Residential Cooktop Performance and Energy Comparison Study

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Revision History

Revision num.	Date	Description	Author(s)
0	July 2019	Initial Release	D. Livchak, R. Hedrick

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Background

The perception that gas residential cooktops are superior in performance to electric cooktops has been prevalent for decades. Gas cooktops offer users the ability to adjust the heat to the pan based on a visual reference to the height of the flame. Many home cooks prefer the immediate response of flame adjustment to the delayed response associated with electric resistance coils.

Induction technology, however, has revolutionized electric cooktop cooking by changing the way heat is transferred to cookware. Using a magnetic field, induction cooktops excite the molecules in a pot or pan, generating heat for cooking. Induction technology results in a near complete energy transfer to the cooking vessel, making induction cooktops incredibly energy efficient relative to other modes of cooking. Other benefits of induction cooktops, in comparison to gas burners and traditional resistance heating elements include increased safety and reduced energy use when not cooking. When a pot or pan is removed from the burner or element on a gas range top or resistance electric range top, the burner or element needs to be manually turned off. But, when a pot or pan is removed from an induction hob, the magnetic coil immediately stops consuming energy, providing the most effective energy control of any range top design. And, since there is no open flame or hot element on an induction range top, there is no chance of igniting any flammable object that might be on or near the range top – increasing fire safety in the kitchen.

Induction cooking technology was developed in the 1990s for the commercial market but has yet to be widely adopted in the U.S. residential market. Growing concerns over climate change and the desire to reduce the burning of fossil fuels is generating interest in induction cooking as a replacement for natural gas; however, consumers' unfamiliarity with the technology, its higher price point, and fears regarding the special cookware that is required are barriers to developing this market. Also, there is relatively little information available to date on the benefits of induction cooking for homeowners, making it difficult to even initiate the push for market transformation. The goal of this study is to address this final barrier by assessing the cooking performance and energy consumption of induction relative to more traditional residential cooktops – gas open burners, electric resistance heat coils, and electric glass-ceramic cooktops.

Approach

Under controlled laboratory conditions, researchers performed the following tests on each cooktop type to test:

- Water Heat Up – The energy and time to bring water to 200°F, which is used to both measure the production capability of the cooktop as well as the energy efficiency. In addition, the overshoot and cool-down from the water heat-up test is used to illustrate the temperature response of each cooktop.
- Simmer – Once the water is boiling, the energy required to keep a pot of water at a simmer, which is used to measure energy consumption under regular cooking conditions for inclusion in an energy cost model.
- Sauté – The energy and time to pan-cook a typical food product, which is used to both measure the production capability of the cooktop as well as the energy efficiency.

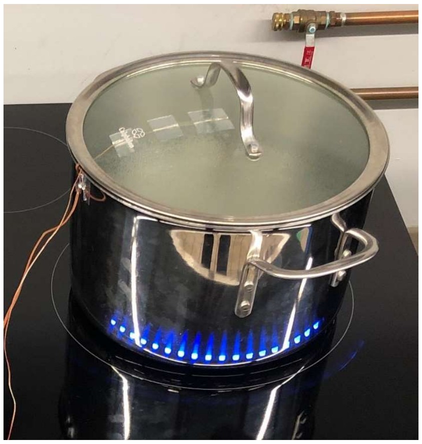


Figure 1: Water Boil and Simmer Test

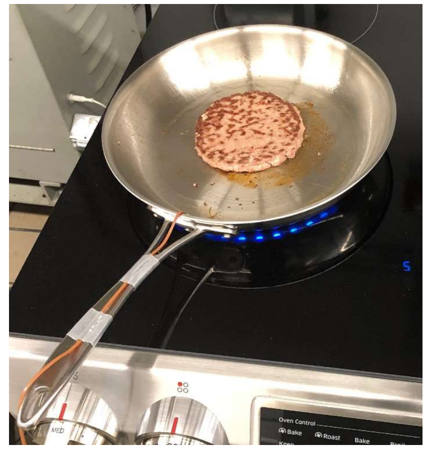


Figure 2: Sauté Test with a Standard Food Product

Each of the performance tests used a modified methodology based on the American Society for Testing and Materials (ASTM) F1521 *Standard Test Methods for Performance of Range Tops* for the heat-up tests and ASTM F1275 *Standard Test Method for Performance of Griddles* for the sauté tests. A summary of the test methodology is provided in Appendix A. These tests were conducted for each of the residential range tops split into four categories:

- Electric Resistance Ceramic Range Top
- Electric Resistance Coil Range Top
- Gas Open Burner Range Top
- Electric Induction Range Top

Figure 3: Electric Resistance Ceramic Range Top

Figure 4: Electric Resistance Coil Range Top

Figure 5: Gas Open Burner Range Top

Figure 6: Electric Induction Range Top

Technology Description

Cooktop technology can be described in terms of respective modes of heat transfer. Identifying the distinct physics of each cooktop technology and the method in which they transfer heat to cookware is the best way to characterize the inherent benefits and drawbacks of each mode. It is industry standard to use the terms “burner” and “element” to describe the heat transfer technologies on gas and electric range tops respectively, with the term “hob” used generically to describe burners or elements on either range top type.

Gas Cooktops:

Heat is transferred to the cookware by an open flame, fueled by an air-gas mixture. The flame transfers its energy by convection and radiant heat through the heated circulating air surrounding the cookware. The main objective of gas/flame cooking is to transfer the maximum amount of energy generated by the gas combustion into the cooking vessel. This is done by maximizing the space for the flame to heat up the pan while minimizing the surface area of the metal grates holding the pan. Some heat is transferred from the grates to the cookware through conduction but, this is insignificant compared to the heat transferred by the convection and radiation from the direct flame. Even though a pot or pan is directly receiving energy from the open flame, this does not mean that energy is being effectively transferred into the food product. As test results have demonstrated, most energy is diverted around the bottom of the pan and ends up as waste heat in the surrounding space.

Electric Resistance Cooktops:

Electric resistance coils became the first commercially popular electric cooktops due to their simple and reasonably inexpensive design. While the physics behind the heating element is typically the same across this cooktop technology, there are some design differences. All resistance heating elements generate their heat by running an electric current through a metal wire with high resistance and thermal conductive properties. When heated, the wire becomes red-hot and emits a great deal of thermal radiation. This material is often thin nichrome wire and therefore must be protected from repeated use and abrasion. Two protective solutions are represented by the two types of resistance electric cooktops tested:

- **For electric resistance coil cooktops,** a common solution consists of encasing the heating element with a metal or ceramic sleeve. All the thermal radiation generated by the heating element is transferred into the metal/ceramic sleeve. The heat is then transferred into the cookware by conduction. Most modern heating coils are designed to maximize the amount of material in contact with the cooking surface by flattening the sleeves and minimizing space between windings; however, imperfections in the coils and the bottoms of the cookware can decrease the efficiency of the conductive heat transfer.

