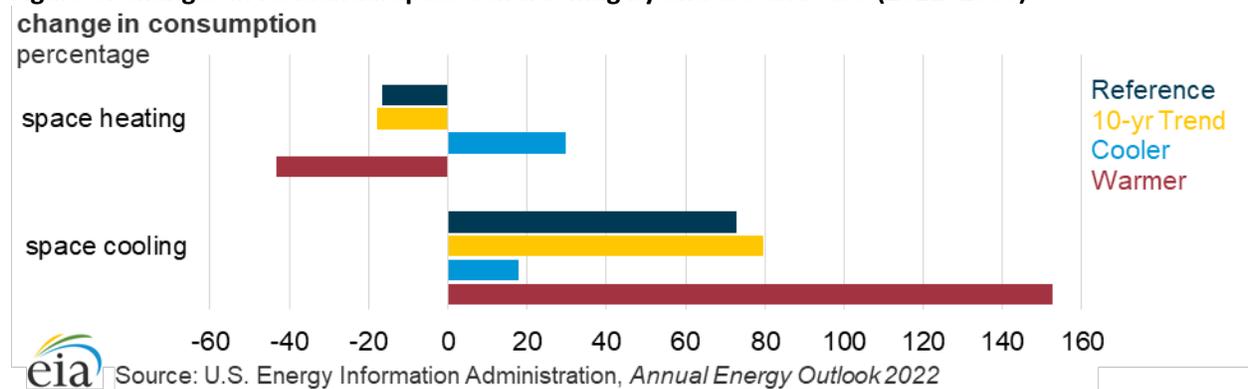
³ Assumptions for energy efficiency standards and subsidies for energy-efficient equipment remain the same in the alternative weather assumptions cases as in the AEO2022 Reference case. As a result, any fuel switching or electrification that occurs in these cases is primarily in response to changing regional space heating or cooling demand and alternative fuel prices.

heat from areas of higher concentration to lower concentration. As a result, their efficiencies can exceed 100%. We assume that electric-resistance equipment converts 100% of electricity consumed into heat.

Consumption by end use

Because there is not a one-for-one inverse correlation between HDDs and CDDs, space heating and space cooling consumption do not change at the same rates over time. Decreasing projected U.S. total HDDs in all cases except the Cooler case continue to drive space heating consumption downward. Residential space heating consumption of 5.5 quadrillion British thermal units (quads) in 2021 increases to 7.2 quads in 2050 in the Cooler case but decreases to 3.1 quads in the Warmer case (Figure 3). By contrast, we project U.S. total CDDs to increase from 2021 to 2050 in all AEO2022 cases except the Cooler case based on trends in historical weather data. We project that residential space cooling consumption will more than double in the Warmer case, growing from 0.9 quads in 2021 to 2.2 quads in 2050.

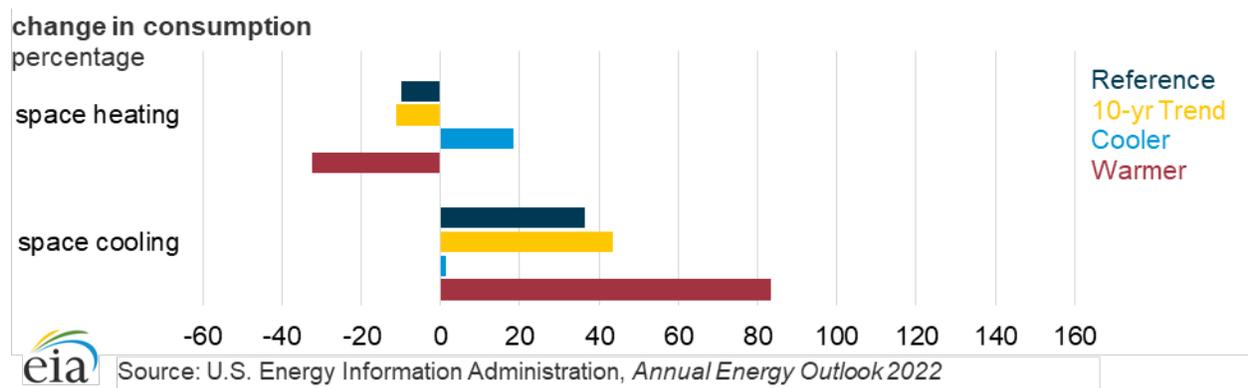
Figure 3. Changes in residential space conditioning by end use and case (2021–2050)



Note: Residential space heating includes air handler fan and boiler circulation pump consumption.

Similar to the residential sector, we project that space heating decreases in all cases except the Cooler case, and space cooling increases in all AEO2022 cases in the commercial sector (Figure 4). Commercial space heating consumption in the Cooler case increases from 2.1 quads in 2021 to 2.5 quads in 2050, but it decreases to 1.4 quads in the Warmer case. Commercial space cooling consumption increases from 0.6 quads in 2021 to 1.0 quad in 2050 in the Warmer case.

