# Condeco Residential Conduction Cooktop Performance and Energy Comparison Study

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## Revision History

| Revision num. | Date | Description | Author(s) |
|---|---|---|---|
| 0 | Jan 2020 | Initial Release | E. Ruan |

## Contents

## Figures



## Tables

## Introduction

The California Energy Commission (CEC) has funded a comprehensive commercial kitchen plug load equipment study designed to assess the energy load and energy reduction potential of unventilated commercial plug load foodservice equipment. The goals of this project are to quantify the energy use of the various types of plug load equipment and characterize the energy savings potential, cost effectiveness, and improved cooking performance of energy-efficient plug load equipment compared to baseline equivalents. By demonstrating energy savings potential using innovative energy-efficient appliance technologies, the data from this project will be used to accelerate the adoption of advanced energy-efficient cooking equipment within the commercial foodservice (CFS) industry.

As a component of the study, Frontier Energy has characterized the performance and energy use of the new Condeco electric conduction cooktop in a controlled laboratory environment. The cooktop's energy saving features include smart controls that adjust input rate based on temperature sensor feedback, insulation that captures and directs heat energy for minimal losses, and durable, precisely flat surfaces for maximum heat transfer efficiency. The conduction cooktop was tested in conjunction with a residential induction range, representative of the most energy-efficient option currently available in residential kitchens.

## Testing Approach

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

- *Heat-Up* – The time and energy required to bring 5-lb of 70°F water to 200°F. This test is used to evaluate both the production capability and energy efficiency of the cooktop.

- *Simmer* – Once the water is boiling, the energy required to maintain a pot of water at a simmer. This test is used to measure energy consumption under regular cooking conditions.

- *Sauté* – The energy and time required to pan-cook a typical food product. This test also evaluates both the production capability and energy efficiency of the cooktop.

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. These tests mirrored prior testing done as part of the *Residential Cooktop Performance and Energy Comparison Study* conducted in July 2019. A summary of the test methodology is provided in Appendix A.

## 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.

## Conduction Cooktop Prototype

The heat source for the conduction cooking system is a thick metallic film layer (silver / palladium) applied to the back of a ceramic silicon nitride hotplate, which serves as an ohmic resistor. An 18 mm thick insulation plate directs the heat through the ceramic hotplate to the paired conduction cookware via conduction. Both the ceramic hotplate and the bottom of the cookware are made of high-quality ceramic material engineered to be precisely flat to maximize contact and heat transfer efficiency.

Beyond the precision engineered flat bottom, the paired cookware also features double walls on both the sides and the lid to minimize heat loss to ambient air. The conduction cooktop also features temperature feedback and programmable features to increase ease of use and maximize energy savings. The featured electronic controls give users the ability to precisely set and maintain a certain temperature. When the sensors read the proper temperature, the unit will cease heating functions until the temperature begins to drop. Maximum temperature is set at 175°C (347°F) for health and safety reasons.

*Figure 1: Condeco Electric Conduction Cooktop*

*Figure 2: Double-Walled Conduction Cookware*

## Induction Cooktops

Electric induction ranges are gaining traction in the residential appliance market and have proven to be more efficient than standard electric resistance coil ranges. Induction heating is accomplished by a high-frequency alternating current flowing through a tightly wound coil of wire, generating a rapidly changing magnetic field on 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, therefore nearly all heat energy is transferred directly into the cookware. The surface material for an induction cooktop is typically glass-ceramic. The specific induction unit used for comparison with the conduction cooktop prototype featured digital rotary controls and a seven-inch diameter cooking surface.

## Results

Frontier Energy researchers used the following performance metrics to compare the two cooktop categories under test:

- Heat-Up Time and Efficiency
- Simmer Energy Consumption
- Sauté Energy Efficiency

### Heat-Up Test

Heat-up time is a function of both 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. Both the conduction and induction cooktops were heated using their maximum settings, resulting in quicker heat-up times for the induction cooktops. Across two tests, the induction cooktop brought 5 pounds of water from 70°F to 200°F in 6.54 minutes while operating at a 2.2 kW rate. The induction cookware used for testing weighed 3.32 lb. The conduction cooktop took a minute and a half longer, bringing the water to 200°F in just under eight minutes while operating at a 1.8 kW rate. The conduction cookware used for testing weighed 4.87 lb. Though the conduction cooktop boiled water at a slower rate due to its lower power, it did so more efficiently – more of the electrical energy used by the cooktop went into the water as heat energy. The conduction pot was also heavier (4.9 lb) than the induction pot (3.3 lb) and thus had a greater thermal mass, contributing to the slower heat-up time. The results from the heat-up tests are presented in Table 1.

