Retrofit Ready Induction Stove

ABT 212 Spring 2022

Ruoming Xu

Joshua Ian Ira

Table of Contents

Background

Problem Description

Redwood Energy is an electrification company based out of Eureka, CA. They own and operate several zero-net-energy housing complexes that provide clean, affordable living spaces for disadvantaged communities and low-income renters across the state.

While the majority of the housing units offered by Redwood Energy are equipped with electric resistance ranges, there are a few units that continue to use gas fired cooktops. Because many tenants in these units are (low income) renters, they often lack the decision-making authority to make large appliance changes. Furthermore, those that are able to convert to cleaner, more efficient cooking alternatives generally cannot afford to.

The barriers to electrification that exist in these complexes are present in external housing projects across the nation. Gas appliances are ubiquitous in disadvantaged communities because they are much cheaper than an electric appliance. They also emit harmful criteria pollutants that sharply degrade indoor air quality, placing a disproportionate public health burden on renters that do not have an affordable alternative to gas appliances.

In an effort to extend the benefits of electrification to renters and non-homeowners both within their housing developments and in external communities, Redwood Energy is leading the development of a retrofit ready induction range in collaboration with Lawrence Berkeley National Labs, the Building Decarbonization Coalition, the Association for Energy Affordability, and SoCal Edison.

The goal is to design an 1800W induction stove that can plug into a standard 120V wall socket, eliminating the need for a time intensive and costly cooktop conversion (*see appendix for full design specifications*). To inform the design specifications for the induction stove, Redwood Energy has collected minute wise cooking session data from multiple units in the Atascadero complex – a housing community for local farm workers and low-income families.

Project Objectives

The primary objective for the project team is to analyze cooking session data taken from the Atascadero housing complex and determine if an 1800W induction cooktop is sufficient for their cooking needs. The project deliverables summarized below reflect the data analysis requests of the client (Redwood Energy) and are within scope of what is extractable from the data set provided.

- Determine what percent of cooking session would be covered by an 1800W induction cooktop
- Find trends in cooking session data for both power draw and duration
- Quantify the energy saving from switching to an induction stove with higher efficiency
- Identify factors that influence the data (behavioral)

Data Analysis Methodology

Overview of Cooking Session Data

More than two years of minute-wise cooking data (June 2018 to August 2020) was collected from 39 different units in the Atascadero Complex using an appliance specific meter that measured power draw from both the cooktop AND the oven. For each cooking session, the following information was recorded:

- Number of occupants in unit
- Cooking session duration
- Average power draw
- Peak power draw
- Median power draw
- Unit number

Data Sorting and Filtering

Due to the large amount of the data and limited computing power, only part of the dataset was selected for analysis. After discussion with the client, the project team chose November to December of 2019 to represent all cooking session data because it is the most recent time frame considered pre-COVID, providing a more accurate representation of user's cooking behavior. More importantly, November and December are cooking intensive holiday seasons, giving the team a conservative estimate for the percentage of cooking sessions covered by an 1800W induction stove. For example, if we see a 90% coverage in the cooking sessions during these months, we expect even greater coverage during non-holiday seasons.

The power draw for all cooking sessions was filtered before any analysis was performed. There were many records of power draw that fell between 0.1 and 10 watts, which the team suspects are auxiliary loads (the hood, the clock, or the oven light). Considering that 10W would not actually cook or boil anything, any cooking sessions with peak or average power draw of 10 watts or lower was excluded (Baker et al.). The project team then looked into the minimum wattage that an electric coil or induction cooktop consumes as an additional filter. Based on the portable induction stove that one of our members acquired, and further market research into the the minimum setting of most electric cooktops, 100 watts was chosen as the final cutoff value.

Because the appliance specific meter measured the combined power draw from both the oven and the cooktop, the team chose a maximum cutoff value as well in an attempt to filter out some the oven usage data. This value was informed by a) average time spent using an oven and b) the specs of the cooking appliance used in the Atascadero complex (FFEF3009P FRIGIDAIRE). The minimum power draw for baking applications was rated at 2600W, with the broil setting rated at 3000W. However, the two larger cooktop burners are rated at 2600W, and unlike an induction stove, there are no power balancing features, meaning that the maximum power draw from this cooktop alone could easily exceed 2600W. A quick google search suggested that the average time to preheat an oven is around 5-15 minutes (10 minutes on average). Considering people spend at least 10 minutes to use oven to cook after pre-heat, people would use an oven for at least 20 minutes. In order to capture some of the cooking session data that included multiple burner usage, the team chose to exclude any cooking session data with a power draw of above 3000W IF the cooking duration for that session was greater than 20 minutes.

Cooktop Efficiency

Cooktop efficiency is difficult to quantify and even more difficult to compare across different cooking technologies because it is dependent on many factors (size of cooking vessel, size of burner, type of food being cooked, etc.). In order to translate the power draw of an electric cooktop into the equivalent power draw for an induction cooktop, the efficiency for each type of cooking element must be clearly defined.

It is helpful to simplify the efficiency of a cooktop to be congruent with the basic definition of efficiency:

$$\text{Efficiency} = \frac{\text{Useful Energy Output}}{\text{Energy Input}} \times 100\%$$

For an electric cooktop, the useful energy output would equal the amount of heat generated by the cooking element (Joules) divided by the amount of energy it took to supply that heat (also in Joules). However, the cooking session data recorded the energy input in terms of power, which is a rate (Watts = Joules per second). To ensure that the denominator has the same units as the numerator, the energy input must be multiplied by the cooking session duration.

The Electric Power Research Institute (EPRI) published a study in 2015 titled *Induction Cooking Technology Design and Assessment* (Sweeney et al.). In this technical report, EPRI quantifies the cooking efficiency of both gas and electric appliances using a testing procedure developed in house, allowing comparison to be made across different cooking appliances.

Results of Cooking Efficiency Testing

EPRI tested each of the consumer cooking appliances according to the induction-compatible test procedure it developed, involving the heating of water from 70° to 200° F (21° to 93° C). As specified by the procedure, three test runs were performed with each device at both half power and full power, with efficiency calculated as the average of the three runs. The results of cooking efficiency testing performed by EPRI are shown in Table 2.

Table 2. Cooking efficiency results measured according to EPRI test procedure

	Large Vessel		Small Vessel	
	Half Power	Full Power	Half Power	Full Power
Induction Cooker A	74.9%	77.6%	76.5%	77.4%
Induction Cooker B	75.7%	77.2%	75.6%	75.1%
Electric Coil	81.6%	83.4%	48.2%	41.5%
Natural Gas	41.7%*	35.2%*	-	30.2%*

*Natural gas range tested at 50° F (10° C).

The results of the efficiency tests serve as a conversion factor for translating the cooking data collected from the electric coil ranges used in Redwood Energies ZNE housing complexes into the equivalent power draw for an induction cooktop. The project team chose to take the average of the large vessel and small vessel at full power for both induction cooker A (rated at 1800W) and the electric coil cooktop, yielding the following efficiencies

- Induction stove efficiency = **78% (Induction Stove A average at full power)**
- Electric stove efficiency = **62% (Electric Coil range average at full power)**

Results & Discussion

The key findings relevant to the project objectives are summarized below.

▪ A **16%** improvement in efficiency yields a **19%** savings in energy (Wh)
▪ Approximately **85%** of cooking sessions **peak power usage** is covered by an induction stove
▪ Approximately **95%** of cooking sessions **average power usage** is covered by an induction stove
▪ **67%** of all cooking sessions fall between 1 and 20 minutes
▪ **15%** of cooking sessions draw between 100 and 200 Watts

Energy Savings

One of the most important findings of this study is that a **16% improvement in efficiency** yields a **~19% savings in energy**. This value will vary depending on appliance and the size of the cooking vessel used but serves as a rough estimate for energy savings from switching from an electric resistance cooktop to an induction cooktop. It is important to note that although users may save around 20% of the total energy needed to meet the same heating output, using an electric appliance might still be more expensive than using a gas-powered appliance, especially in areas where the levelized cost of electricity is high (California, for example).

Relationship between occupancy and power draw

To determine if a relationship exists between number of occupants per household and peak/average power draw, the team constructed histograms that illustrated the distribution of power draw based on the number of occupants in each unit surveyed.

The project team hypothesized that a greater number of occupants per household would shift the distribution towards a higher average and peak power draw. To verify this hypothesis, the histograms for each size of household were compared to see how the power draws shifted (*see appendix Figure (x) and Figure (y))*

Based on these histograms, there was an observable shift to a greater peak and average power as occupancy increased as hypothesized, but it was not consistent.

Percentage of Cooking Session Covered by an Induction Stove

To calculate the percentage of cooking sessions covered by an 1800W induction cooktop, the bins for each histogram were modified to reflect the equivalent wattage for an electric cooktop since the original dataset reflects power draw for an electric cooktop. This cutoff value was informed by the efficiency conversion discussed in previous sections.

The cutoff value for the electric coil histograms is 1800W and remains unchanged. However, the cutoff value for the induction stove histograms was calculated to be 2200W. Because an induction stove is more efficient, it takes less energy to meet the same heating output. Therefore, a larger portion of the dataset can be covered (1800W induction = 2200W electric resistance).

