

Evaluating the new KIC Navigator Option to Select Optimal Oven Recipe for Reduced Power Consumption, for Sn-Pb and Pb-Free Reflow Soldering

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Goal

To study the efficiency of new Navigator Power option in KIC 2000, to select an optimal oven recipe for reduced power consumption, for Sn-Pb and Pb-Free reflow soldering.

Objective

- To use the new KIC Navigator option to generate and select oven recipes for reduced power consumption
- To measure the reduction in energy consumption by comparing the following:
 - The energy consumed for the existing in-spec oven recipe, for a production run and
 - The equivalent energy consumed after changing the oven recipe to the settings suggested by the new KIC Navigator option

KIC 2000 – Navigator

The new KIC 2000 Navigator Power software has the following three profile optimization settings:

- **Minimize PWI:**
 - This option will search for different set point temperatures and conveyor speeds which will reduce the PWI (Process Window Index)
- **Maximize Conveyor Speed:**
 - This option will search for the set point temperatures that will maximize the conveyor speed
- **Minimize Energy Consumption:**
 - This option will search for an in-spec profile with lower temperature settings and conveyor speed that will minimize power consumption and maintain the PWI below a specified maximum

KIC 2000 Terminology

Process Window Index (PWI)

The PWI is a measure of how well a profile performs relative to critical process limits. It is specified as an absolute value in %. The lower the PWI, the closer the profile is to the specification targets. The center of the process window is zero and the extreme ends of the process window are $\pm 99\%$. A PWI of 100% or more will indicate that the profile is not in specifications.

In-spec Profile

An in-spec profile for a product refers to any reflow profile with $PWI < 100\%$. In Fig.1, the area enclosed by the outer most circles (100%) forms the in-spec profile area. Any region outside the largest circle is considered out-of-spec.

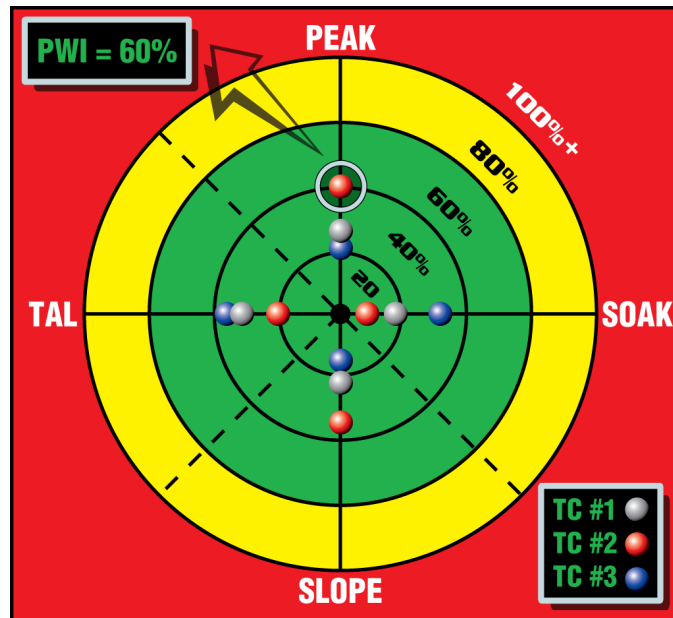


Figure 1: Process Window Index (PWI) and In-spec Profile

The individual data points for each parameter are represented by the solid beads. The bead farthest from the center (max PWI) is the worst-case scenario in PWI and is considered the PWI of the profile.

Experimental Study

- Three different companies were selected for this project.

Company A: Surmotech CMS is a full-service contract manufacturer specializing in high-reliability medical, industrial and military applications. Located in Victor, NY, Surmotech is an ISO 9001:2000 registered company that focuses on providing complete turnkey solutions that include design, prototyping, engineering, materials management, testing and field service.

Company B: Marquardt is a global manufacturer of electromechanical and electronic components, supplying the hand tool and automotive industries.

Company C: SenDEC is organized into two main business units: the Contract Electronics Manufacturing (CEM) Group and the Products Group. SenDEC's CEM Group provides electronics manufacturing services (EMS) including design, prototype, PCB assembly, electromechanical assembly, test engineering, rework, material management and turnkey box build services. The SenDEC Products Group manufactures its own family of digital monitoring, display and control devices for numerous markets across the globe.

- The different assemblies considered for the experimental runs in the three companies is shown below:

	Sn-Pb	Pb-Free
Company A	✓	
Company B	✓	
Company C	✓	✓ (2)*

*The number in the parenthesis indicates number of products run

- Power consumption measurement was carried out by installing a meter on the oven at each site, to record the amount of power being consumed for the production runs, for each profile.