*Table 1: Cooktop Heat-Up Time Results*

| | Conduction | Induction |
|---|---|---|
| Heat-Up Time (min) | 7.96 | 6.54 |
| Heat-Up Rate (°F/min) | 16.5 | 20.0 |
| Heat-Up Energy (Wh) | 236.8 | 243.8 |
| Input Rate (W) | 1,791 | 2,236 |
| Heat-Up Efficiency (%) | 90.5 | 84.8 |

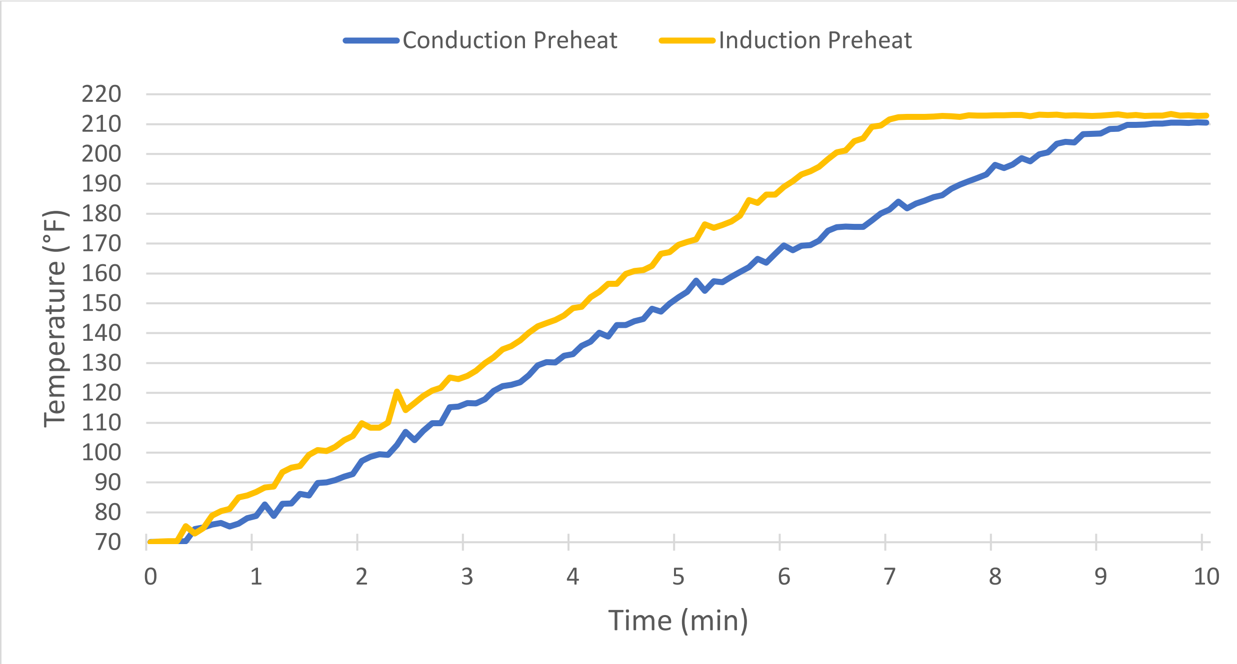


*Figure 3: Conducton vs. Induction Cooktop Water Heat-Up Test Results*

## Simmer Test

A common cooking practice is to bring a pot to a boil using maximum input then reduce the input to maintain a simmer, or low boil. This test was designed to compare the energy required to maintain five pounds of water in a just boiling state inside a covered pot. This simmer state would be verified using a visual indication of bubbling to mirror residential cooking practices. For the conduction cooking system, this test was performed by setting the temperature to 100°C (212°F), which the system then maintained through its smart controls. The cookware used for testing was the double-walled conduction pot with a simmer surface diameter of 8 inches. For the induction range, the test was conducted using different knob settings to mirror possible residential cook settings and determine the minimum setting that provided the boiling desired. The cookware used for testing was an induction pot with a simmer surface diameter of 7.25 inches. Researchers also measured the temperatures of both the pot exterior and lid during these tests to determine the effect of the conduction cookware's double-walled construction on kitchen safety.