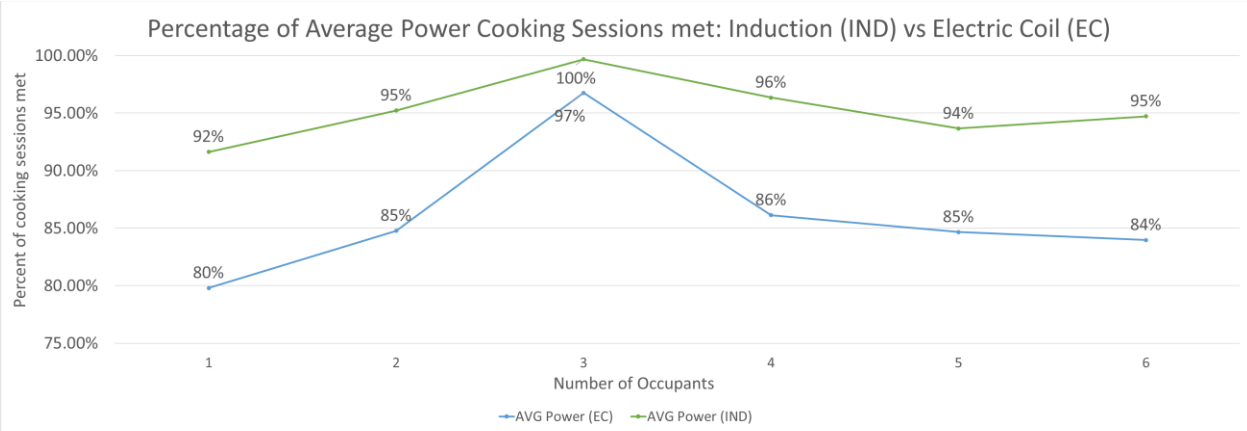


Figure 1 Percentage of Average Power Cooking Sessions met induction 1800W: Induction (IND) & Electric Coil (EC)

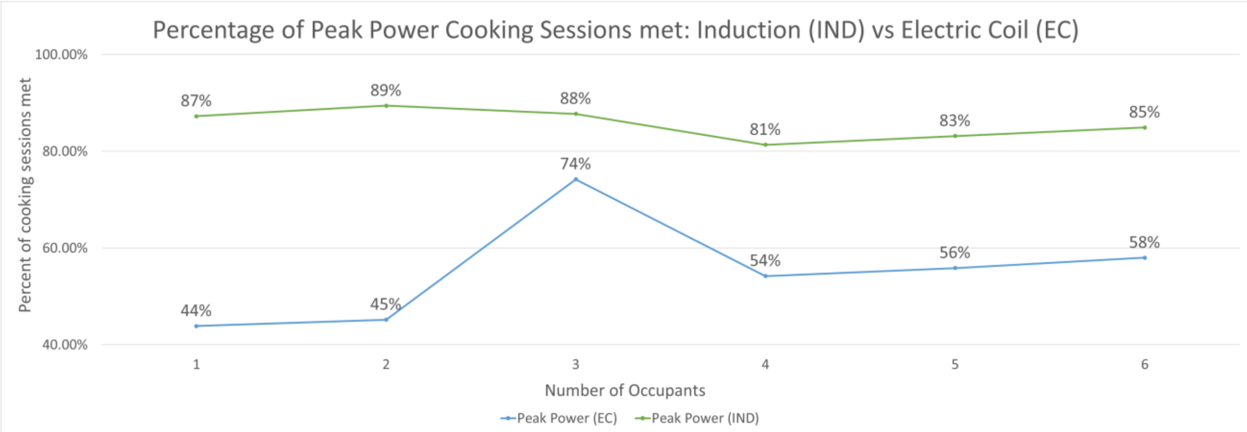


Figure 2 Percentage of Peak Power Cooking Sessions met induction 1800W: Induction (IND) & Electric Coil (EC)

Figures 1 and 2 combine the information from each set of histograms (electric coil and induction) to compare the percentage of average and peak power cooking sessions covered by each type of stove and how this coverage varies by number of occupants. Based on the efficiency conversion alone, the team expected that there would be a higher percentage covered by an induction stove, which holds true for both figures. The team also expected that a larger percentage of average power cooking session would be covered than peak power, which also holds true (**~85% coverage for peak and ~95% coverage for average**).

The team also predicted that as occupant size increased, the percentage of cooking sessions covered would decrease, however this trend is not as evident. In Figure 1, the trends in coverage are similar but not what the team expected. From 1 to 3 occupants, the percentage of average power cooking sessions covered increases and peaks at 3 occupants, followed by a decrease in coverage from 3 to 6 occupants. A similar trend is observed for the electric coil line in Figure 2 (blue line). However, the percent coverage for the induction stove in Figure 2 (green line) exhibits coverage closer to what the team expected – as occupancy increase, the percent coverage decreases.

It is important to note that the number of units representing 1-6 occupants was not consistent (*see appendix)*. For example, there were 14 units surveyed that had 5 occupants, while only 4 units were surveyed that had 1 occupant. The team suspects that this may yield inconsistencies in the percentage of cooking session covered for each household size, like the peak in coverage observed for 3 occupants.

Trends in Cooking Session Duration

Figure 3 illustrates the distribution of cooking session duration for all sessions. Based on the graph, 67% of all sessions fall between 1 and 20 minutes, suggesting that most users do not use the cooktop to cook for extended periods of time. The peak at 60 minutes plus could include some of the oven usage data or reflect the larger portion of cooking intensive holidays in the time frame used for analysis.

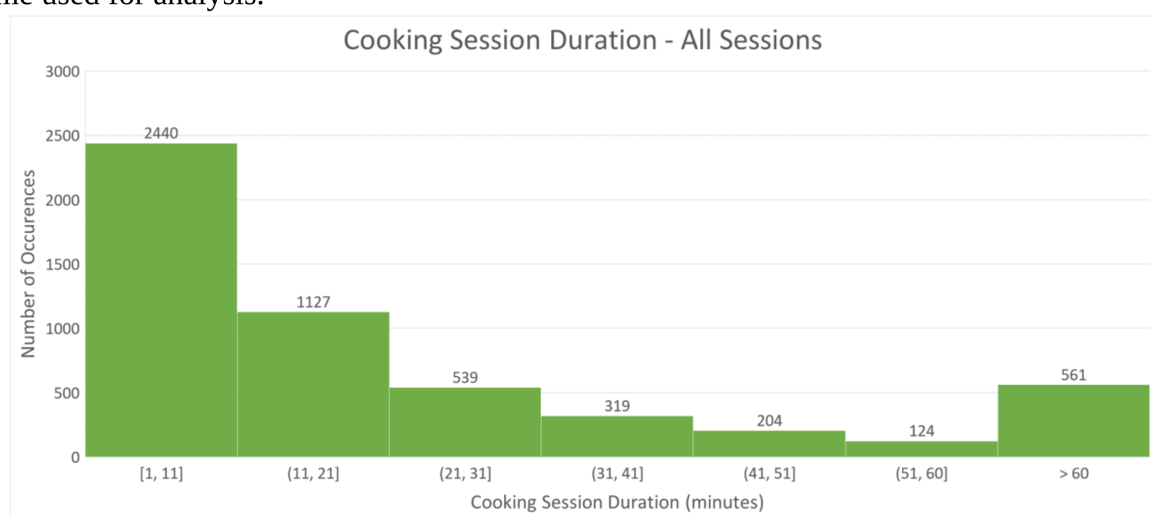


Figure 3 Cooking Session Duration - All Sessions for number of occupancies vs. cooking session duration in minutes

Trends in Cooking Session Power Draw

Figure 4 and figure 5 show the distribution of average and peak power draw for all cooking sessions regardless of household size. The purpose of these figures is to a) illustrate trends in power draw and b) investigate the percent of cooking sessions covered by different sized burners. It is important to note that the trends observed in these graphs reflect differences in cooking behavior, and any suggestions as to why these trends are evident cannot be supported without second wise data that shows which burners are in use and for how long.

In Figure 5, there are four major trends in power draw:

- 100-200W (low heat applications – simmering, keeping food warm, sauces)
- 1100-1200W (medium heat applications – sautéing, cooking larger dishes)
- 1900-2100W (high heat applications like frying or perhaps operation of multiple burners)
- >2200W (long duration cooking / oven use)

In Figure 4, the graph resembles a gaussian (normal) distribution, where the peak is in between 1100 to 1200 W. This is because the power draw for these sessions is aggregated across the entire cooking duration.

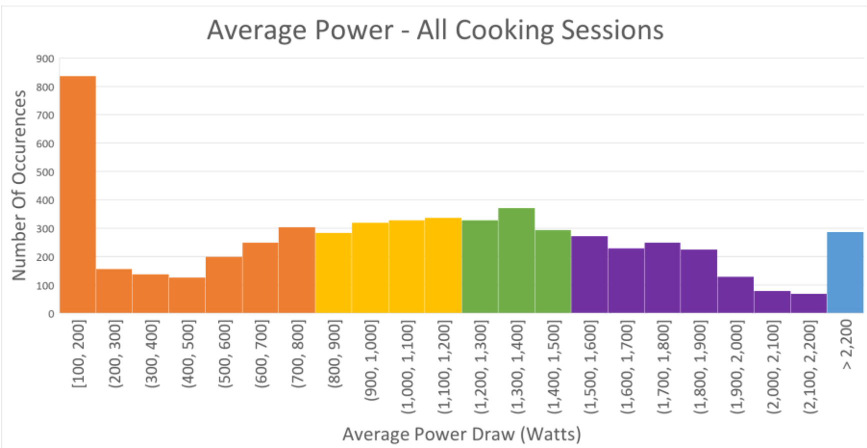


Figure 4 Average Power - All Cooking Sessions

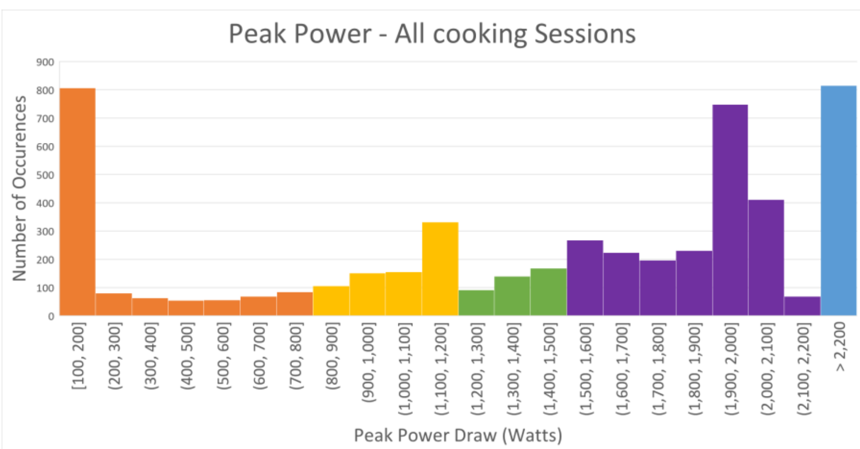


Figure 5 Peak Power - All Cooking Sessions

The most significant finding from these figures is that **approximately 15% of the data falls between 100 to 200 watts**. This could be a result of the minimum cutoff value chosen in the data analysis methodology or reflect dishes that require low heat and are common in these types of communities.