Figure 4. Changes in commercial space conditioning by end use and case (2021–2050)



Note: Excludes ventilation equipment consumption.

Regional results

The share of fuels consumed for residential space heating varies across the country, but natural gas exceeded other fuels in all census divisions in 2021 (Figure 5). The same is true for the commercial sector, except for the New England Census Division, where 55% of space heating came from distillate fuel oil versus 42% from natural gas in 2021 (Figure 6).

Figure 5. Residential space heating consumption shares by fuel and U.S. census division, Reference case (2021)

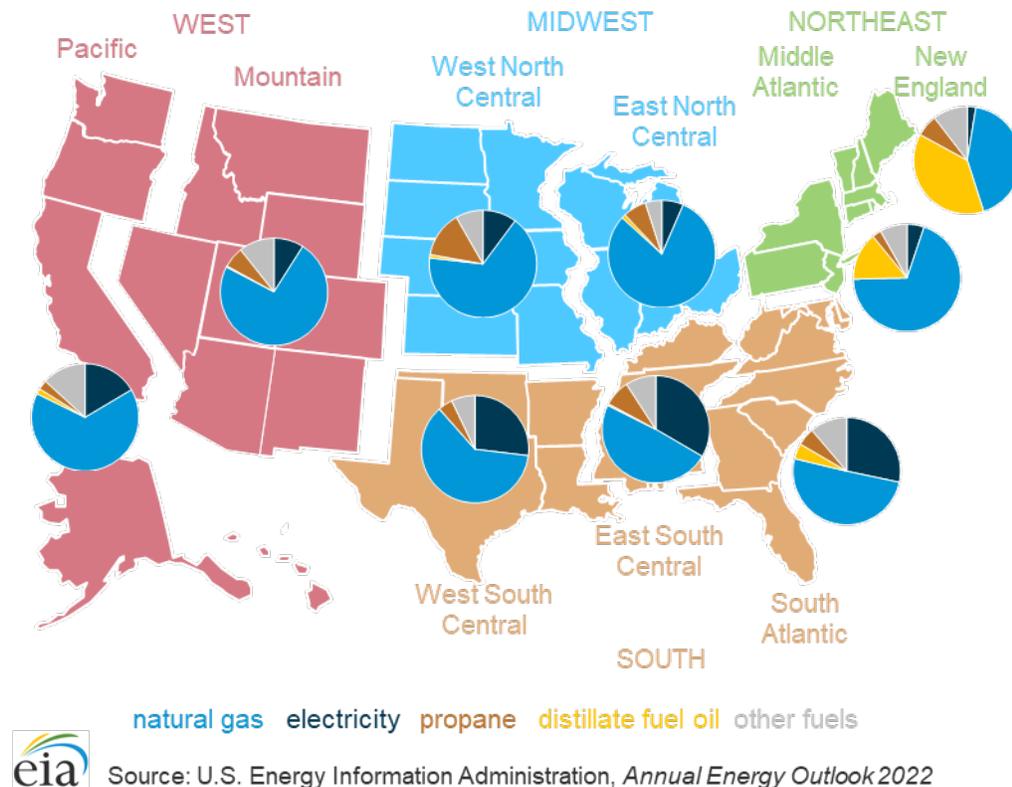
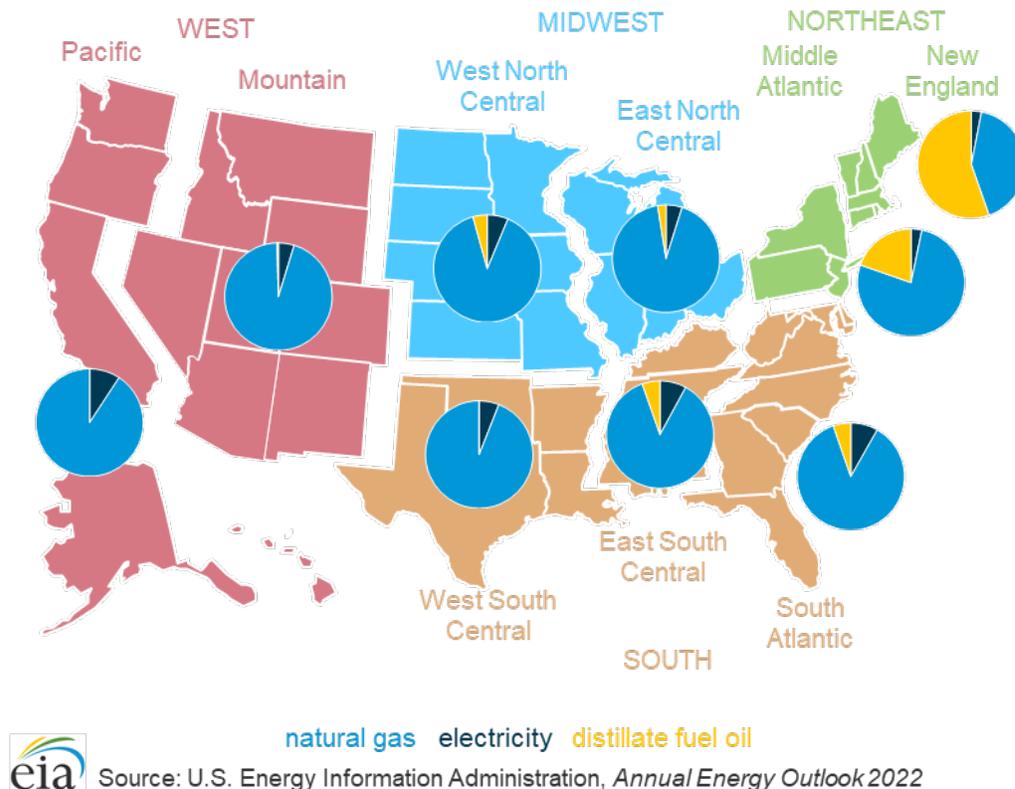