Researchers tested the induction range in four different modes deemed most likely to be used for simmering purposes. The "Simmer" setting was too weak to produce any bubbles. Bubbles were first detected using the 4$^{th}$ setting, which was able to maintain the boiling state. However, the "Medium" setting is the most clearly marked on the unit and thus is most likely to represent the common user's default lower boil setting. The 6$^{th}$ setting was excessively strong and would be unlikely to be used for simmering purposes.


*Figure 4: Conduction Simmering Setpoint*


*Figure 5: Knob Controls on the Induction Range*

*Table 2: Induction Range 5-lb Pot Simmer Test Energy Rate Results*

| Setting | Simmer (2nd Setting) | 4th Setting | Medium (5th Setting) | 6th Setting |
|---|---|---|---|---|
| Energy Rate (W) | 105 | 450 | 683 | 885 |
| Water Temp (°F) | 205.4 | 212.2 | 213.1 | 213.0 |
| External Pot Temp (°F) | 201.7 | 209.0 | 209.9 | 209.7 |
| Pot Lid Temp (°F) | 193.7 | 205.5 | 207.7 | 207.8 |

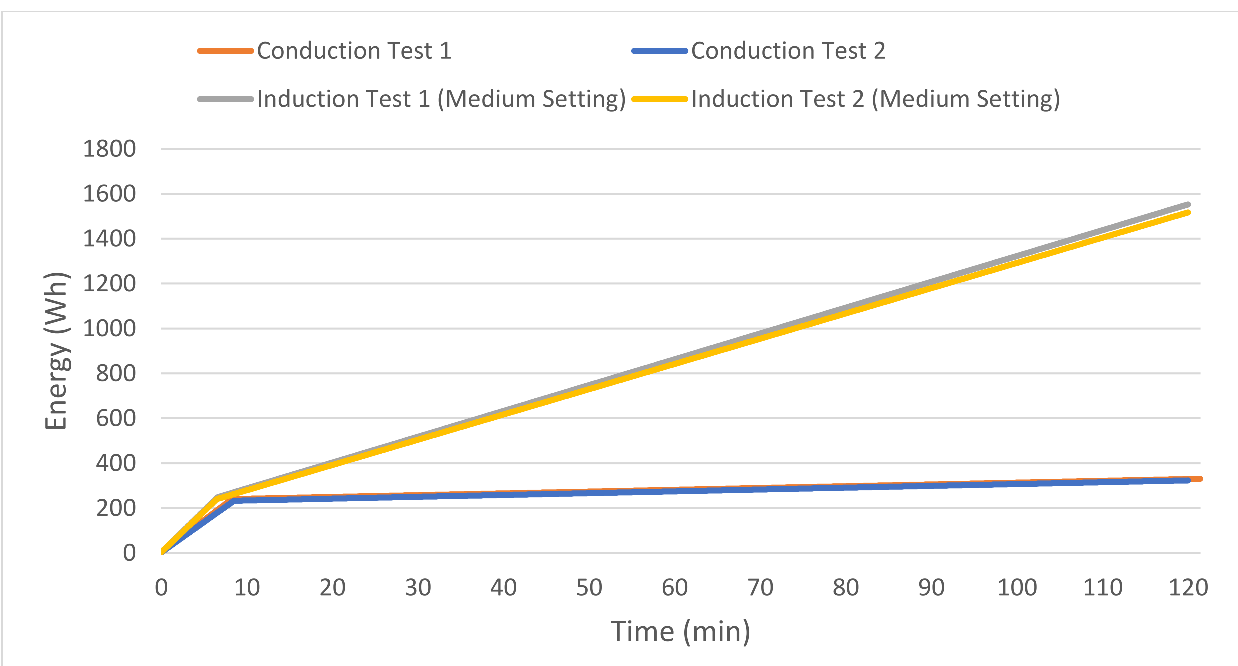


*Figure 6: Energy Consumption Over Time of Conduction vs Induction (at Medium Setting) during Simmer Test*