- **For electric resistance infrared cooktops,** a solution for protecting the heating element is to encase it beneath a glass-ceramic top. There are performance benefits and drawbacks to utilizing glass as a heat transfer medium. Glass offers high emissivity but low conductivity. The glass-ceramic top is excellent for allowing thermal radiation to pass through due to its high emissivity. Most of the energy transferred to the cookware comes from thermal radiation emitted from the heating element located beneath the glass. Glass is not a good conductor, so less energy is transferred to the cookware through conduction. However, since the glass-ceramic surface is one continuous piece, the low thermal conductivity has the advantage of maintaining the heat within the localized cooking surface over the heating element. This provides some degree of thermal isolation around an element - allowing a cooking zone over an element that is set on a high temperature to have minimal thermal impact on the other cooking zones of the range top.

Electric Induction Cooktops:

Induction heating is the most efficient means of transferring heat from the cooktop to the cookware. Close to 90% of the energy consumed by the induction hob is transferred into the cooking vessel. Induction heating is accomplished by allowing a high frequency alternating current to flow through a tightly wound coil of wire, generating a rapidly changing magnetic field at the surface of the cooktop. When a pot or pan containing ferrous (magnetic) material is placed on the surface of the cooktop, the magnetic field induces an "eddy current" in the material, causing heat to be generated directly in the bottom and sides of the cookware. Non-magnetic materials are not affected by the presence of the magnetic field so, nearly all the energy is transferred directly into the cookware. The surface material for an induction cooktop is typically glass-ceramic.

Equipment Description

Researchers conducted energy and performance testing on six (6) different residential cooktops (three induction, two resistance, and one gas). Below are the cooktop specifications:

Frigidaire FGIF3036TF - Electric Induction Cooktop

- Number of Elements: 4
- Cooktop Controls: Digital Button 1-9 (and power boost)
- Oven Type: Convection
- Tested Elements*: 9.4″ 3.6 kW; 7.0″ 2.8 kW
- Retail Price: $1,199

*Maximum Input Rate (kW) in power boost mode

GE Profile PHS930SL2SS - Electric Induction Cooktop

- Number of Elements: 4+1 warmer
- Cooktop Controls: Digital Touchpad 0-100% (5% Increments)
- Oven Type: Convection
- Tested Elements*: 11.0″ 3.7 kW; 8.0″ 2.5 kW
- Retail Price: $2,399

*Maximum Input Rate (kW)

Samsung NE58K9560WS - Electric Induction Cooktop

- Number of Elements: 4
- Cooktop Controls: Digital Rotary (Analogue Look)
- Oven Type: Dual-Fan Convection
- Tested Elements*: 11.0″ 3.3 kW; 7.0″ 1.8 kW
- Retail Price: $2,199

*Maximum Input Rate (kW) in power boost mode

Whirlpool WFE515S0ES1 - Electric Resistance Glass-Ceramic Top

- Number of Elements: 4
- Cooktop Controls: Rotary Dial 1-9
- Oven Type: Standard Non-Convection
- Tested Elements: 9.0″ 2.5 kW; 6.0″ 1.2 kW
- Retail Price: $579

Frigidaire FFEF3016USB - Electric Resistance Coil

- Number of Elements: 4
- Cooktop Controls: Rotary Dial 1-9
- Oven Type: Standard Non-Convection
- Tested Elements: 8.0″ 2.4 kW; 6.0″ 1.5 kW
- Retail Price: $579

Samsung NX58H5600SS – Gas Burner Range

- Number of Burners: 5
- Cooktop Controls: Analog rotary dials
- Oven Type: Convection
- Tested Burners: 3.8″ 17 kBtu/h; 2.9″ 9.5 kBtu
- Retail Price: $799

Cooktops were selected based on the most popular models on the market. The largest induction elements were rated at 2.3 kW and ranged between 3.0 kW and 3.7kW when operated in the power boost mode. The largest resistance cooktop elements were 2.5 kW and the largest gas burners ranged between 15 and 17 kBtu/h. Medium burners/elements were usually ½ to ¾ the input of the largest burners/elements and the smallest burners/elements were not tested because they were designed to be used for warming, not cooking. Cooktop prices depended on the cooktop heating methods, control features (e.g., analogue dials, Wi-Fi connectivity), and oven features (e.g., convection, multiple fans).

Results

Researchers used the following performance metrics while comparing the four cooktop categories:

- Heat-Up Time
- Temperature Response
- Energy Efficiency
- Simmer Energy Consumption
- Standby Energy Consumption

Heat-Up Time

Heat-up time is a function of cooktop power and efficiency – the more powerful and efficient the cooktop, the faster it will heat up a pot of water. A cooktop may have a high input-rate and low efficiency but heat up water just as fast as a low-input and high-efficiency range top. Two of the three induction cooktops include “power boost” modes, which increase the wattage to the element by up to 50% for a period of 10 minutes. The third induction cooktop operates in a default power boost mode and throttles down the wattage to the element as more elements are turned ON. All the induction cooktops were operated with their elements at the maximum or power-boost setting for the Heat-Up Time tests. Across the board, the induction cooktops (operated at the highest power setting) demonstrated faster heat-up times than both the electric resistance and gas models. Researchers conducted heat-up tests on the largest gas burner or hob/element of each cooktop using an 8-quart pot with 12-pounds of water as well as the medium burner or hob/element of each cooktop using a 3.5-qt pot with 5-lb of water. The test consisted of heating the water from 70°F to 200°F and the results are presented in Table 1 and Figures 7 and 8. The energy to heat up the pot is also included in the efficiency calculations.

Table 1: Cooktop Heat-Up Time Results

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Medium Hob Input Rate	2.8 kW	2.5 kW	2.3 kW	1.2 kW	1.5 kW	9.5 kBtu/h
Equivalent kBtu/h	9.5	8.5	7.8	4.0	5.1	9.5
5-lb water heat up time (min)	5.3	5.8	6.4	18.8	11.5	14.1
Efficiency	86.2%	86.8%	85.3%	70.3%	72.3%	30.6%
Large Hob Input Rate	3.6 kW	3.7 kW	3.3 kW	2.5 kW	2.4 kW	17 kBtu/h
Equivalent kBtu/h	12.3	12.6	11.3	8.5	8.2	17.0
12-lb water heat up time (min)	9.8	9.3	11.6	17.8	15.5	18.6
Efficiency	85.2%	86.1%	83.0%	75.5%	79.3%	31.9%
Production* Capacity (lb/h)	73.5	77.2	62.2	40.4	46.5	38.6

*calculated based on a single high-input element or burner heating 12 lb of water from 70 to 200°F in an 8 qt pot.