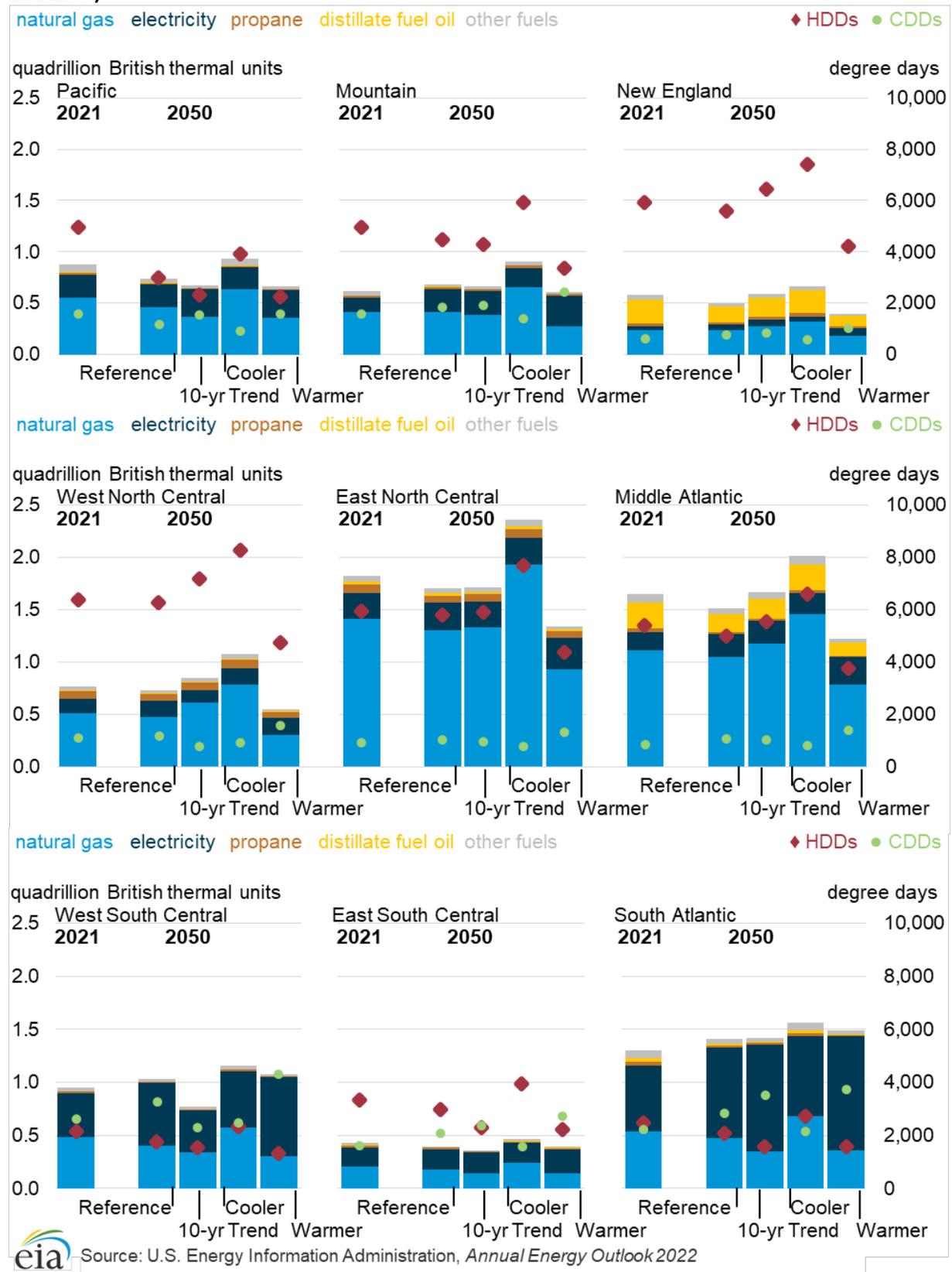
Figure 6. Commercial space heating consumption shares by fuel and U.S. census division, Reference case (2021)



HDDs and CDDs differ across the country, and the rates at which they change over time vary (Figure 7). Although the Reference case shows HDDs decreasing in all census divisions by 2050, the 10-yr Trend case projects increasing HDDs over the same period in the New England, Middle Atlantic, and West North Central Census Divisions. Conversely, we project the number of CDDs to decrease in West North Central and West South Central Census Divisions in the 10-yr Trend case.