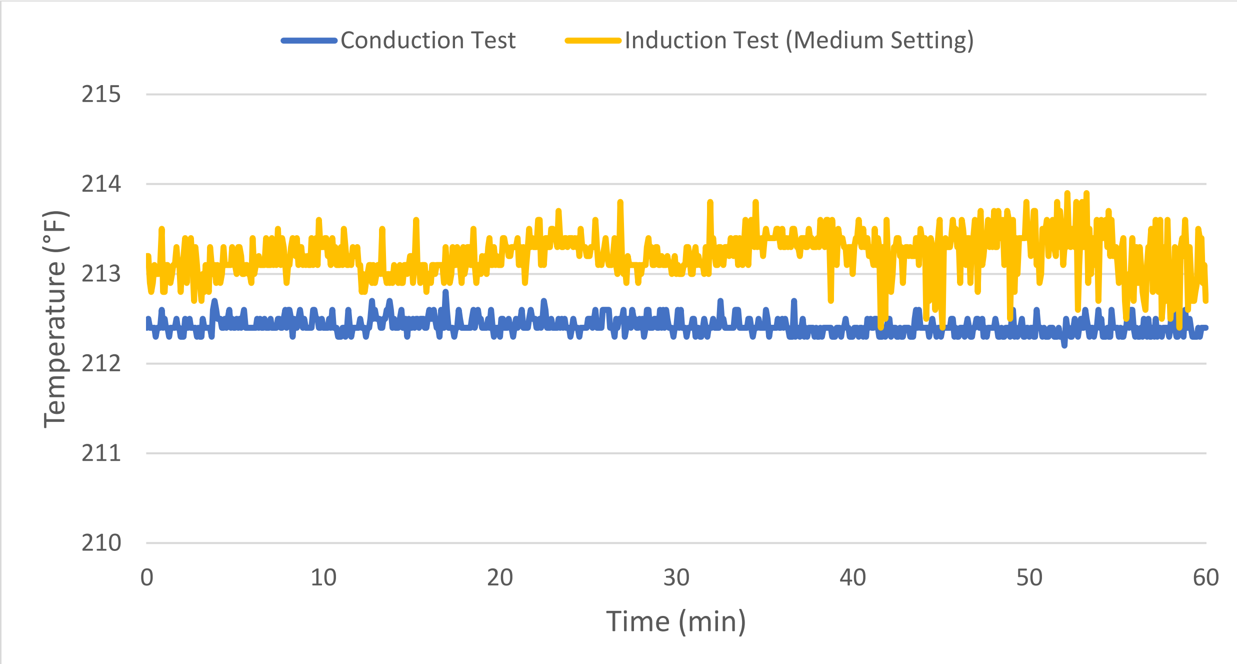


*Figure 7: Temperature Profiles of Conduction vs. Induction (at Medium Setting) during Simmer Test*

The conduction unit maintained the simmering state using an idle rate significantly lower than any of the tested induction range settings including the "Simmer" setting that was unable to maintain the desired boiling state. When used in conjunction with the specialized conduction cookware, the conduction unit used 89% less energy than the induction range's 4$^{th}$ setting and 93% less energy than the induction range's "Medium" setting. The simmer duty cycle, defined as the ratio of simmer energy to the total maximum input energy was very low. Given this sizable difference, researchers also tested the conduction cooking unit using the same pot used to perform the induction test, to determine whether the energy savings were due to the conduction cooktop or the specialized insulated cookware. The results indicated that the energy savings was due to both the cooktop and the cookware.