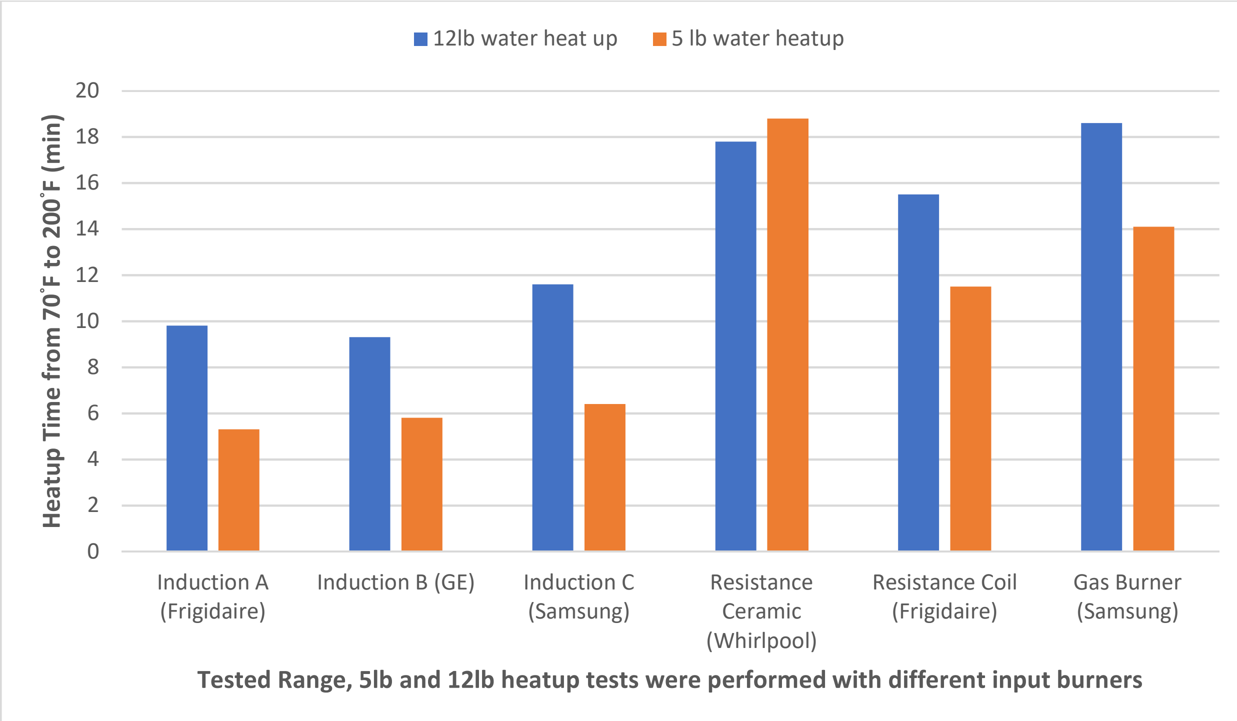
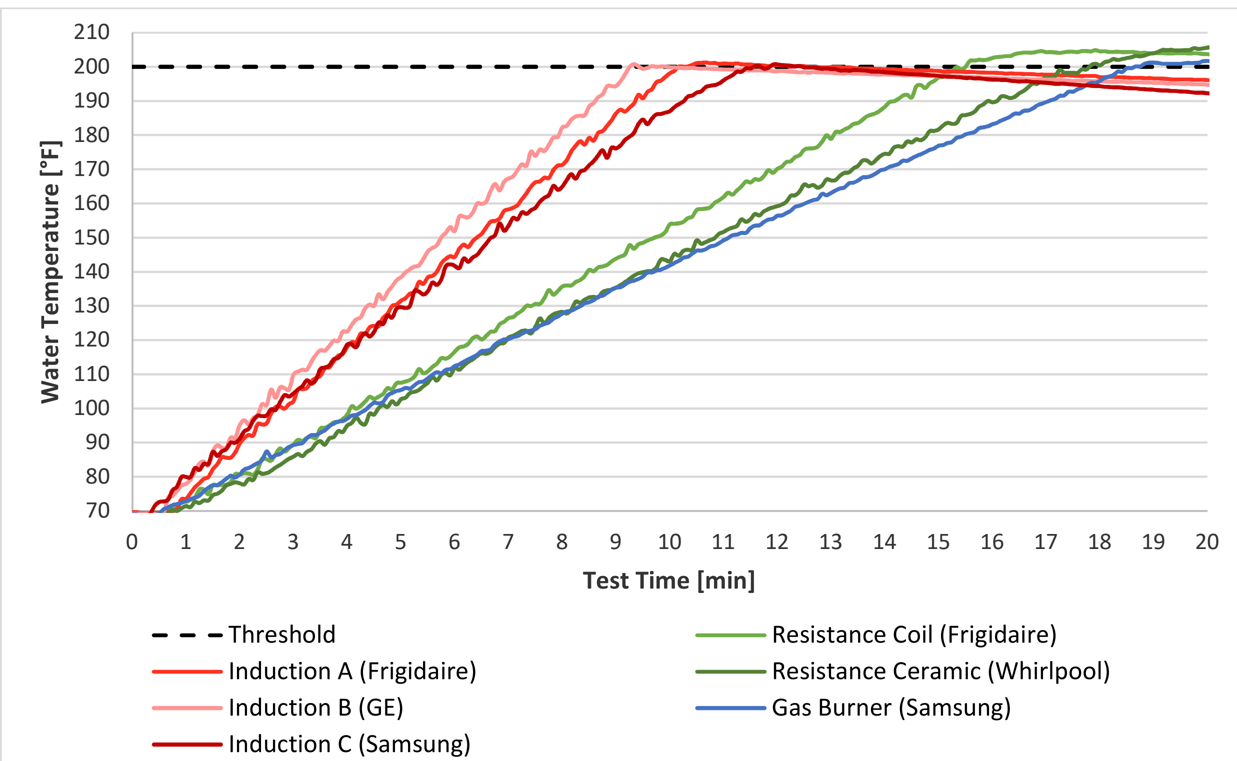


Figure 7: Water Heat-Up Times



*calculated based on a single high-input element or burner heating 12 lb of water from 70 to 200°F in an 8 qt pot

Figure 8: Water Heat-Up Rate Test Results

With water heat-up times averaging 10 minutes for the large 12-lb pot of water and efficiencies averaging 85%, the induction cooktops displayed the best heat-up performance among all tested cooktops. The induction cooktops had the highest hob input rate (averaging 3.5 kW in power boost mode) compared to the standard resistance cooktops, which average 2.5 kW for the largest elements.