Experimental Procedure

- At each site, the product that is to be used for the production runs is identified.
- Reflow profile set points and paste details for that product are taken from the customer.
- The product is run using the existing profile set points to check if the reflow profile is in-spec with respect to the paste manufacturer specifications or the company's approved specifications.
- If the profile is not in-spec, the customer is asked to bring the process in-spec, using their current method.
- Once the profile is in-spec, the production run is executed for at least a 3-hour period.
- Following the 3-hour period, the new KIC Navigator option is used to identify a recipe (oven setpoints) for reduced power consumption.
- The new recipe is loaded in the oven. After the oven stabilizes, a test board is run for approval by the quality control department within the company.
- Subsequent to the approval from the quality department, the production run is executed for the next 3-hour period.
- The power consumption is recorded continuously for both the profiles and then analyzed for difference and statistical significance of the difference, using a t-Test.

Data collection

Company A:

- Oven name: Speedline Technologies Electrovert Bravo 8105
- No of Zones: 8
- No of products run: 1 Sn-Pb

Sn-Pb Product	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6	Zone #7	Zone #8	Conveyor Speed	PWI	Temperature set point difference
Existing set points	120	140	170	170	180	205	230	245	30 in/min	N/A	13°C
KIC set points	112	130	160	182	182	194	245	242	25 in/min	22%	

Company B:

- Oven name: Rehm V8 Nitro 32 B
- No of Zones: 7
- No of products run: 1 Sn-Pb

Sn-Pb Product	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6	Zone #7	Conveyor Speed	PWI	Temperature set point difference
Existing set points	120	140	165	180	240	200	165	27 in/min	N/A	107°C
KIC set points (Paste Specs)	94	129	154	193	234	166	133	24 in/min	93%	

Sn-Pb Product	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6	Zone #7	Conveyor Speed	PWI	Temperature set point difference
Existing set points	120	140	165	180	240	200	165	27 in/min	N/A	21°C
KIC set points (JEDEC Specs)	120	139	161	170	237	187	175	24 in/min	53%	

Company C:

- Oven name: Vitronics Soltec XPM2
- No of Zones: 8
- No of products run: 1 Sn-Pb, 2 Pb-Free

Pb-Free Product #1	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6	Zone #7	Zone #8	Conveyor Speed	PWI	Temperature set point difference
Existing set points	110	120	160	180	200	240	270	275	25	N/A	8°C
KIC set points	110	120	160	180	199	234	270	274	23	63%	

Pb-Free Product #2	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6	Zone #7	Zone #8	Conveyor Speed	PWI	Temperature set point difference
Existing set points	135	145	155	185	220	245	285	275	23	N/A	45°C
KIC set points	97	124	151	183	222	247	286	290	22	72%	

Sn-Pb Product	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6	Zone #7	Zone #8	Conveyor Speed	PWI	Temperature set point difference
Existing set points	90	130	180	180	180	220	240	220	28	N/A	50°C
KIC set points	71	117	181	170	159	209	249	234	23	69%	

Data Analysis

Company A:

The data analysis for the Sn-Pb product run is discussed below:

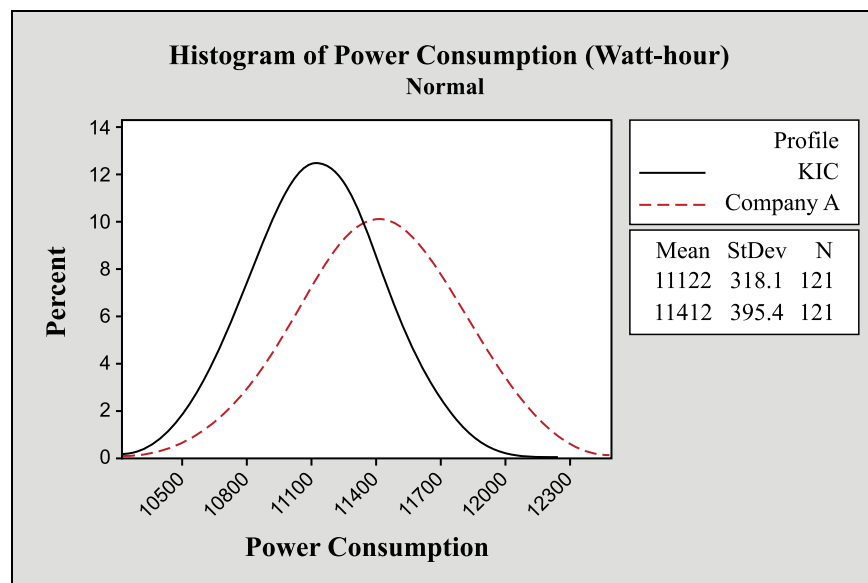


Figure 2: Mean Power Consumption Comparison – Company A

From Figure 2 it is evident that the KIC profile appears to be consuming less power than Company A's profile. This is indicated by the means (11122 and 11412 Watt-Hour respectively) shown in the table within the graph, as well as the relative position of the peaks for the fitted normal distribution. The standard deviation for Company A's profile (395.4 Watt-Hour) is