Testing the induction pot on the conduction cooktop required researchers to increase the setpoint on the conduction cooktop from 100°C (212°F) to 120°C (248°F) to maintain the simmer state within the pot. The conduction cooktop prototype controls were calibrated to match with the specific pot provided for testing, and the weaker surface contact with the induction pot meant that the 100°C (212°F) could no longer generate a 100°C (212°F) temperature within the pot. This doubled the simmering energy rate from 48.5W to 98W, which was still significantly below the input rates of the induction range's 4$^{th}$ or "Medium" settings. The input rate was still even below the "Simmer" setting on the induction range, which was unable to maintain the boil state when tested with the same induction pot. Thus, while the conduction cooking system benefits most substantially when paired specifically with the conduction cookware (because of the matching flat surfaces and added insulation), the conduction cooktop itself still offers an energy benefit in comparison to the induction range. However, the time required to boil the water in the induction pot on the conduction cooktop was much longer than with the paired conduction pot. For practical application, it is not recommended that the conduction cooktop be used with anything other than the corresponding cookware.

*Table 3: Condeco Conduction Range 5-lb Pot Simmer Test Energy Rate Results*

| | Conduction Pot | Induction Pot |
|---|---|---|
| Energy Rate (W) | 49 | 98 |
| Simmer Duty Cycle | 1.9% | 3.8% |
| Water Temp (°F) | 212.2 | 210.8 |
| External Pot Temp (°F) | 178.8 | 205.6 |
| Pot Lid Temp (°F) | 139.3 | 200.1 |

## Sauté Cooking Energy Efficiency

Cooking 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. Efficiency tests were conducted by determining the time and energy required to properly cook a burger, which is representative of pan frying or sautéing. 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, which was the 4th setting for the induction range and 175°C (348°F) for the conduction cooktop. The conduction test was conducted with the paired test pot that weighed 4.9 lb to deliver heat more quickly and maintain more precise temperature control of the product. The induction test was conducted using a pan that weighed 2.0 lb. Researchers attempted to conduct a cook test on the conduction unit with same pan as the induction unit for comparative purposes, but the heat-up and cooking were too slow for practical usage – the conduction unit can only be properly used with the paired conduction cookware. The table below shows conduction pot and induction pan heat up times and energies prior to and during cooking.

*Figure 8: Conduction Burger Cooking*

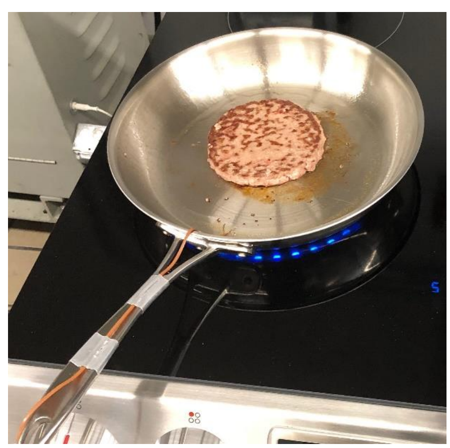

*Figure 9: Induction Burger Cooking*

*Table 4: Sauté Cooking Energy Efficiency Test Results*

| | Condeco Conduction Cooking System | Induction Range |
|---|---|---|
| Setpoint | 175°C (348°F) | $4^{th}$ Setting |
| Heat Up Time (min) | 1.33 | 2.44 |
| Heat Up Energy (Wh) | 45 | 30 |
| Sauté Time (min) | 9.17 | 7.05 |
| Sauté Energy (Wh) | 38 | 61 |
| Sauté Input Rate | 245 W | 515 W |
| Sauté Duty Cycle | 9.6% | 22.3% |
| Sauté Efficiency* | 92.7% | 54.0% |

*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 165°F. Sauté efficiency does not account for pan heat up energy.

The conduction cooking system took about two minutes longer than the induction range to cook the product to the required specifications but did so while operating at less than half the electric input rate and a significantly higher efficiency. Like the heat-up test, the sauté test indicated that the conduction cooking system may perform more slowly than induction due to the functions of the smart control algorithms, which were designed to prevent the burning of food product for health purposes. Like the simmer tests, however, the sauté test also reinforces that the heating done through the conduction cooking system is significantly more efficient. The conduction cookware also requires more energy to heat up before cooking though because of its higher thermal mass – this may be reduced once specific cookware for sautéing is developed. Since the heat is transferred directly from the plate, there is also the possibility for food to be cooked directly on the cooktop surface in future iterations of the conduction cooktop. This would theoretically make the cooktop more efficient, lowering the heat up energy to around 12 Wh. However, the specific energy implications of direct grilling could not be evaluated given the unsealed structure of the prototype.