The ability of the electronically controlled induction cooktops to boost the power to individual hobs is a feature that is not available on the cooktops with traditional resistance elements, which have a fixed maximum kW based on their physical resistance. This important feature allows a user to install a cooktop with increased cooking performance on the same sized electrical service as a standard electric resistance cooktop. The induction cooktop adjusts the kW input automatically to provide maximum cooking performance without exceeding the available electric supply.

Most residential gas cooktops list a maximum input rate in the 15-17 kBtu/h range. The 17 kBtu/h burner tested was one of the higher input burners on the market, yet it had heat-up times closer to the resistance cooktops and significantly slower than the induction cooktops. This can be explained by revisiting the physics of how gas burners interact with the pot. The gas burner is delivering 17,000 Btu/h of heat energy in the zone above the burner where the pot will sit. Some of this heat will hit the bottom of the pot and be absorbed by the metal and the liquid inside the pot, but most of the heat will move up the sides of the pot and radiate out into the surrounding space. The efficiency of the gas burner for the 12 pounds of water heat-up test was just 32%, meaning that the pot and contents received only 5,440 Btu/h of heat energy out of the input rate of 17,000 Btu/h; the rest was lost to the surrounding air. Comparatively, the largest element on the ceramic top electric range top has a rating of 2.5 kW, which is the equivalent of 8,500 Btu/h; at an efficiency of 75.5%, the burner can deliver the equivalent of 6,417 Btu/h to the pot and the liquid, thus finishing the test almost a minute faster than the gas burner. The induction hob, with an efficiency of 85%, can deliver the equivalent of over 10,000 Btu/h to the pot and the liquid, cutting the heat-up time in half. The Energy Efficiency section of this report includes a definition of energy efficiency as applied to the cooktop testing as well as a detailed explanation of the testing procedures. The effects of hob energy-efficiency on energy delivery are summarized in Table 2 below.

Table 2: Effect of Energy Efficiency on Energy Delivered – 12-lb Water Heat-up Test

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Large Hob Input Rate	3.6 kW	3.7 kW	3.3 kW	2.5 kW	2.4 kW	17 kBtu/h
Equivalent kBtu/h	12.3	12.6	11.3	8.5	8.2	17.0
Efficiency	85.20%	86.10%	83.00%	75.50%	79.30%	31.90%
Effective kBtu/h	10.5	10.8	9.4	6.4	6.5	5.4

Temperature Response

Temperature response is defined as the response time and sensitivity of a burner or element/hob to adjustment of the range top's controls. This could include how fast a burner or element/hob heats from cold start, how quickly it responds to a turn-down of the temperature setting, how much it overshoots the desired temperature endpoint, and how effectively it can hold a single temperature setpoint. While the Heat-Up Test is a good measure of the effective power and efficiency of a range top for heavier production, like boiling water for pasta, the Temperature Response is a measure of how well the operator can control and fine-tune the cooking process. Temperature response is important when cooking dishes that are sensitive to temperature fluctuations. This is most apparent when preparing delicate foods like melting or tempering chocolate, making a roux, or melting butter. The goal is to heat up the food item to a desired temperature without overheating and burning the contents. Good temperature response is also important when heating up a stock or gravy to a simmer without boiling.

Electric resistance cooktops are typically poor at temperature response. There is an initial temperature lag as the resistance coil, which has a relatively high thermal mass, comes up to temperature. There is an equally delayed response when the temperature setting is reduced during cooking, as the energy stored in the fully heated resistance coil dissipates slowly, causing the electric resistance element to continue heating the food long after the element is turned down or off. For this reason, many recipes call for removing the pot or pan off the element after bringing the food to the desired temperature. This is the biggest complaint against electric resistance cooktops when compared to gas cooktops, which deliver very good temperature response including fast heat up, quick temperature adjustment and minimal temperature overshoot.

Gas burners have infinite adjustability and immediately respond to changes in the burner controls. While the burner grates do create a thermal mass that can slow temperature response, this mass contains less thermal inertia than the electric resistance range tops, so the gas burners respond faster than resistance elements but not as fast as the induction hobs, which have even less thermal mass.

Induction cooktops offer the best temperature response of the three technologies. Induction cooktops deliver the heat directly into the cookware and do not add any additional heat to the surface of the cooktop. The lack of residual energy in the cooktop surface allows the unit to respond much more quickly to control changes while virtually eliminating temperature overshoot.

Also, because the induction controls vary the intensity of the magnetic field, similar to the way a gas range top's controls vary the intensity of the flame, the induction cooktop provides dynamic and precise control over the heat to the cooking unit. Gas range tops provide the ability to hold a very precise temperature, but the operator must constantly monitor the flame and fine-tune the burner to maintain the setpoint. An induction range top can also hold a very precise temperature by modulating the magnetic field around a proscribed setpoint but, unlike the gas burner, the operator does not have to constantly monitor and fine-tune the controls. Once set, the power input remains the same and the temperature delivered to the pot remains constant.

To demonstrate the temperature response of the different cooktops, researchers repeated the water heat-up tests, bringing a large 8-quart pot with 12-lb of water and a medium 3.5-quart pot with 5-lb of water to 200˚F, and then turning off the element/hob or burner and leaving the pots of water in place. Water temperature was measured for 40 minutes after turning off the HOB or burner to see how much residual heat was transferred to the water above the 200˚F end of test, defined as overshoot, and how fast the water cooled down to 190˚F. Satisfactory temperature response is characterized by a minimal temperature overshoot and faster cooldown time. This means that if you heat up a pot of stock to a desired temperature and turn off the element/hob or burner, the stock will not overheat above the desired temperature. Table 2 presents the temperature response results for the three different cooktop types.

Table 3: Cooktop Temperature Response Results

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Medium Pot 200°F Overshoot (°F)	1.4	0.0	0.4	7.4	8.5	1.3
Large Pot 200°F Overshoot (°F)	0.8	0.8	0.8	7.1	4.9	1.7
Medium Pot Cooldown to 190°F (min)	12.2	12.5	9.5	26.0	22.5	16.3
Large Pot Cooldown to 190°F (min)	18.8	20.6	18.8	38.1	26.5	23.9

Figures 9 and 10 compare the overshoot and response times of electric induction, resistance, and gas cooktops.