Electric Coil Burner Size (W)	Induction Stove equivalent (W)	Peak Power Cooking Sessions Covered by Burner	Average Power Cooking Sessions Covered by Burner
750	600	22%	32%
1100	900	31%	51%
1450	1200	43%	71%
2200	1800	85%	95%

Table 1 Electric Coil burner (EC) and Induction stove (IND) coverage for different burner size (W)

Table 1 shows the percent of cooking sessions covered by different sized burners. The size of the induction stove burners (in watts) reflects the design specifications for retrofit ready stove as well as the four major trends overserved in Figure 5. This serves to inform the optimum size for each burner included in the induction stove design. It is clear that there is a need for a small burner with relatively low power output, as well as an intermediate sized burner with a larger output (around 1100W)

Recommendations

- Analysis of second wise data would provide better resolution and would help the project team
    - separate oven data from cooktop data
    - determine which cooking elements are being used and when multiple elements are in use
    - inform increments for controls

- A behavioral study (ex: survey) may provide valuable insight into how tenants use different cooking elements and thus inform the size and power draw for each hob

- Providing tenants with a prototype and gathering data from usage of this retrofit ready induction stove could help Redwood Energy refine the design specifications

Bibliography

Baker, R. C., et al. "Electrical Energy Used and Time Consumed When Cooking Foods by Various Home Methods: Eggs." *Poultry Science*, vol. 59, no. 3, Mar. 1980, pp. 545–49. *DOI.org (Crossref)*, https://doi.org/10.3382/ps.0590545.

Sweeney, Micah, et al. *Induction Cooking Technology Design and Assessment*. Electric Power Research Institute (EPRI), 2014.

Appendices

Appendix A Induction Stove Design Specifications

Induction Stove Design Specifications

- 9” induction coil, 1800W, load balancing.
- 7” induction coil, 1800W load balancing.
- 5” induction coil. 900W, load balancing
- Compatible with a 120V wall outlet (no wiring upgrade needed)
- 1800W maximum for total electricity usage

Appendix B Number of units surveyed by occupant size

Number of units surveyed by occupant size:

1 occupant – 4 units

2 occupants – 5 units

3 occupants – 8 units

4 occupants – 5 units

5 occupants – 14 units

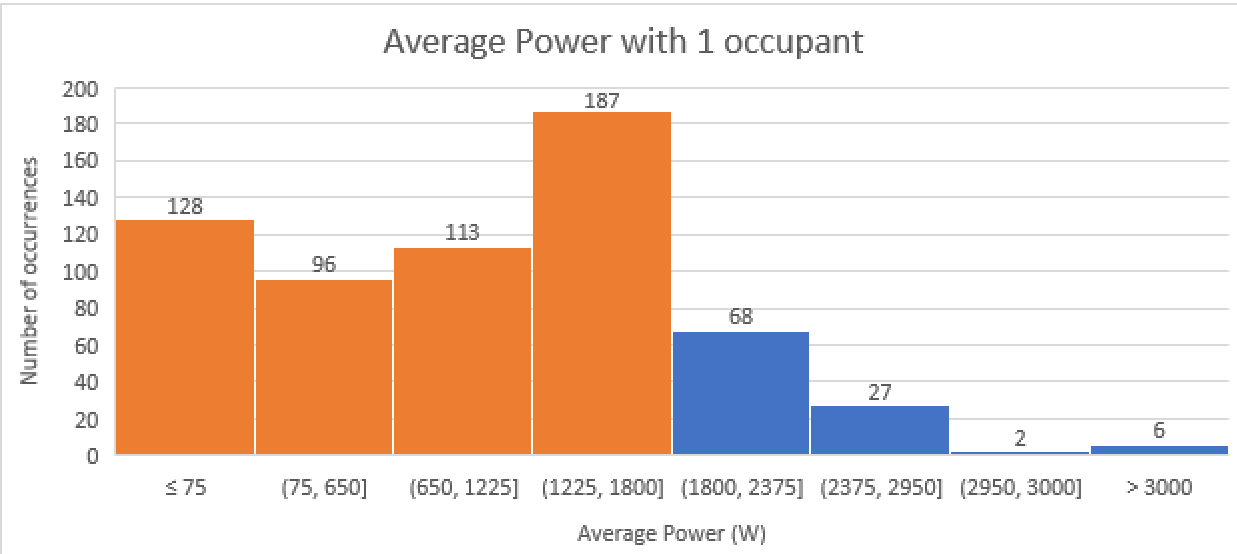
6 occupants – 3 units

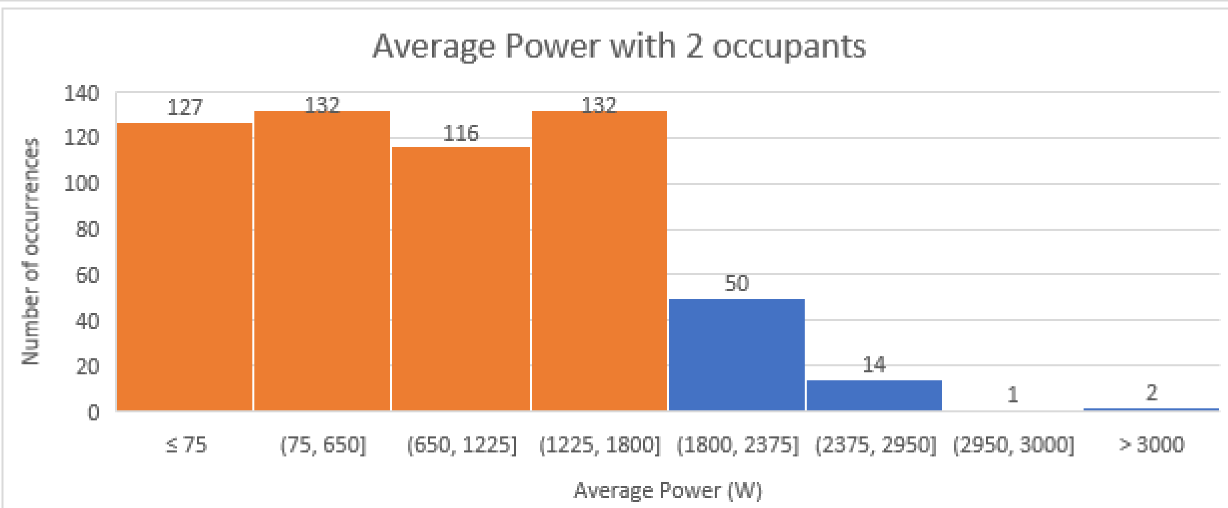
Total surveyed units: 39

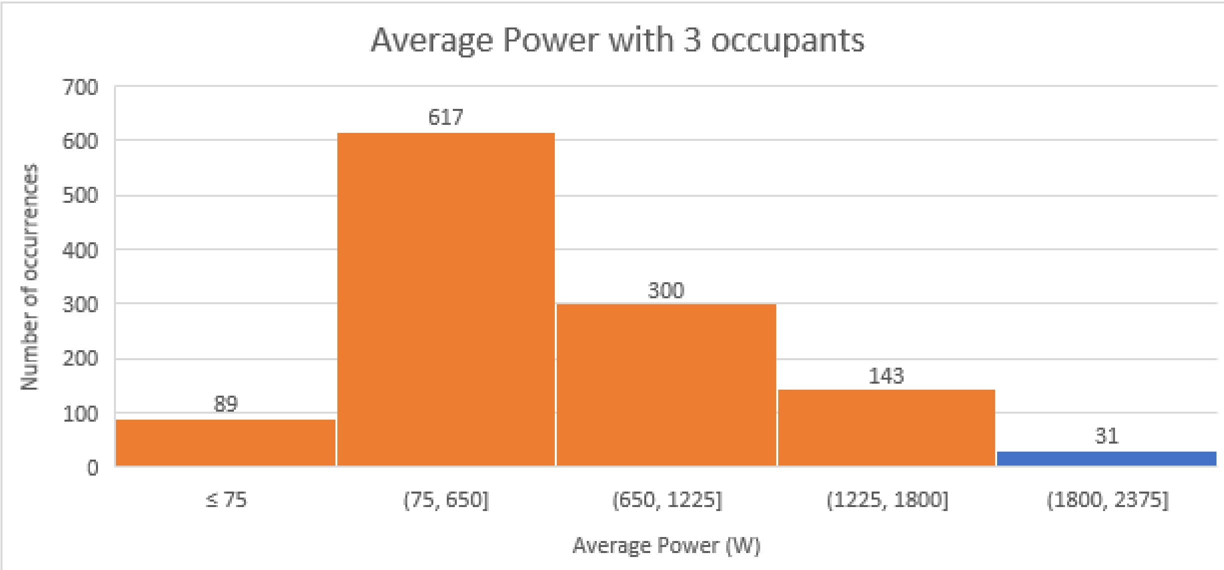
Appendix C: Average Power with 1 to 6 occupants for electric coil cooktop