## Energy Cost Model

Frontier Energy aggregated the test data to create an energy cost model, estimating and comparing the expected annual energy cost of residential conduction and induction units for an average household. Below is a table of input assumptions for the energy model derived from the cooking usage findings in The Lawrence Berkeley National Laboratory (LBNL) study *Cooking Appliance Use in California Homes* and closely mirroring the previous Frontier Energy study *Residential Cooktop Performance and Energy Comparison Study.* The average household is assumed to use their range five days a week, cooking two sauté dishes and boiling one five-pound pot of water (followed by 15 minutes of simmering) per day of use.

*Table 5: Energy Model Assumptions*

| | |
|---|---|
| Days Cooking Per Week | 5 |
| Number of 5-lb pots boiled per day | 1 |
| 5-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* |

*average cost of electricity in California

*Table 6: Energy Model Calculations*

| Cooktop | Conduction Cooking System | Induction Range* |
|---|---|---|
| Boil Energy Per Day (Wh) | 236 | 244 |
| Simmer Energy Per Day (Wh) | 12 | 171 |
| Sauté Energy Per Day (Wh) | 165 | 182 |
| Total Energy Per Day (Wh) | 413 | 597 |
| Total Energy Per Year (kWh) | 107 | 155 |
| Energy Cost Per Year ($)* | $17.26 | $24.95 |

*using $0.16/kWh average cost of electricity in California

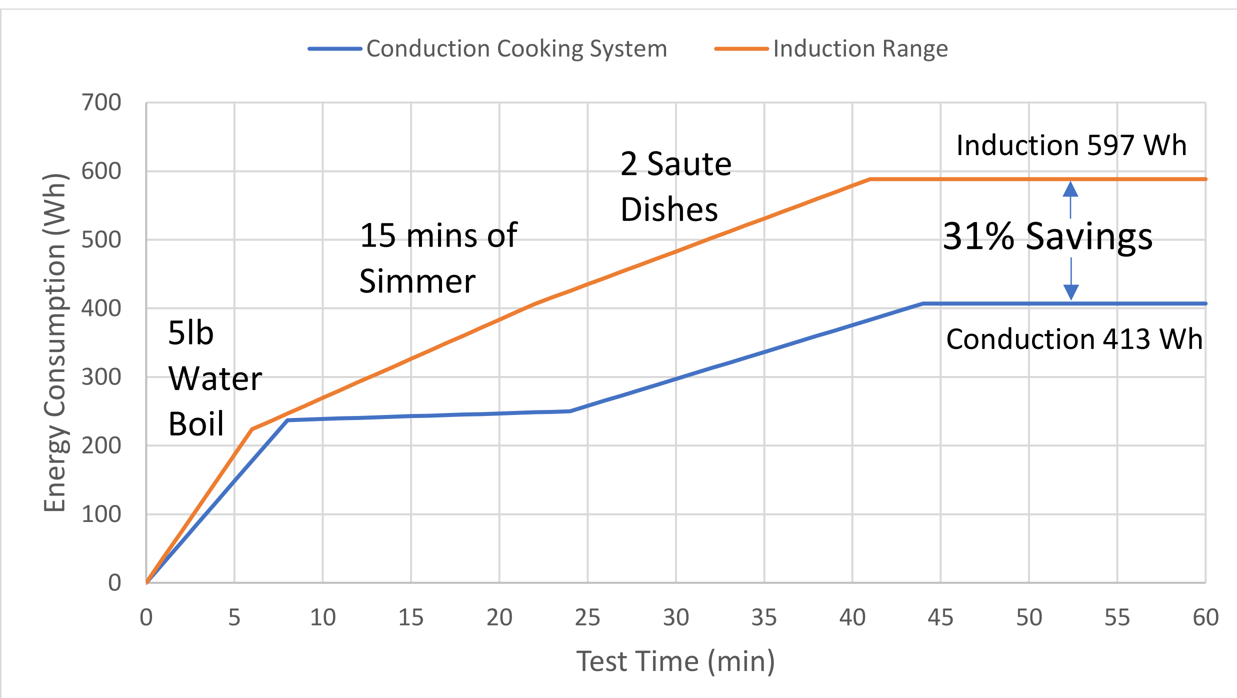


*Figure 10: Daily Cooking Energy for Average Household*

While the conduction cooking system saves energy while sautéing, most of the energy savings are from the conduction cooking system's much lower simmering energy. Based off the findings of the LBNL study, the average household is expected to reduce their cooking energy by about 31% using the conduction system compared to the induction range, saving $7.69 annually on their electricity bill. However, cooking practices vary substantially from household to household and the savings can be substantially larger for households which do a lot of boiled dishes or broth/soup making. Table **7** lists the savings for households who engage in extensive simmering when cooking.