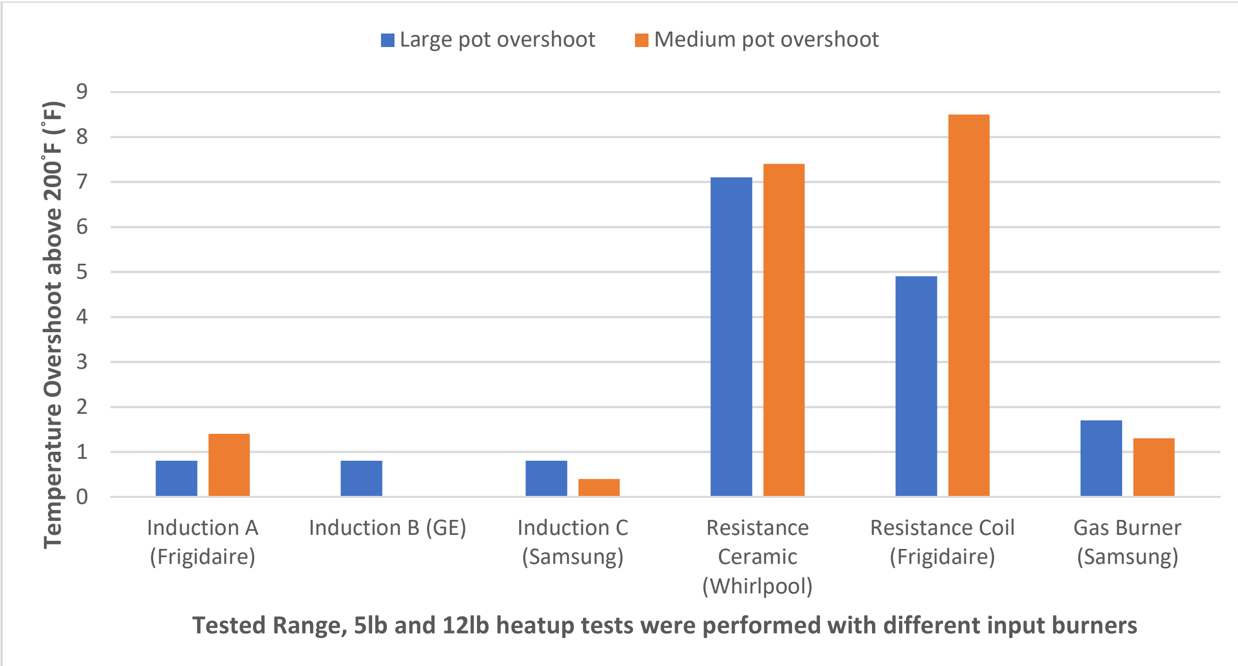
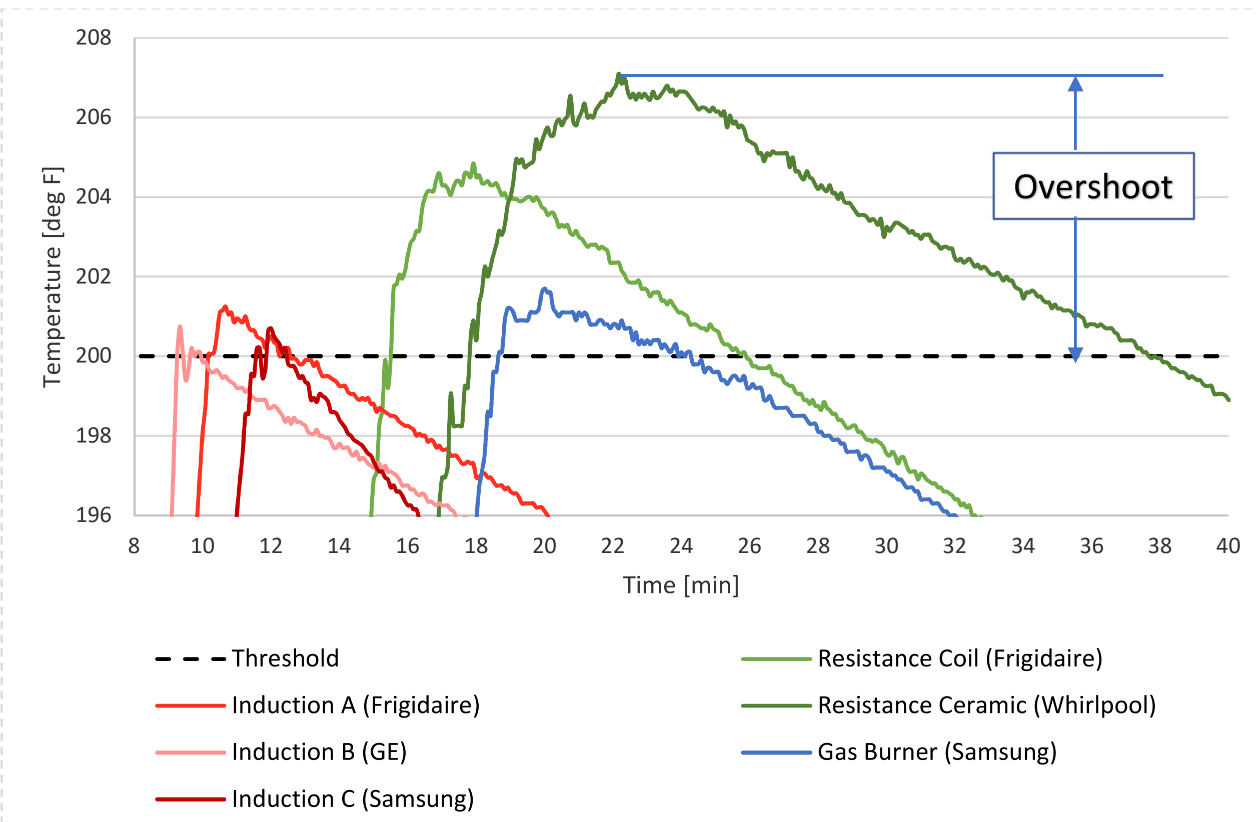


Figure 9: Cooktop Temperature Overshoot



*calculated based on a single high-input element or burner heating 12 lb of water from 70 to 200F in an 8 qt pot

Figure 10: Temperature Overshoot Results for 12-lb of Water

Overshoot is defined as the highest temperature recorded above the 200°F end-of-test water temperature, after the burner or element/hob is turned off. In summary, the induction cooktops had the lowest temperature overshoot and quickest cool down times, demonstrating the superior temperature performance of induction technology. The resistance ceramic and resistance coil elements, having the most thermal mass, demonstrate the greatest temperature overshoot and slowest response times. Gas falls somewhere in the middle, with a temperature overshoot comparable to induction and cool down times longer than induction but faster than electric resistance.