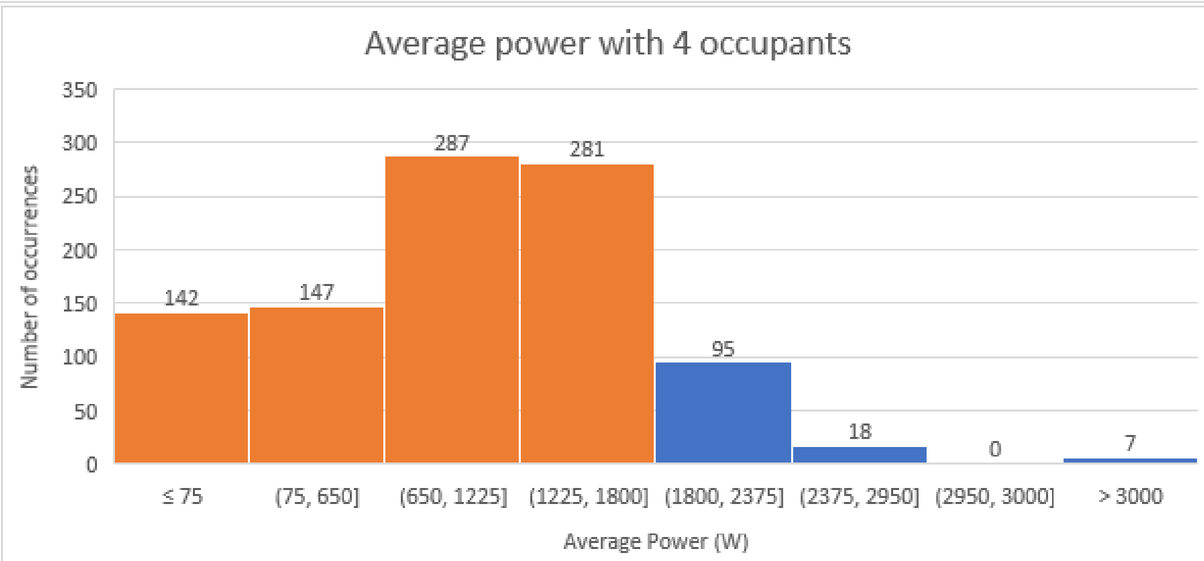
Orange Bars = Covered by Induction Stove

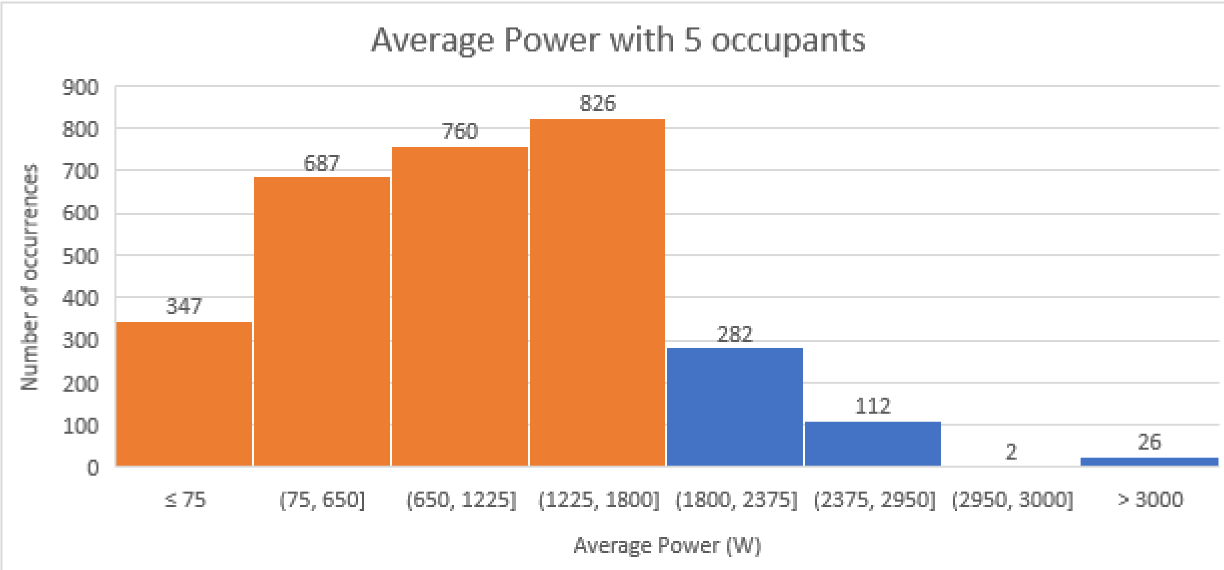
Blue Bars = Not covered by Induction Stove



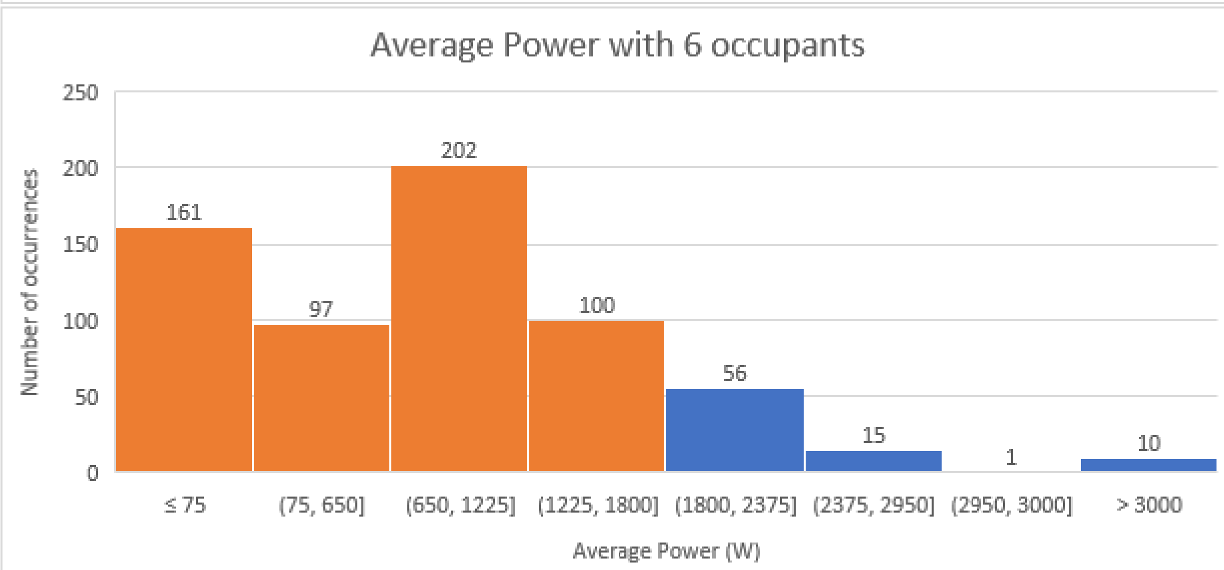



Average Power with 3 occupants
Number of occurrences
700
600
500
400
300
200
100
0
89
617
300
143
31
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
Average Power (W)


Average power with 4 occupants
Number of occurrences
350
300
250
200
150
100
50
0
142
147
287
281
95
18
0
7
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
(2375, 2950]
(2950, 3000]
> 3000
Average Power (W)

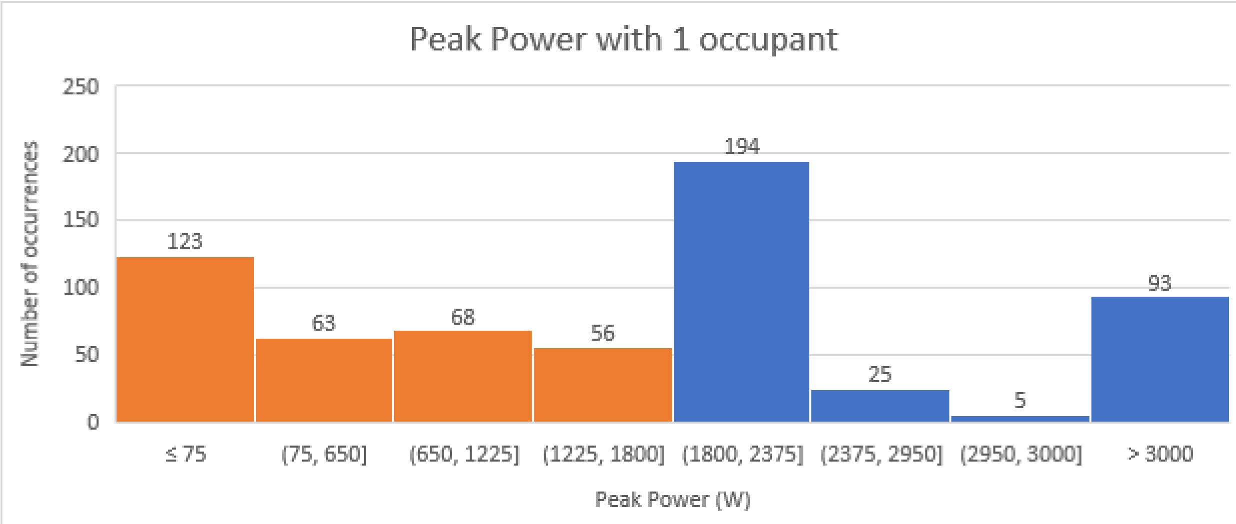


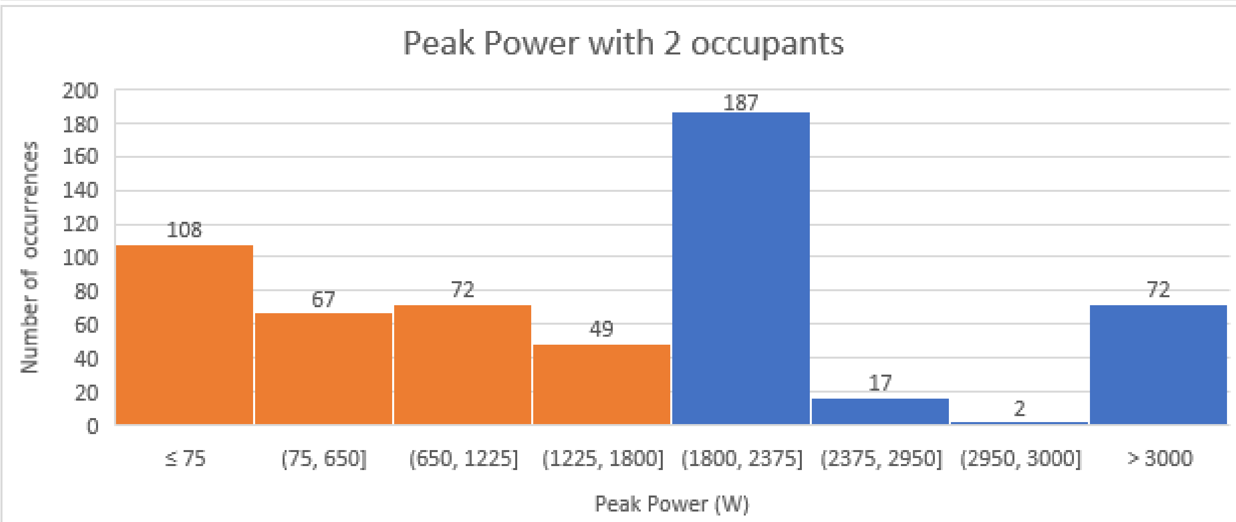
Average Power with 5 occupants
Number of occurrences
Average Power (W)
0
100
200
300
400
500
600
700
800
900
347
687
760
826
282
112
2
26
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
(2375, 2950]
(2950, 3000]
> 3000