Compared with other regions, a greater share of the energy used for space heating in the New England and Middle Atlantic Census Divisions comes from distillate fuel oil. Of the fuel used in U.S. buildings in 2021 in the AEO2022 Reference case, the New England Census Division accounts for 5% and the Middle Atlantic Census Division accounts for 15% of total fuel consumption.

Figure 7. Buildings space heating and cooling consumption versus degree days by fuel and case (2021 and 2050)



Fossil fuels accounted for 53%–63% of residential and commercial consumption for *all* end uses in the heating-dominated West North Central, East North Central, Middle Atlantic, and New England Census Divisions in 2021. In the Cooler case, HDDs are 23%–30% higher in 2050 than in 2021 in these census divisions, and we project fossil fuel consumption will be 13%–34% higher in 2050 than in 2021 (compared with 2%–10% lower consumption in the Reference case).

Electricity accounted for 62%–66% of all residential and commercial building energy consumption in the cooling-dominated West South Central, East South Central, and South Atlantic Census Divisions in 2021. In the Warmer case, CDDs are 65%–70% higher in 2050 than in 2021 in these census divisions, and we project electricity consumption will be 26%–49% higher in 2050 than in 2021 (compared with 21%–38% higher consumption in the Reference case).

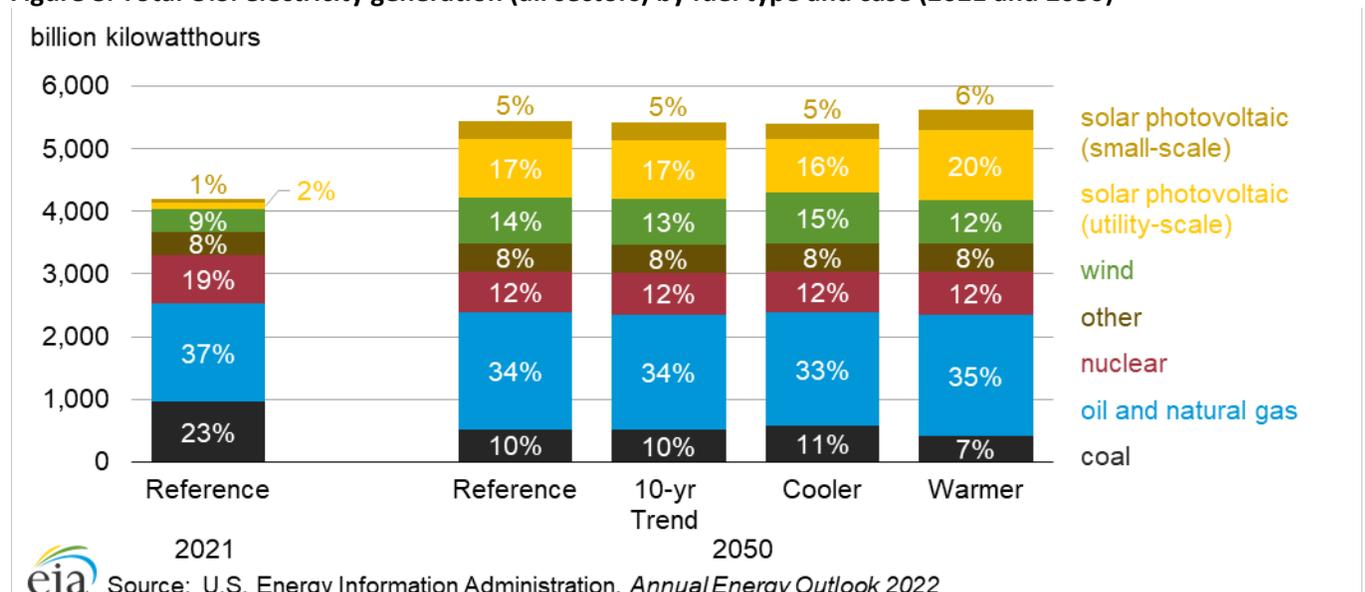
Although natural gas is predominantly consumed as a space heating fuel in buildings, the commercial sector also uses natural gas-fired chillers and engine-driven rooftop air conditioners to meet space cooling demand. In the Reference case, natural gas accounted for 12% of commercial space cooling consumption in 2021 in the Middle Atlantic Census Division compared with 1%–5% in other census divisions.