Energy Efficiency

Energy efficiency is defined as the ratio of energy into the food product versus the energy into the appliance. The higher the energy efficiency, the lower the thermal losses into the kitchen environment. Gas cooktops have the highest thermal losses because the gas flame heats up the air around the pot or pan, which in turn heats up the kitchen. Induction cooktops have the highest efficiency and the lowest thermal losses because they heat up the pot or pan directly and not the surrounding air. The heating elements in resistance electric cooktops have high thermal mass resulting in higher thermal losses into the cooktop itself, which heats the air indirectly.

Efficiency tests were conducted under two conditions: (1) a full input rate water heat-up test while heating up an 8-quart pot containing 12 pounds of water (previously described in the heat-up test section), and (2) a partial input rate test cooking a burger in a pan. These two tests are representative of how cooktops are used in a day-to-day home kitchen. The water heat-up test is used to determine the cooktop efficiency when preparing a pot of water for a stock, soup, pasta, or rice load. This test is conducted at maximum input. The burger test is representative of frying or sautéing a smaller dish. It is important to note that efficiency is maximized by increasing the amount of product to be heated; burger tests produce lower efficiency results because the 0.25-lb of beef product is a smaller thermal mass when compared to the 12-lb of water.

Researchers conducted the burger test with a frozen 80/20 burger patty cooked to 35% moisture loss, which provided a 165°F internal temperature (per ASTM F1275). Sauté cooking requires a lower input rate as to not burn the food product before the internal temperature reaches the target. Testers selected a power level to achieve a 350-400°F nominal pan temperature before placing the frozen burger in the pan. Frozen burger cook times for all cooktops ranged between 6.5 and 7.0 minutes. Pan preheat times for all cooktops ranged between 2 and 3.5 minutes depending on the power setting.

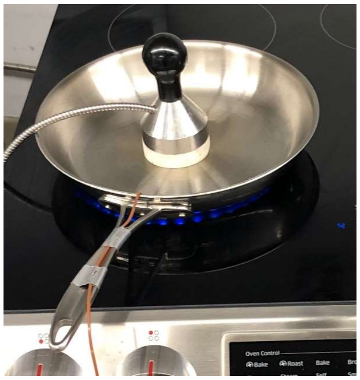


Figure 9: Preheating the pan and temperature verification

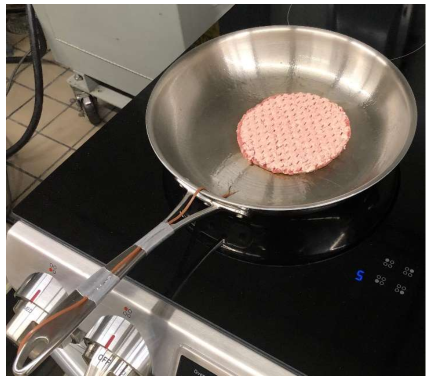


Figure 10: Frozen product placement in the pan

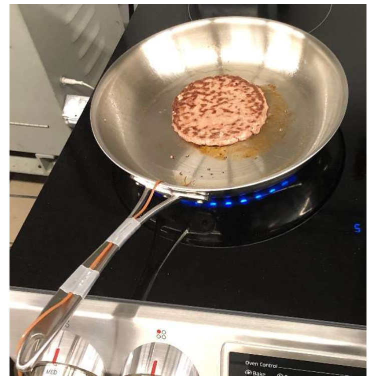


Figure 11: Product flip after 60% of elapsed time

Table 4: Energy Efficiency Results

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Max Burner/Hob Input Rate	3.6 kW	3.7 kW	3.3 kW	2.5 kW	2.4 kW	17 kBtu/h
Heat-Up Efficiency	85.2%	86.1%	83.0%	75.5%	79.3%	31.9%
Sauté Power Level Setting	6	55%	4	50%	70%	6
Sauté Time (min)	7.04	6.69	7.05	7.03	7.03	7.08
Sauté Input Rate	523 W	585 W	515 W	507 W	758 W	4.4 kBtu/h
Sauté Efficiency*	52.5%	47.8%	54.0%	54.8%	38.0%	22.8%

*Sauté efficiency was calculated according to ASTM F1275 which takes in account initial and final moisture content of the burger patty, specific heat of ground beef and energy for melting phase change of the burger heated from 0 to 165F. The test was conducted in triplicate.

Two induction cooktops (A and C) showed the highest sauté efficiency, but not markedly higher than the resistance glass-ceramic cooktop. Induction Cooktop B had a comparable efficiency at a 45% power level but had slower cook times. When testers increased the power to 55%, the cook times were more comparable to the other units, but the efficiency suffered slightly due to a higher sauté input rate. The resistance coil had a high heat-up efficiency, but its sauté efficiency was significantly lower due to a high input rate required to properly sear the burger. Thermal imaging also showed uneven temperature distribution in the pan for the resistance coil cooktop compared to gas and induction cooktops, which may have contributed to low sauté efficiency.

Figure 12: Resistance Coil Cooktop

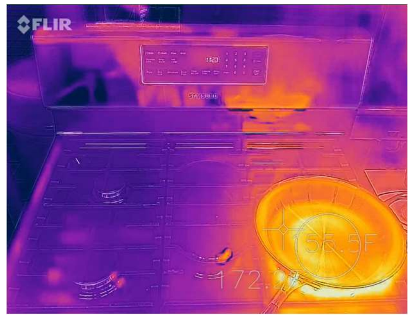


Figure 13: Gas Cooktop

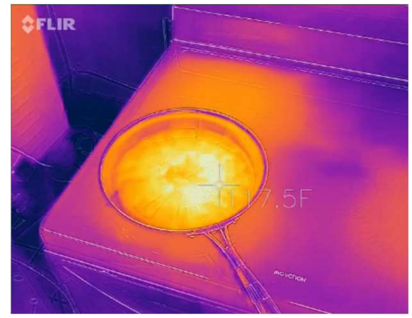


Figure 14: Induction Cooktop

Simmer Test

A common cooking practice is to bring a pot to a boil then reduce to a simmer for 15 minutes or more for pasta or rice, or up to 4 hours for complex stocks or soups. Simmer energy is a measurement of energy consumption that represents a typical application of a range top burner or element/hob and is useful for building an accurate energy-cost model of a range top. Simmer temperature is defined to be between 205-210°F without vigorous bubbling due to boiling. The Simmer Test results are summarized in Table 4. The simmer energy rate is similar across all three technologies because the pot and the water are already hot and have a considerable amount of thermal mass, meaning that it takes only about a third of the total burner/element energy input-rate to keep the contents at the target temperature.