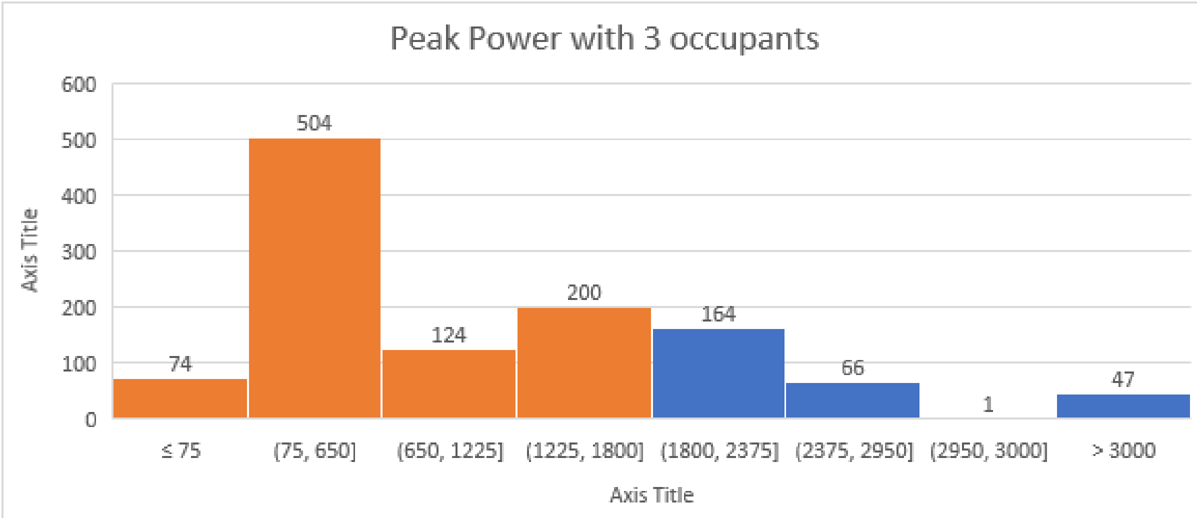


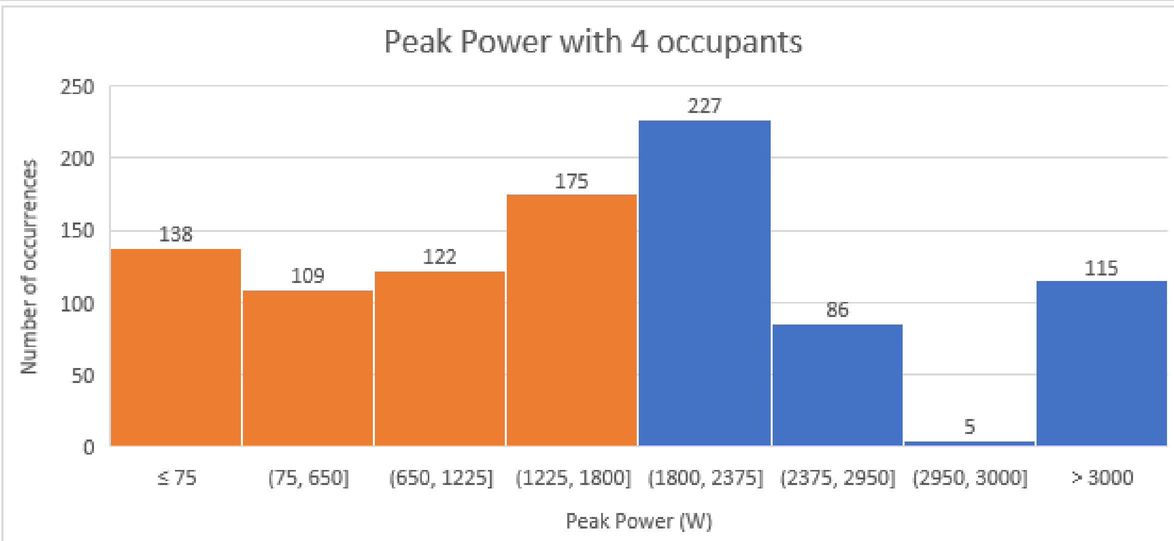
Average Power with 6 occupants
Number of occurrences
Average Power (W)
0
50
100
150
200
250
161
97
202
100
56
15
1
10
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
(2375, 2950]
(2950, 3000]
> 3000

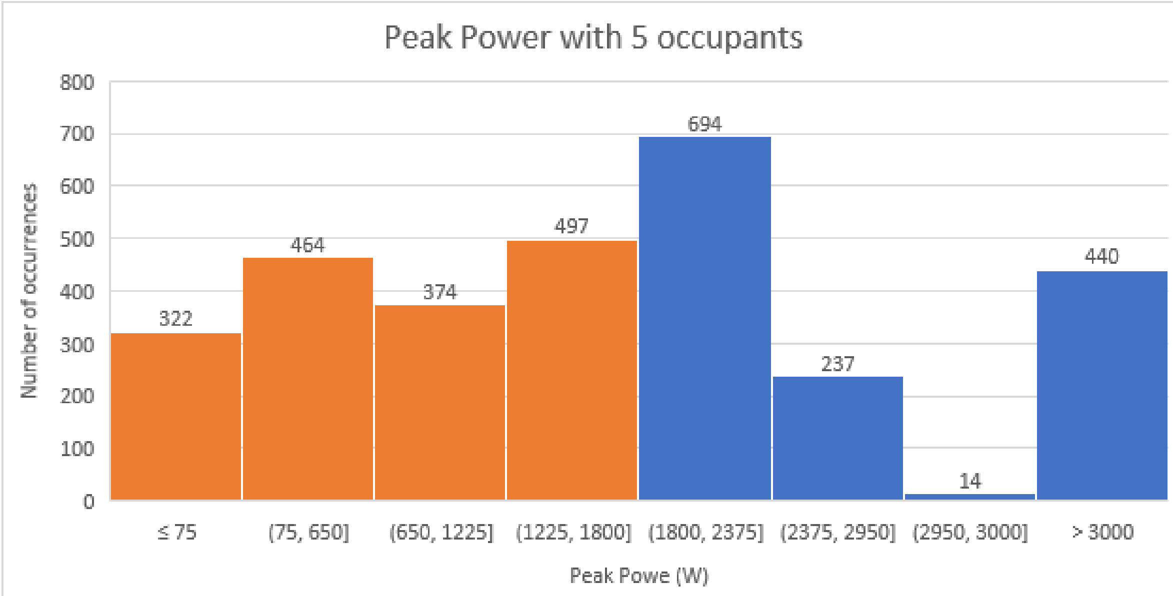
Appendix D: Peak Power with 1 to 6 occupants for electric coil cooktop

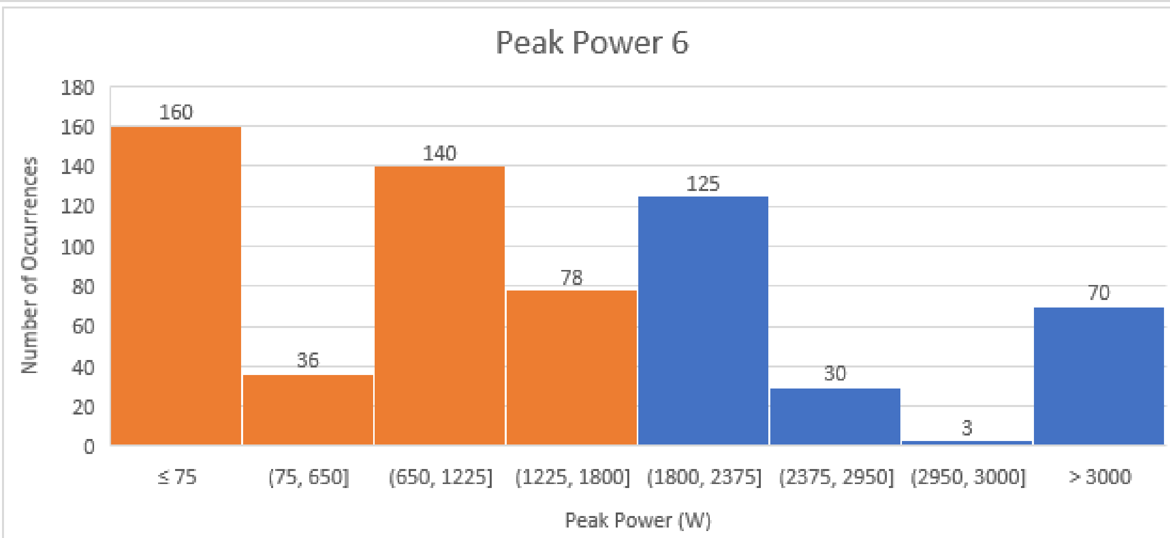





Peak Power with 3 occupants
Axis Title
600
500
400
300
200
100
0
504
200
164
124
74
66
47
1
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
(2375, 2950]
(2950, 3000]
> 3000
Axis Title