Energy supply

Electricity generation mixes

Total U.S. electricity demand is similar across these alternative weather assumption cases by 2050, but the highest demand is projected in the Warmer case (Figure 8). In this case, total generation from all sectors increases at a faster rate through the projection period than in other cases and is 3% higher (at 5,633 billion kilowatt-hour [BkWh]) than the Reference case in 2050. Despite similar electricity demand, the 2050 generation fuel mix differs across the cases, ranging from 7%–11% for coal, 33%–35% for oil and natural gas, 12%–15% for wind, and 21%–26% for solar photovoltaic (PV).

Figure 8. Total U.S. electricity generation (all sectors) by fuel type and case (2021 and 2050)



Note: Totals may not equal sum of components due to independent rounding.

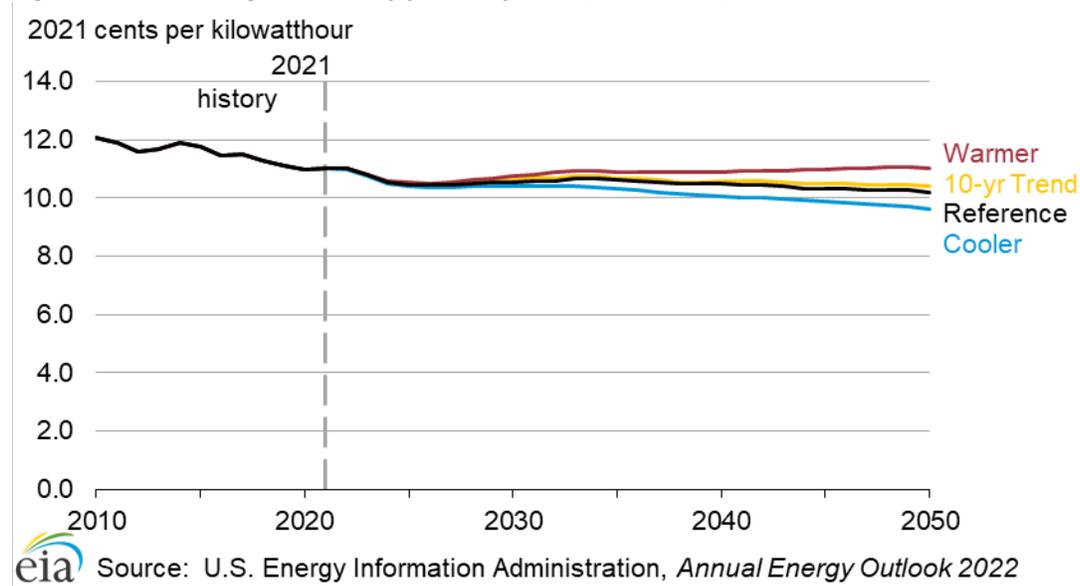
In the Warmer case, higher electricity demand is projected to occur particularly during the summer months from the higher assumed CDDs. Solar PV generation—both small scale and utility scale—is the most economical technology choice to meet the higher cooling load during the daytime. As a result, incremental electricity demand is mostly met by solar PV. Higher oil and natural gas-fired generation is also needed to meet the higher summer cooling load. Electricity demand during winter months is slightly lower compared with the Reference case. Due to cheaper winter natural gas prices and higher natural gas-fired generating capacity additions for summer electricity demand, coal-fired power plants operate less during winter months; therefore, shifts in seasonal electricity demand result in less coal generation on an annual basis relative to the Reference case.

By contrast, the electricity-based portion of higher heating demand in the Cooler case is met by higher coal-fired and wind generation rather than solar PV. We project demand to be lower during the summer with fewer assumed CDDs, and higher during the winter with more assumed HDDs compared with the Reference case. Capacity additions that are typically built to meet increasing demand during the summer are reduced in the Cooler case because of fewer CDDs, while less retirements of coal-fired generating capacity allow existing capacity to meet the projected demand. Wind is the most cost-competitive technology to meet the incremental demand because more wind resources are available during the winter months, and we project generation from wind to be the highest across the cases.

We expect electricity generation in the 10-yr Trend case to be similar to the Reference case by 2050. We project electricity demand to be higher during the summer in some regions and higher during the winter in other regions; therefore, average electricity demand is largely unchanged from the Reference case.

Energy prices and other market impacts

Average electricity prices across all sectors in the Reference case and all alternative weather assumption cases range between 10.3 cents per kilowatthour (kWh) and 10.9 cents per kWh (2021 dollars) in the near- to mid-term (Figure 9). However, prices in the Cooler and Warmer cases start to diverge further from the Reference case starting around 2035. We project that, by 2050, the average electricity prices in the Warmer Case will be 8% higher than in the Reference case (11.0 cents per kWh compared with 10.2 cents per kWh) and 14% higher than in the Cooler case (11.0 cents per kWh compared with 9.6 cents per kWh). We project generation from low-cost sources such as solar PV to be higher, but high-cost generation from natural gas will likely be higher as well, particularly during the summer, which in turn raises the average generation cost component of the electricity price over the projection. In addition, higher summer peak demand results in greater reserve capacity requirements and more investment in new generating capacity and supporting infrastructure. The cost of the additional capacity additions and capital investment must be recovered over total sales that may not grow as quickly as the increased peak demand.