Table 5: Simmer Energy Rate Results

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
12-lb Pot Simmer Energy Rate	952 W	910 W	1000 W	907 W	976 W	6,702 Btu/h
12-lb Pot Simmer Water Temp (°F)	208	209	205	208	209	209
5-lb Pot Simmer Energy Rate	557 W	745 W	518 W	546 W	594 W	3,046 Btu/h
5-lb Pot Simmer Water Temp (°F)	210	209	209	208	209	208

Standby Energy

One question with induction cooktops is the potential standby energy or ‘phantom load’ that could occur when all the hobs are off. Researchers conducted an overnight standby test with a high-resolution electric meter on the three induction cooktops. While the Frigidaire induction cooktop recorded no noticeable energy consumption, both the Samsung and GE induction cooktops recorded comparable standby energy consumptions between 3-6 watts. 6 watts standby energy over the course of a year amounts to 52.6 kWh, or $8.4/year at $0.16/kWh. One of the potential factors for this standby energy may be due to the additional technical features such as the LCD screen and Wi-Fi capabilities. After these tests, it cannot be accurately concluded that the higher standby energies are inherent to the induction technology itself.

Energy Cost Model

Components of the above energy tests were compiled into an energy model to estimate the amount of annual energy consumed for each type of cooktop. Below is a table of input assumptions for the energy model, which assumes a 12-lb pot of water heated for pasta per day then simmered for 15 minutes and two sauté cook loads conducted five days per week.

Table 6: Energy Model Assumptions

Days Cooking Per Week	5
Number of 12-lb pots boiled per day	1
12-lb pot simmer duration	15 minutes
Number of sauté dishes cooked per day	2
Days Cooking Per Year	260
Electric Energy Cost*	$0.16 / kWh
Gas Energy Cost	$1.56 / therm

*normalized average of SMUD 2019 Time-of-Use summer and winter rates, with assumption that summer cooking occurs on peak with weekly cooking during 3 weekdays and 2 weekend days.

These assumptions were applied to the six different cooktop models in the table below. To build a model that would include both the direct cost to operate the range top as well as the potential costs from the interaction with the residential heating and cooling system, the researchers estimated the heating and cooling loads that would be offset or increased by the waste heat from each range top type. A detailed explanation of the methodology is included in Appendix B. These estimates are for informational purposes only and are meant to present a general idea of the holistic costs for each range top type.

Table 7: Energy Model

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Heat-Up Energy Per Day	563 Wh	561 Wh	581 Wh	641 Wh	606 Wh	5,148 Btu
Simmer Energy Per Day	238 Wh	228 Wh	250 Wh	227 Wh	244 Wh	1,676 Btu
Sauté Energy Per Day	169 Wh	207 Wh	182 Wh	182 Wh	238 Wh	1,326 Btu

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Total Energy Per Day	970 Wh	996 Wh	1013 Wh	1050 Wh	1088 Wh	8,150 Btu
Total Energy Per Year	252 kWh	259 kWh	263 kWh	273 kWh	283 kWh	21.19 therms
Energy Cost Per Year	$40.55	$41.62	$42.35	$43.89	$45.48	$33.06
Annual Cooling Costs*	$4.62	$4.74	$4.82	$5.00	$5.18	$9.10
Annual Heating Savings*	$6.23	$6.39	$6.50	$6.74	$6.99	$12.27
Total Annual Costs	$38.94	$39.97	$40.66	$42.15	$43.68	$29.89

*see Appendix B for heating and cooling calculation methodologies

Conclusion

This residential range top study compared the performance of three different induction cooktops to traditional gas and electric cooktops. Induction technology offers precise control, focused heat, quick response and greater energy efficiency over the more traditional cooktop technologies. The clear advantage from induction is the level of precision and control over the amount of heat delivered to the pot or pan, which is a vast improvement over other electric cooking options.

The results mirror previous testing of commercial range tops at the Food Service Technology Center. The residential induction cooktops exhibited comparable heat-up efficiencies to commercial-grade induction cooktops, while providing comparably quick heat-up times to similarly rated commercial units. While the three induction cooktops exhibited close performance to each other, it should be noted that not all appliances are equal and a unit with lower input ratings may exhibit slower heat-up times.

The induction cooktops in these tests demonstrated superior heat-up times and temperature response when compared to both electric resistance and gas. The more direct power of the induction hobs provided significantly faster water heat-up times, nearly twice the speed of the gas and electric resistance cooktops. Temperature response was measured by looking at the overshoot and the cool-down times. Relative to the electric resistance cooktops, the induction cooktops on average exhibited an 84-89% improvement in overshoot and a 27-49% improvement in cool-down time. Relative to the gas cooktop, the induction cooktops on average exhibited a 53% improvement in overshoot and a 19% improvement in cool-down time.

The simmer and sauté tests represented other cooking operations. In these tests, all the range tops exhibited comparable performance. Simmer rates for all the electric cooktops tested were within 10% of one another. There was no noticeable trend between sauté efficiency results based on the single frozen hamburger test used for this study. Table 7 compares the final test results from the six cooktops and includes the energy cost analysis presented earlier.

Table 8: Results Summary

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Large Hob Input Rate	3.6 kW	3.7 kW	3.3 kW	2.5 kW	2.4 kW	17 kBtu/h
12-lb water heat up time (min)	9.8	9.3	11.6	17.8	15.5	18.6
Heat-Up Efficiency	85.2%	86.1%	83.0%	75.5%	79.3%	31.9%
Production Capacity (lb/h)	73.5	77.2	62.2	40.4	46.5	38.6
Large Pot 200°F Overshoot (°F)	0.8	0.8	0.8	7.1	4.9	1.7
Large Pot Cooldown to 190°F (min)	18.8	20.6	18.8	38.1	26.5	23.9
Sauté Input Rate	523 W	585 W	515 W	507 W	758 W	4.4 kBtu/h
Sauté Efficiency	52.5%	47.8%	54.0%	54.8%	38.0%	22.8%
12-lb Pot Simmer Energy Rate	952 W	910 W	1000 W	907 W	976 W	6,702 Btu/h
Estimated Energy Cost Per Year	$40.55	$41.62	$42.35	$43.89	$45.48	$33.06

Although the energy cost to run a gas cooktop in California is currently lower than an induction cooktop, the air conditioning cost impact of gas cooktop cooking is higher due to a higher heat load to space. This waste heat has a benefit during the cooler months and the gas cooktop offered heating savings that somewhat mitigated the increased cooling costs during the warmer months. This analysis does not, however, address comfort impacts due to the kitchen being warmer than other rooms of the house.

The appeal of residential induction cooktops lies in the superior temperature response, ease of cleaning, and increased safety associated with cooler surfaces. As customer demand for induction technology continues to rise with more information dissemination, hands-on demonstration, and commissioned test studies, production costs will decrease with increased production volume, further increasing the technology adoption rates.