Peak Power with 4 occupants
Number of occurrences
250
200
150
100
50
0
227
175
138
122
115
109
86
5
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
(2375, 2950]
(2950, 3000]
> 3000
Peak Power (W)

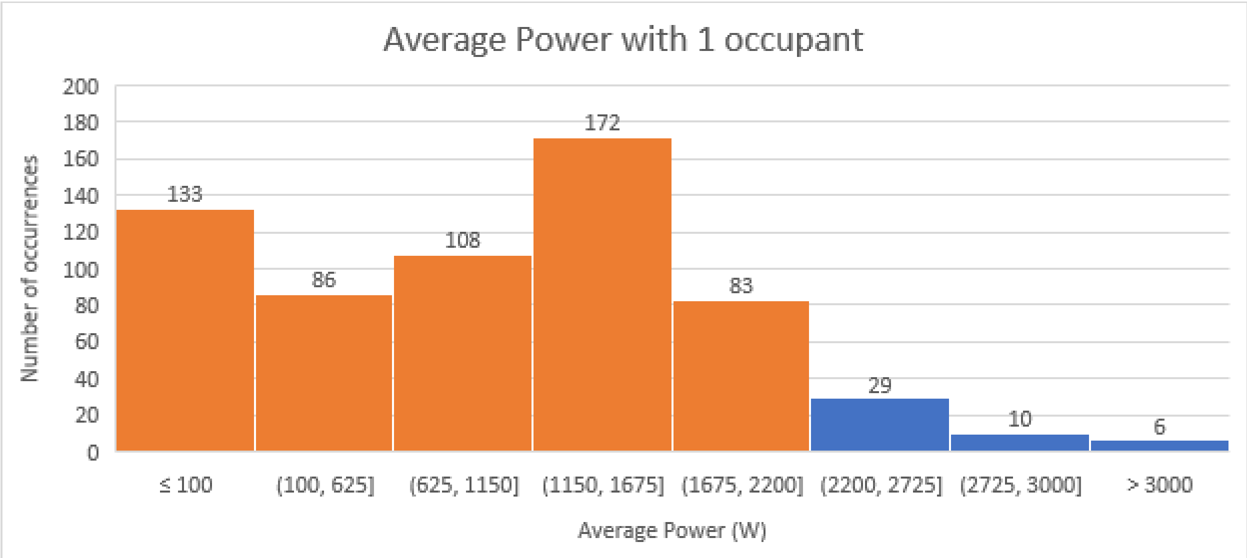

Peak Power with 5 occupants
800
700
600
500
400
300
200
100
0
Number of occurrences
322
464
374
497
694
237
14
440
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
(2375, 2950]
(2950, 3000]
> 3000
Peak Powe (W)

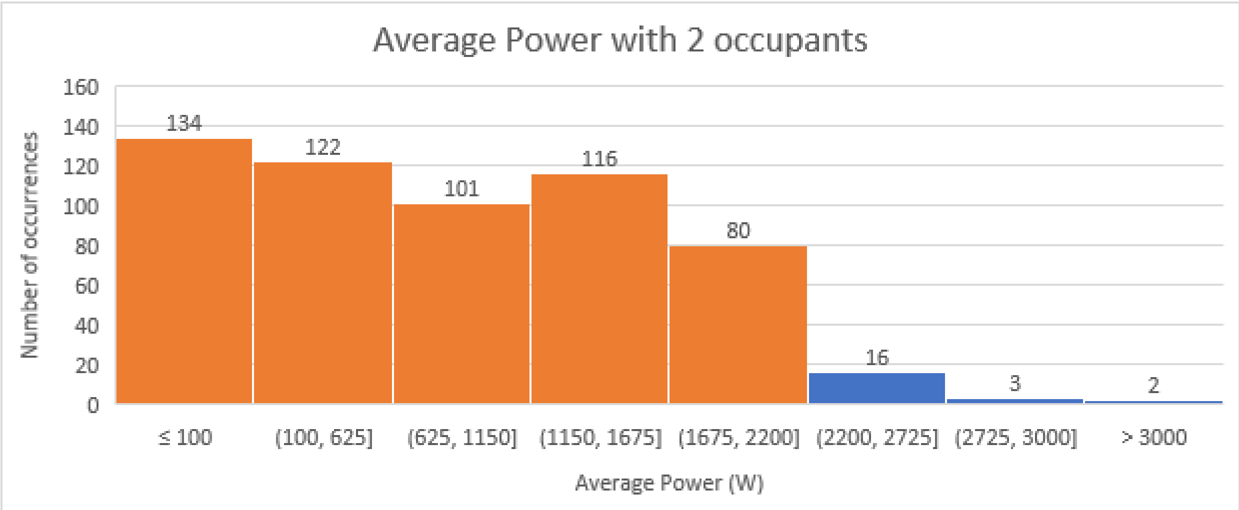

Peak Power 6
180
160
140
120
100
80
60
40
20
0
Number of Occurrences
160
36
140
78
125
30
3
70
≤ 75
(75, 650]
(650, 1225]
(1225, 1800]
(1800, 2375]
(2375, 2950]
(2950, 3000]
> 3000
Peak Power (W)

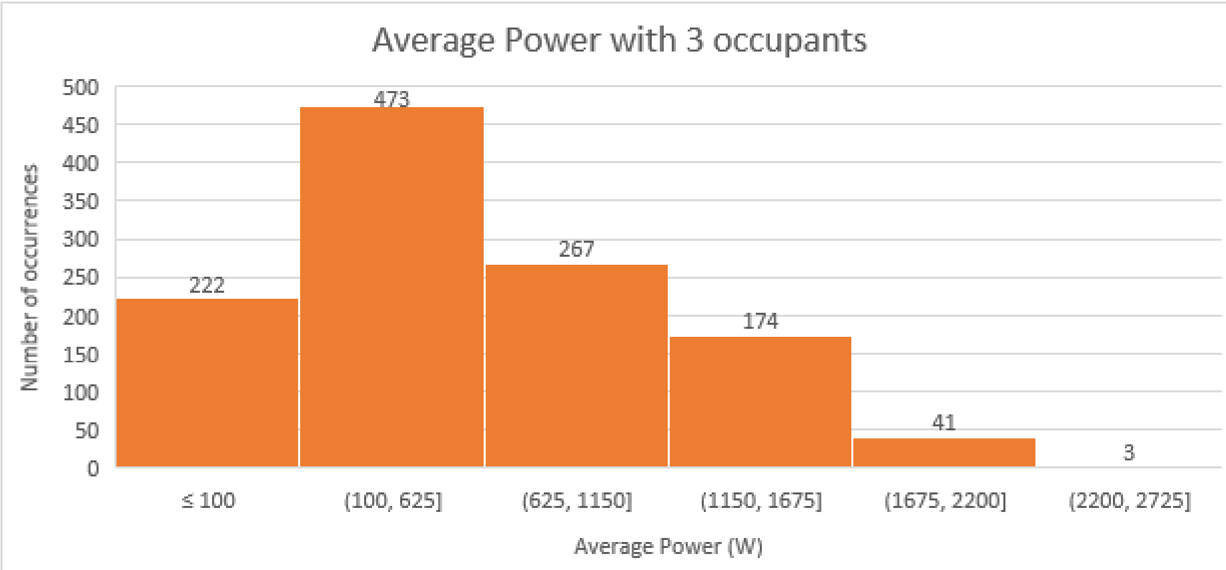
Appendix E: Average Power with 1 to 6 occupants for induction cooktop

Orange Bars = Covered by Induction Stove

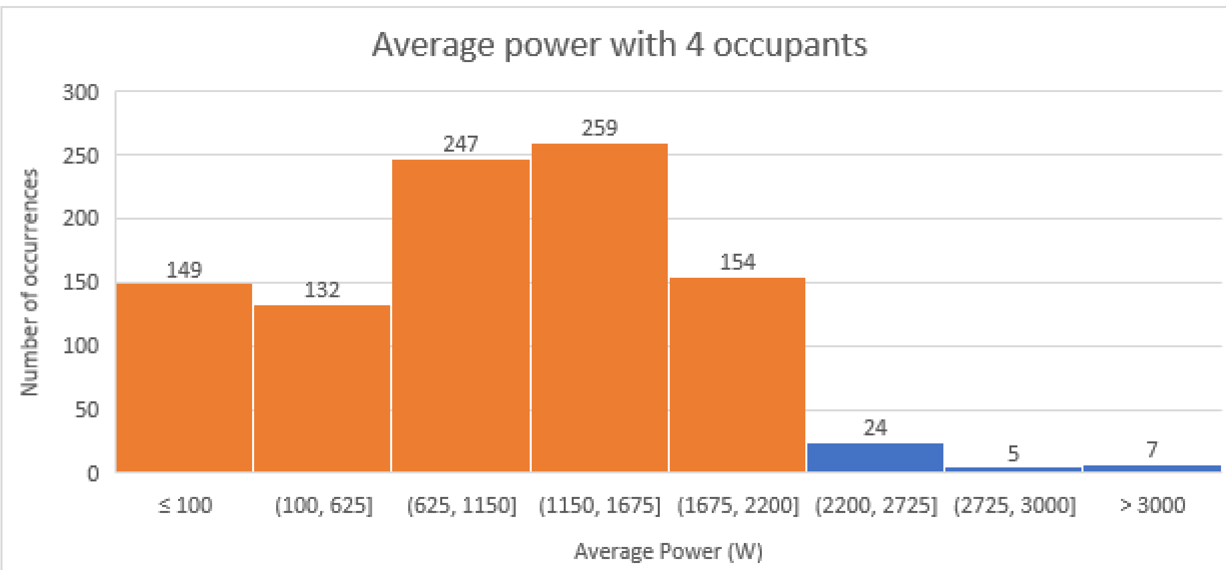
Blue Bars = Not covered by Induction Stove