Figure 9. U.S. average electricity prices by case (2010–2050)

In contrast, electricity prices in the Cooler case trend lower than those in the Reference case starting around 2030. Demand shifts from the summer months, which tend to have higher electricity prices, to off-peak periods. The capacity reserve requirements and investment in new generating additions are also lower, resulting in lower average annual electricity prices.

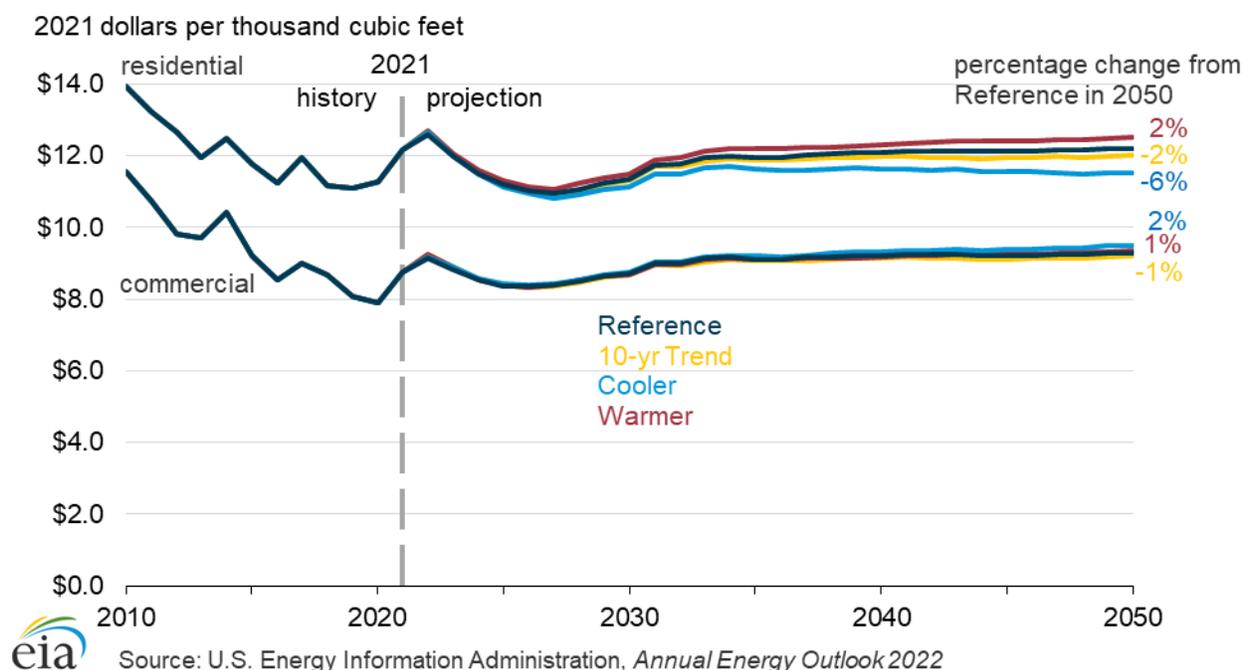
We project residential delivered natural gas prices to be lowest in the Cooler case, and commercial delivered natural gas prices to be highest (Figure 10). The opposite is true in the Warmer case, where projected residential delivered natural gas prices are highest. This difference in natural gas prices occurs because the total consumed volume of natural gas increases in the Cooler case and decreases in the Warmer case. This change in total consumed volume of natural gas is nearly twice as much relative to the Reference case in the residential sector compared with the commercial sector (Figure 2). Residential and commercial natural gas bills feature a fixed component (for example, customer charge). So, an increase in consumption volume, while resulting in higher monthly bills, can lead to a decrease in price on a per-unit basis because the fixed component makes up a smaller share of the total bill, and the opposite is true when consumption volume decreases.

In order to capture seasonal effects, each projection year the NEMS [Natural Gas Markets Module](#) (NGMM) adds interstate pipeline capacity by evaluating pipeline utilization in a peak winter month and a peak summer month. It assesses a colder-than-projected winter and a warmer-than-projected summer to represent increased load on pipelines and determines if additional capacity is needed. In the Cooler case, 15% more natural gas pipeline capacity by 2050 carries natural gas out of the Middle Atlantic and Ohio to the Eastern Midwest region compared with the AEO2022 Reference case. This increased capacity helps connect rising natural gas production from areas such as the Marcellus and Utica shale plays to demand areas such as the Midwest. Because of the already large pipeline capacity from the Middle Atlantic and Ohio to the Eastern Midwest in the Reference case (20.2 billion cubic feet per day in 2050), this increase over the Reference case is especially notable. Other interregional capacity changes occur in the Cooler case, such as increased natural gas capacity from Canada into New England after

2030. However, these differences are an order of magnitude smaller than pipeline capacity changes out of the Middle Atlantic and Ohio.