*Table 7: Energy Savings for Higher Usage Households*

| | Average Daily Simmering Duration | | | |
|---|---|---|---|---|
| | **15 min** | **30 min** | **1 hour** | **2 hours** |
| Energy Cost Per Year – Conduction ($)* | $17.26 | $17.77 | $18.77 | $20.78 |
| Energy Cost Per Year – Induction ($)* | $24.95 | $32.08 | $46.36 | $74.91 |
| Annual Savings ($) * | $7.69 | $14.32 | $27.59 | $54.13 |
| Annual Savings (kWh) | 48 | 89 | 172 | 337 |
| Percent Energy Savings (%) | 31% | 45% | 60% | 72% |

*using $0.16/kWh average cost of electricity in California

## Conclusion

The conduction and induction cooktops demonstrated similar heat-up energy requirements, though the lower input rate resulting from the smart controls resulted in the conduction cooking system taking about a minute and a half longer to reach boiling temperature. The simmer and sauté tests showed that the conduction cooking system operated significantly more efficiently than induction when cooking. This difference in energy efficiency is particularly apparent when requiring precision – the conduction system allows for more exact temperature control with its temperature feedback system than an induction system with a smaller number of discrete power settings. The energy efficiency of the conduction system is maximized when paired with the conduction cookware; energy savings are theoretically still possible when using the conduction cooktop with a normal induction pot, but the effect of the pot on the smart controls makes the heating too slow to be practical. The conduction system also currently operates slightly slower than induction due to its lower input rate and smart control algorithms, though the control algorithms could possibly be modified to increase input rate to make boiling time on par with induction. The current algorithms programmed to promote healthy cooking make the duty cycles of the conduction cooktop significantly lower. The double-walled construction of the conduction cookware also reduces external pot temperature in comparison to induction by about 25°F for the sides of the pot and 60°F for the lid. This results in safer and more efficient cooking, but the specific savings per household will vary depending on usage. Table 8 compares the final test results from the conduction and induction cooktops.

*Table 8: Conduction vs. Induction Cooktop Test Results Summary*

| Cooktop | Conduction Cooking System | Induction Range* |
|---|---|---|
| Heat-Up Input Rate (W) | 1.8 kW | 2.2 kW |
| 5-lb Water Heat-Up Time (min) | 8.0 | 6.5 |
| 5-lb Water Heat-Up Energy (Wh) | 236 | 244 |
| 5-lb Water Heat-Up Efficiency (%) | 90.5 | 84.8 |
| Production Capacity (lb/h) | 37.7 | 45.9 |
| 5-lb Water Simmer Energy Rate (W) | 48 | 683 |
| Simmering Pot Exterior Temperature (°F) | 179 | 210 |
| Simmering Pot Lid Temperature (°F) | 139 | 208 |
| Cooking Heat-Up Time (min) | 1.33 | 2.44 |
| Cooking Heat-Up Energy (Wh) | 45 | 30 |
| Sauté Time (min) | 9.17 | 7.05 |
| Sauté Energy (Wh) | 38 | 61 |
| Sauté Input Rate (W) | 245 | 515 |
| Sauté Duty Cycle | 9.6% | 22.3% |
| Sauté Efficiency | 92.7% | 54.0% |

*Heat-Up done with Power Boil setting, Simmer done on Medium setting ($5^{th}$ setting) and Sauté done on $4^{th}$ setting

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## Appendix A: Test Methodology