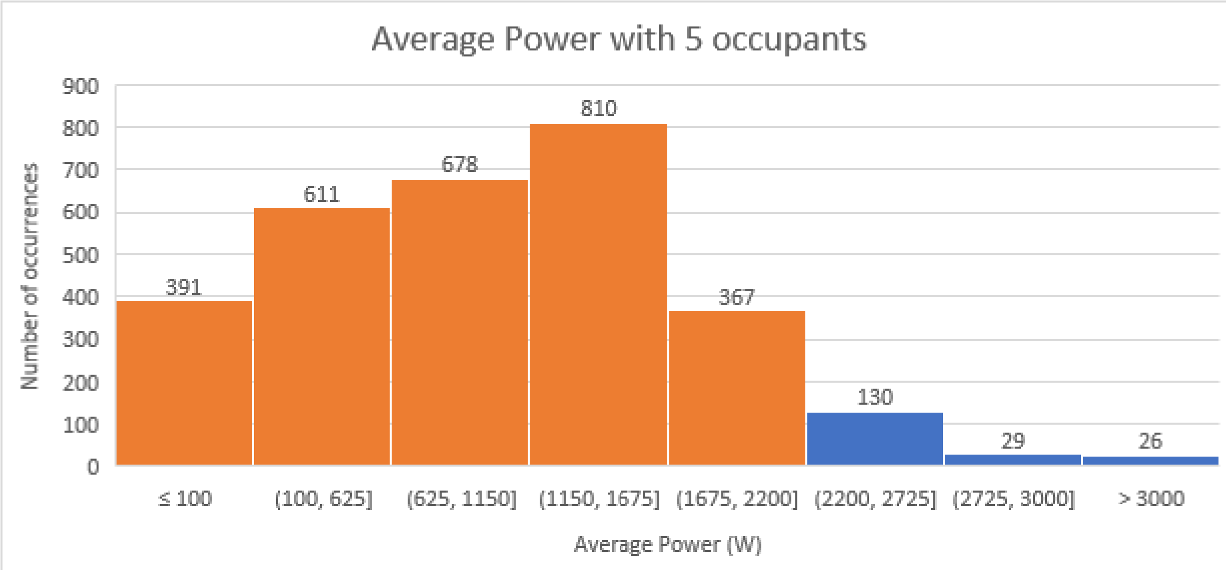


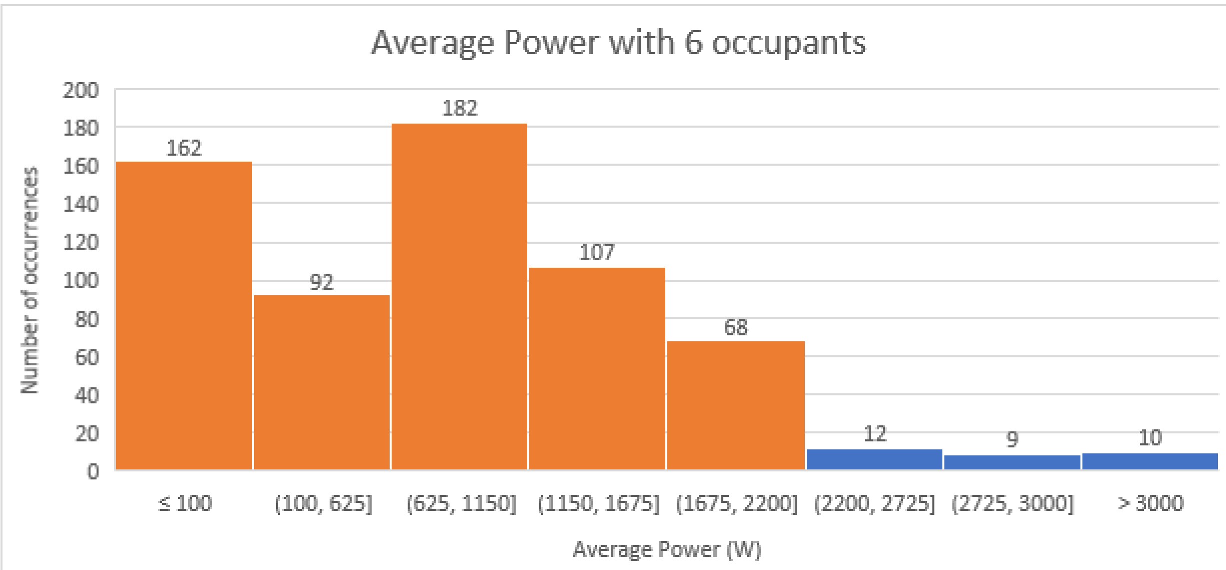


Average Power with 3 occupants
Number of occurrences
500
450
400
350
300
250
200
150
100
50
0
222
473
267
174
41
3
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
Average Power (W)

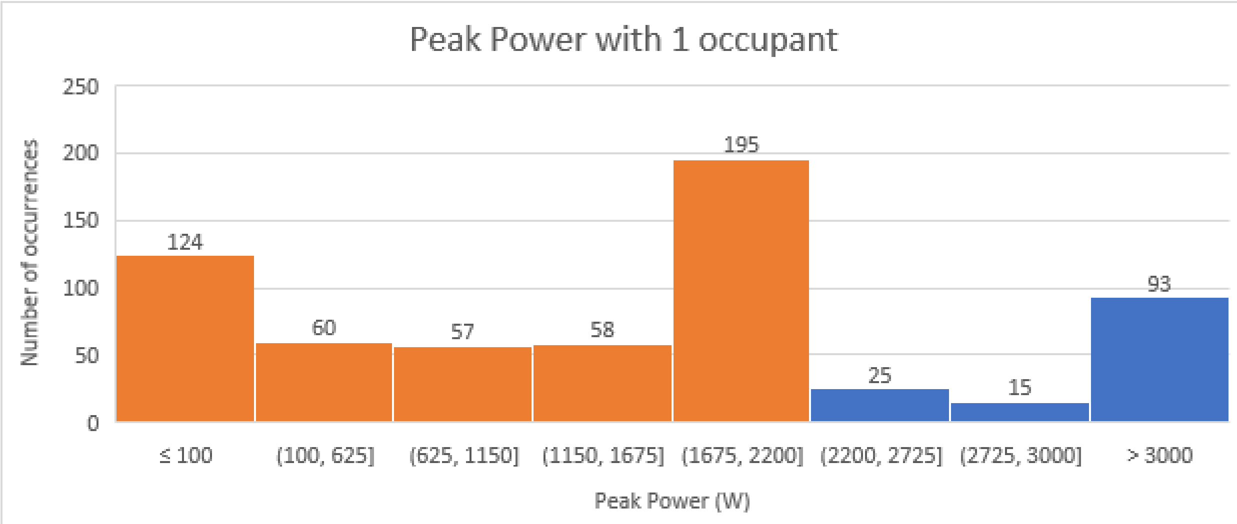


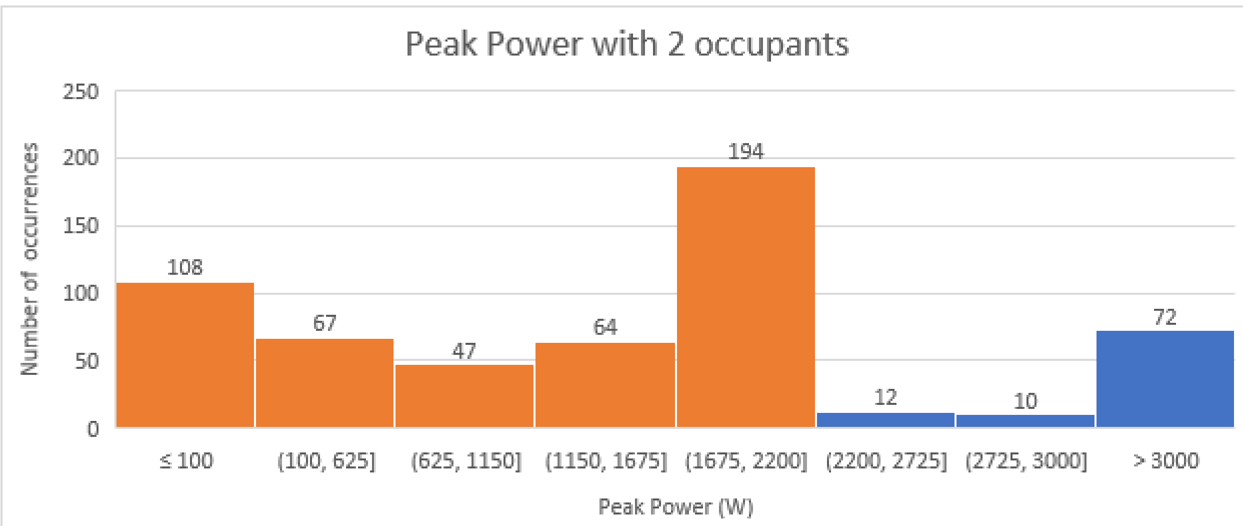
Average power with 4 occupants
Number of occurrences
300
250
200
150
100
50
0
149
132
247
259
154
24
5
7
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
(2725, 3000]
> 3000
Average Power (W)