Regional degree day directional differences contribute to commercial-sector natural gas prices being the lowest in the 10-yr Trend case. In the South Atlantic Census Division, HDDs are 25% lower in 2050 than in the Reference case. South Atlantic commercial natural gas prices are about 1% lower in 2050 than in the Reference case, while residential natural gas prices are 6% higher than in the Reference case.

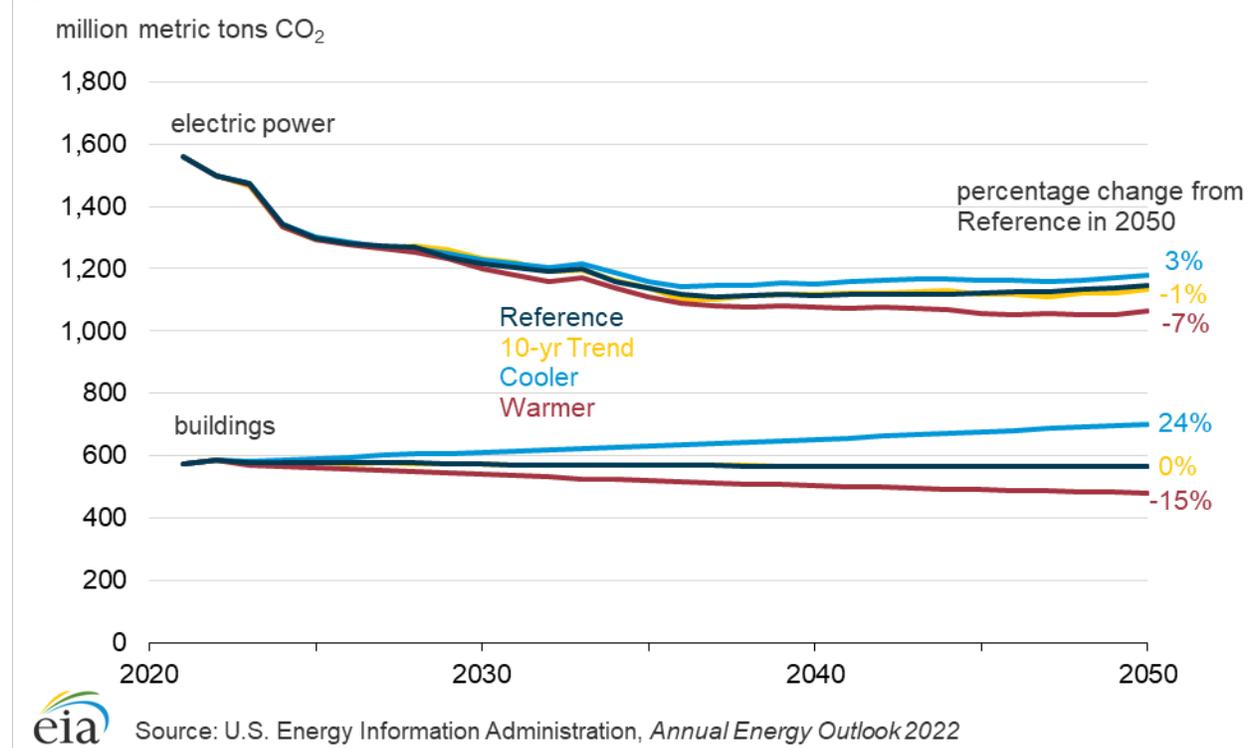
Figure 10. Buildings sector natural gas prices by case, (2021–2050)