Appendix A: Test Method

1. Install cooktop according to manufacturer's specifications
2. Take appliance setup pictures:
    a. Whole cooktop/oven for report
    b. Controls
    c. Nameplate
    d. Cooktop top (all burners or elements)
    e. Zoomed out picture including test computer and electric meter
    f. Pot #1, #2, and Pan on cooktop top burners/elements
    g. Top surface temperature measurement location (induction and resistance only see 5f)
3. Document cooktop burner input rates per manufacturer's documentation for each burner
4. Use the same cookware set for all cooktops tested
    a. Pot #1 – Large 10-qt pot with lid; 12-lb of water
    b. Pot #2 – Medium 4-qt pot with lid; 5-lb of water
    c. Pan – Medium 10" top diameter; ¼-lb, 80/20 frozen hamburger
5. Attach thermocouples to each cooking vessel:
    a. Pot #1:
        i. Geometric center 1" from the bottom
        ii. Geometric center 1" submerged in liquid from the top lid
    b. Pot #2:
        i. Geometric center 1" from the bottom
        ii. Geometric center 1" submerged in liquid from the top lid
    c. Pan:
        i. Welded to cooking surface, 1" from handle joint, not to interfere with hamburger cooking
        ii. An additional, removable temperature probe or puck should be used in order to verify pan pre-heat temperature for center of cooking pan.
    d. Freezer:
        i. Monitor temperature for the last hour of burger holding with a thermocouple logger and a thermocouple inside the burger box
    e. Final Burger:
        i. Use multi-surface probe at the end of the hamburger cooking cycle to verify final temperature is 165 ± 5˚F.
6. Verify the test voltage at full burner input is within 5% of specification
7. Verify the tested input rate is within 5% of specification during water heat-up test
8. Water heat-up test is conducted with specified amount of water in section 4 for two pot sizes.
    a. Initial water temperature 70 ± 2˚F
    b. Record pot weight and material
    c. Initial burner/element/hob temperature 70 ± 2˚F
    d. Burner input rate set to maximum at initiation of test
    e. Final water temperature 200˚F per data acquisition system
    f. Conducted as a single replicate
    g. Record temperature, time, energy and voltage
    h. Leads to cool down test
9. Simmer test conducted with specified amount of water in section 4 for two pot sizes.

a. Achieve 212 ± 2˚F
b. Set burner input level to maintain simmer
c. Record temperature, time, energy and voltage during simmer for 15 minutes
d. Verify simmer conditions are steady throughout the 15-minute test
e. Adjust input rate and repeat if 9d not met

10. Sauté test conducted with a pan and product specified in section 4c
    a. Use frozen product stabilized in a 0 ± 5˚F environment for at least 12 hours, do not have product out of freezer for more than 1 minute prior to cooking
    b. Record pan weight and material
    c. Record initial food product weight using a high-resolution scale
    d. Preheat pan to 375˚F per temperature probe listed in 5cii
    e. Record temperature, time and energy to preheat pan
    f. Place frozen hamburger patty in the hot pan
    g. After 60% of elapsed time, flip the patty with a spatula
    h. Remove patty when conditions in 5e are met
    i. Stop recording temperature, time and energy to cook burger
    j. Record final product weight using a high-resolution scale
    k. Verify cooked weight loss was 35±2% and 165 ± 5˚F, repeat if needed
    l. Conduct the test 3 times
11. Surface top cool down test
    a. At the end of the Pot #2 water heat-up test 8d turn off burner or heating elements at 200˚F
    b. Leave the pot on the element or burner and monitor time and temperature to cool down the water to 190˚F.
    c. Record maximum temperature (overshoot over 200˚F) during cool down test.

Appendix B: Ventilation Requirements and Ambient Heat Impacts

The energy consumed by a residential cooktop is converted to heat to cook food. The energy is then released to the kitchen as heat through the food or as waste heat from the heat source (e.g., gas burner, electric element, or the cooktop itself). Most residential ventilation hoods recirculate the cooking effluent and heat generated by cooking on a cooktop. Where commercial kitchens hoods are required to vent to the outside, very few residential installations vent to the outside.

The higher the cooktop cooking energy efficiency, the less energy is required to cook the food, therefore generating less wasted heat to the space. The less heat wasted into the space, the less air conditioning energy required to cool the space down to maintain the thermostat setpoint. The energy consumed by the cooktop can be directly related to the amount of cooling required to offset the heat generated by the cooktop.

It is estimated that air conditioning is required in Sacramento from May 17th through September 18th. All cooktop cooking during this period is performed when the air conditioning is on. If cooktop cooking is conducted 5 out of 7 days per week, there are 89 days when cooktop cooking is done with the AC on. If the residential AC system Coefficient of Performance (COP) is 3.0 and 80% of all the gas burner energy is turned into heat, the heat generated by the gas cooktop has twice the impact on the air conditioning load than the induction or resistance cooktops.

Ventilation cost assumptions are shown in Table 8 and the results summary is shown in Table 9.

Table 9: Ventilation Assumptions

AC months per year*	May 17th - Sept 18th
AC months per year	5
AC days per year	125
Cooking days per week	5 / 7
AC cooking days per year	89
AC system coefficient of performance (COP)	3.0
Hours cooking per day	1
Gas Combustion Efficiency	80%
Electricity Cost $ / kWh	0.16

*estimated on 2020 weather forecast provided by SMUD

Table 10: Ventilation Cost Estimations

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Total Energy Per Day*	970 Wh	996 Wh	1013 Wh	1050 Wh	1088 Wh	8,150 Btu
Heat Generated Per Day (Btu)	3,310	3,397	3,456	3,583	3,712	6,520
Annual Cooling Load (Btu)	295,504	303,302	308,603	319,875	331,451	582,143
Cooling Load input (Btu)	98,501	101,101	102,868	106,625	110,484	194,048
Cooling Load input (kWh)	28.87	29.63	30.15	31.25	32.38	56.87
Annual Cooling Costs	$4.62	$4.74	$4.82	$5.00	$5.18	$9.10

*Details shown in Table 8

Just as the cooktops contribute to air conditioning costs in the summer, the heat given off by cooktops during the winter saves on heating costs. Weather forecast data provided by SMUD for 2020 showed an estimated 152 of heating days from November 1st through March 31st which would include 109 heated cooking days. Assuming gas heating combustion efficiencies of 80%, the gas heating savings generated by the range tops would exceed the annual cooling penalties, the combined heating and cooling results are shown in table 9.

The ventilation and filtration of the cooking byproducts in residential hoods is inefficient and may lead to poor indoor air quality. The byproducts of cooking can be very small respirable particles along with grease, vapor, and other gasses. Flue products from gas burners introduce additional gasses. Direct venting the hood to the outside can mitigate most of the air quality problems.

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