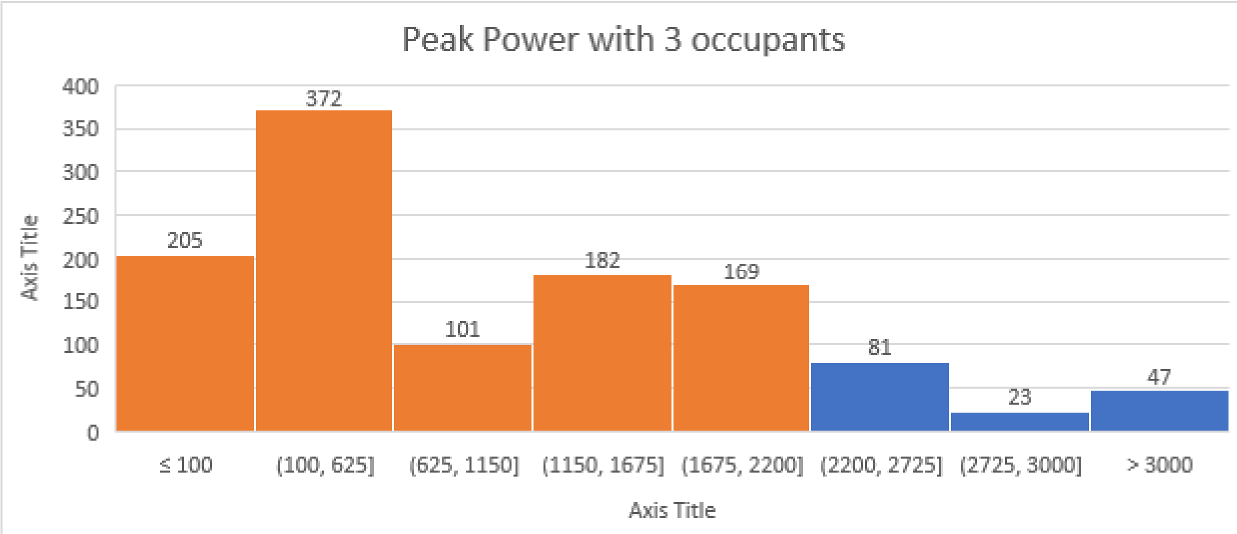

Average Power with 5 occupants
Number of occurrences
900
800
700
600
500
400
300
200
100
0
391
611
678
810
367
130
29
26
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
(2725, 3000]
> 3000
Average Power (W)

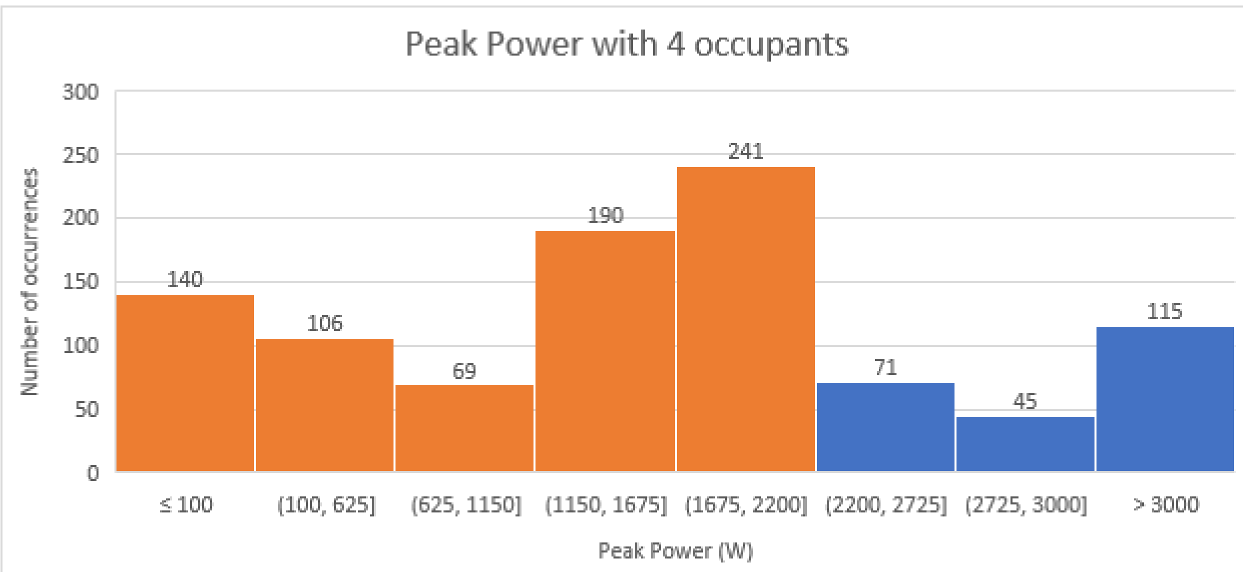

Average Power with 6 occupants
Number of occurrences
200
180
160
140
120
100
80
60
40
20
0
162
92
182
107
68
12
9
10
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
(2725, 3000]
> 3000
Average Power (W)

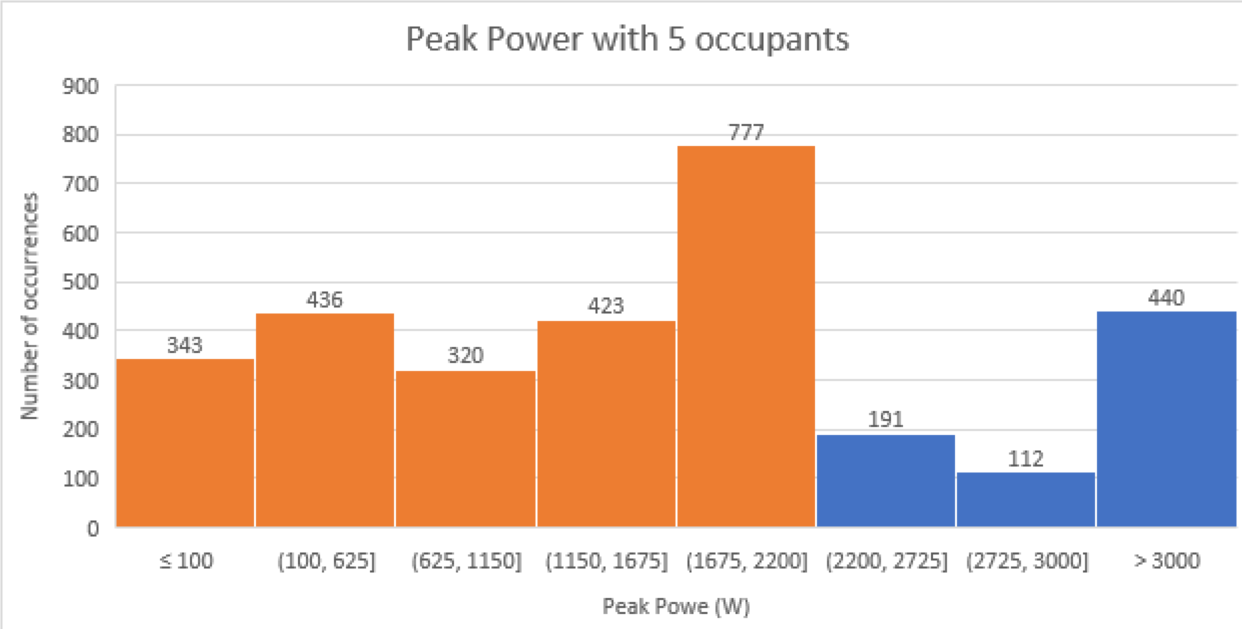
Appendix F: Peak Power with 1 to 6 occupants for induction cooktop



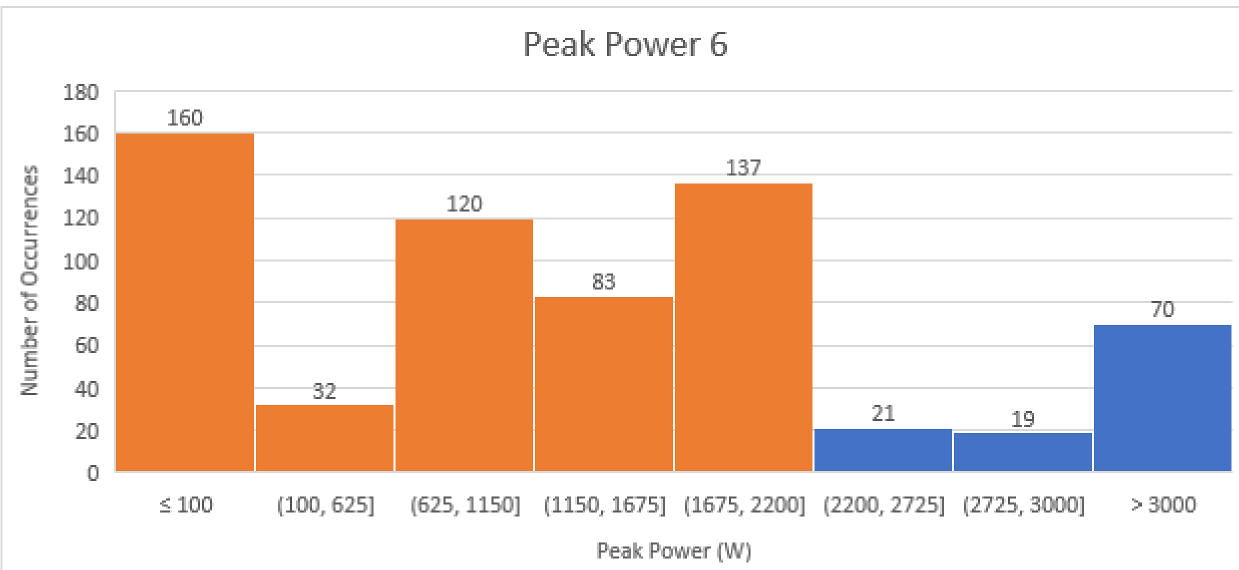



Peak Power with 3 occupants
400
350
300
250
200
150
100
50
0
Axis Title
205
372
101
182
169
81
23
47
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
(2725, 3000]
> 3000
Axis Title


Peak Power with 4 occupants
300
250
200
150
100
50
0
Number of occurrences
140
106
69
190
241
71
45
115
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
(2725, 3000]
> 3000
Peak Power (W)



Peak Power with 5 occupants
Number of occurrences
0
100
200
300
400
500
600
700
800
900
343
436
320
423
777
191
112
440
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
(2725, 3000]
> 3000
Peak Powe (W)



Peak Power 6
Number of Occurrences
0
20
40
60
80
100
120
140
160
180
160
32
120
83
137
21
19
70
≤ 100
(100, 625]
(625, 1150]
(1150, 1675]
(1675, 2200]
(2200, 2725]
(2725, 3000]
> 3000
Peak Power (W)