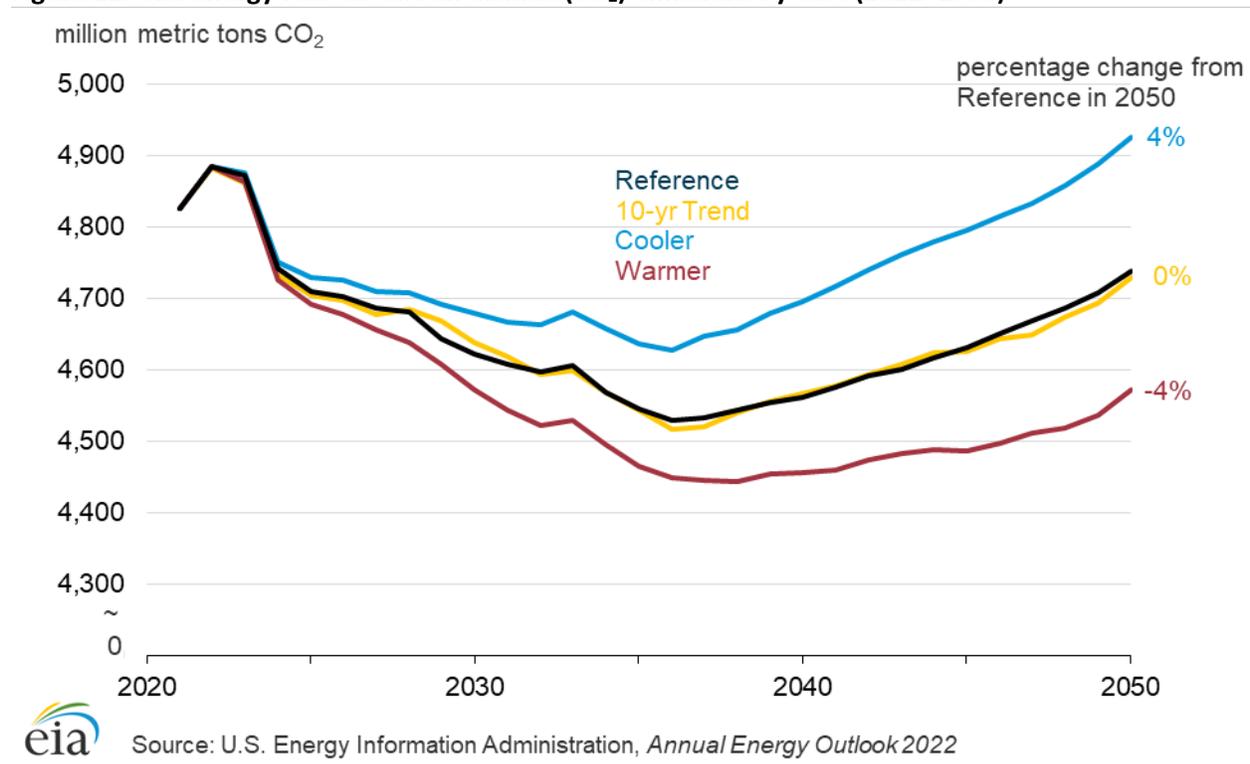
Energy-related CO₂ emissions

Emissions by sector

As in the Reference case, electric power sector CO₂ emissions decline through the mid-2030s across all cases because of continued coal-fired generating resource retirements (Figure 11). In the longer term, however, we project that CO₂ emissions remain relatively flat or increase slightly both in the Reference and Cooler cases because the decline in emissions from coal-fired generation is offset by the increase in natural gas-fired generation. In the Warmer case, we project emissions from the electric power sector to be the lowest across the cases because coal-fired generation makes up the smallest share of the electricity generation mix and generation from nuclear and renewables have higher shares. However, CO₂ emissions remain steady after the mid-2030s because of higher emissions from natural gas resulting from the increase in electricity demand for space cooling.

Figure 11. Direct carbon dioxide (CO₂) emissions in selected sectors by case (2021–2050)

Direct energy-related CO₂ emissions from buildings—excluding emissions associated with utility electricity generation—grow in the Cooler case because of increased fossil fuel consumption for space heating. In the AEO2022 Reference case, direct energy-related CO₂ emissions from the residential sector decrease 0.2% per year on average from 326 million metric tons (MMmt) in 2021 to 305 MMmt in 2050. Commercial emissions increase 0.2% per year on average from 245 MMmt to 259 MMmt over the same period. In the Cooler case, the increase in emissions averages 0.8% per year in the residential sector and 0.6% per year in the commercial sector from 2021 through 2050. Overall, total U.S. energy-related CO₂ emissions are 4% higher in the Cooler case and 4% lower in the Warmer case than in the Reference case in 2050 (Figure 12). This increase in emissions in the Cooler case is due to the higher CO₂ intensity of fossil-fuels used for space heating compared with electricity consumed for space cooling in the Warmer case.

Figure 12. U.S. energy-related carbon dioxide (CO₂) emissions by case (2021–2050)

Conclusion

Relative changes in weather around the country can affect residential and commercial fuel and end-use energy consumption in different ways. The types of equipment, the fuels consumed, and the prices paid for those fuels all differ regionally and contribute to changing energy consumption in buildings over time. The AEO2022 10-yr Trend, Cooler, and Warmer cases investigate the uncertainty of future weather by illustrating a range of possible changes to space heating and space cooling demand in buildings.

In this analysis, we examine how alternative weather assumptions drive not only consumption of fuels within buildings but also how changing demand can affect energy supply and distribution. Changes in energy supply, in turn, affect average energy prices paid by all energy end users. Cooler weather increases fossil fuel consumption, and warmer weather drives growth in electricity consumption. Direct energy-related CO₂ emissions grow and decline with fossil fuel consumption both in buildings and in the electric power sector, but the emissions impacts associated with direct fuel use in buildings outweigh the emissions impacts to the electric power sector under the alternative weather assumptions in the Cooler and Warmer cases.