1. Install cooktop according to manufacturer's specifications
2. Document cooktop burner input rates per manufacturer's documentation for each burner
3. Attach thermocouples to each cooking vessel:
    a. Conduction Pot:
        i. Geometric center 1" from the bottom
        ii. Geometric center 1" submerged in liquid from the top lid
    b. Induction Pot:
        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
4. Verify the test voltage at full burner input is within 5% of specification
5. Verify the tested input rate is within 5% of specification during water heat-up test
6. Water heat-up test:
    a. Record pot weight and material
    b. Fill pot with five pounds of water
    c. Ensure initial water temperature is 70 ± 2˚F
    d. Ensure initial burner/element/hob temperature is 70 ± 2˚F
    e. Start data acquisition program and set burner input rate set to maximum
    f. Record temperature, time, energy, and voltage until the water temperature reaches 200˚F per data acquisition system
7. Simmer test – conducted immediately following the water heat-up test:
    a. Achieve 212 ± 2˚F
    b. Set burner input level to maintain simmer
    c. Record temperature, time, energy, and voltage while in the simmering state
    d. Verify simmer conditions are steady and appropriate for use
    e. Adjust input rate and repeat if 7d not met
8. Sauté test conducted with a pan and product specified in section 4c
    a. Prepare ¼-lb, 80/20 frozen hamburgers stabilized in a 0 ± 5˚F environment for at least 12 hours
    b. Estimate a cook time required to produce a 35 ± 2 % moisture loss in the burger
    c. Record pan weight and material
    d. Record initial food product weight using a high-resolution scale (do not have product out of freezer for more than 1 minute prior to cooking)
    e. Preheat pan to 375˚F
    f. Record temperature, time, and energy to preheat pan
    g. Place frozen hamburger patty in the hot pan
    h. After 60% of estimated cook time, flip the patty with a spatula
    i. Remove patty once the total cook time reaches the initial estimate
    j. Stop recording temperature, time, and energy to cook burger
    k. Record final product weight using a high-resolution scale
    l. Verify cooked weight loss was 35 ± 2%; if not, modify the estimated cooking time and repeat steps c-l until the proper conditions are reached.

## Appendix B: Detailed Test Results

*Table 9: Cooktop Heat-Up Test Detailed Results*

| | Conduction | | Induction | |
|---|---|---|---|---|
| | Test #1 | Test #2 | Test #1 | Test #2 |
| Heat-Up Time (min) | 7.42 | 8.50 | 6.58 | 6.50 |
| Heat-Up Rate (°F/min) | 17.6 | 15.3 | 19.9 | 20.1 |
| Heat-Up Energy (Wh) | 240.0 | 232.5 | 247.5 | 240.0 |
| Input Rate (W) | 1941 | 1641 | 2257 | 2215 |
| Heat-Up Efficiency (%) | 89.2 | 91.8 | 83.5 | 86.0 |

*Table 10: Conduction Cooktop Sauté Test Detailed Results*

| | Test #1 | Test #2 |
|---|---|---|
| Test Time (min) | 10.92 | 10.92 |
| Cook Time (min) | 9.17 | 9.17 |
| Burger Initial Weight (lb) | 0.245 | 0.250 |
| Burger Final Weight (lb) | 0.155 | 0.160 |
| Burger Initial Moisture Content (%) | 58.6% | 58.6% |
| Burger Final Moisture Content (%) | 46.2% | 46.4% |
| Burger Fat Content (%) | 23.9% | 23.9% |
| Test Voltage (V) | 219 | 218 |
| Electric Energy Consumption (Wh) | 38 | 38 |
| Ambient Temperature (°F) | 70.1 | 70.2 |
| Burger Weight Loss (%) | 36.7% | 36.0% |
| Specific Heat of Burgers (Btu/ lb °F) | 0.72 | 0.72 |
| Sensible Energy (Btu) | 29 | 30 |
| Latent Fusion Energy (Btu) | 21 | 21 |
| Latent Vaporization Energy (Btu) | 70 | 70 |
| Total Energy to Food (Btu) | 120 | 121 |
| Energy to Food (Btu/lb) | 120 | 121 |
| Electric Cooking Energy Rate (kW) | 0.21 | 0.21 |
| Energy to Equipment (Btu/lb) | 531 | 520 |
| Cooking Energy Efficiency (%) | 92.3 | 93.1 |
| Production Capacity (lb/h) | 1.3 | 1.4 |