greater than the KIC profile (318.1 Watt-Hour), indicating a much tighter power consumption profile for KIC recommended setpoints, when compared to Company A’s setpoints.

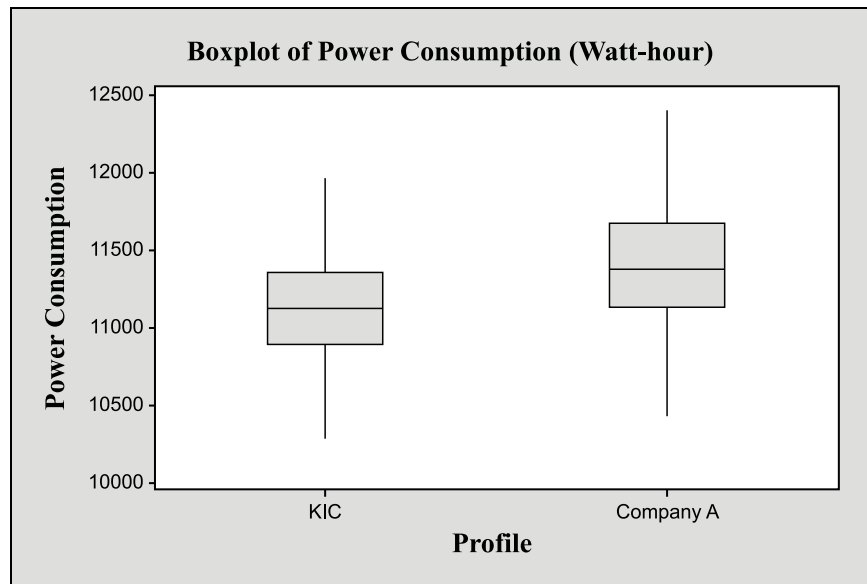


Figure 3: Boxplot for Power Consumption in Company A

The box plot (Figure 3) reveals that the median power consumption for KIC recommended profile was lower than Company A’s profile and the power consumption distribution for KIC recommended profile was considerably tighter than that for Company A’s profile. Even though graphically there seems to be a difference in the power consumption, KIC recommended profile providing lesser power consumption than the Company A’s profile, it was necessary to determine if the difference observed was statistically significant. This was carried out using the 2-Sample t-Test.

The 2-Sample t-Test is a hypothesis test for two population means to determine whether they are significantly different. This procedure uses the null hypothesis that the difference between two population means is equal to a hypothesized value ($H_0: \mu_1 - \mu_2 = 0$), and tests it against an alternative hypothesis, which can be left-tailed ($\mu_1 - \mu_2 < 0$) or right-tailed ($\mu_1 - \mu_2 > 0$). If the t-Test’s p-value is less than the chosen significance level ($\alpha = 0.05$), the null hypothesis will be rejected.

Two-Sample T-Test and CI: Power Consumption, Profile

Two-sample t-Test for Power Consumption				
Profile	N	Mean	StDev	SE Mean
KIC	121	11122	318	29
Company A	121	11412	395	36

Difference = μ (KIC) - μ (Company A)
 Estimate for difference: -290.9
 95% upper bound for difference: -214.7
 t-Test of difference = 0 (vs <): T-Value = -6.31; p-Value = 0.000; DF = 229

The results of the t-Test (p-value < 0.05) indicate that the difference between the average power consumption for the two profiles is significant. Furthermore, there is a reduction in power consumption of 2.55% (290.9 Watt-Hour) with the KIC recommended profile.

Company B:

Company B had been using JEDEC specifications instead of the paste specifications for the Sn-Pb product considered for the experiment. JEDEC specifications are much wider than the paste specifications, thereby posing the challenge of shrinking the process window within tighter specifications without compromising on the quality of the output. For a better analysis, the KIC Navigator option was used to generate profiles for both the JEDEC and the paste specifications. The data analysis is discussed below:

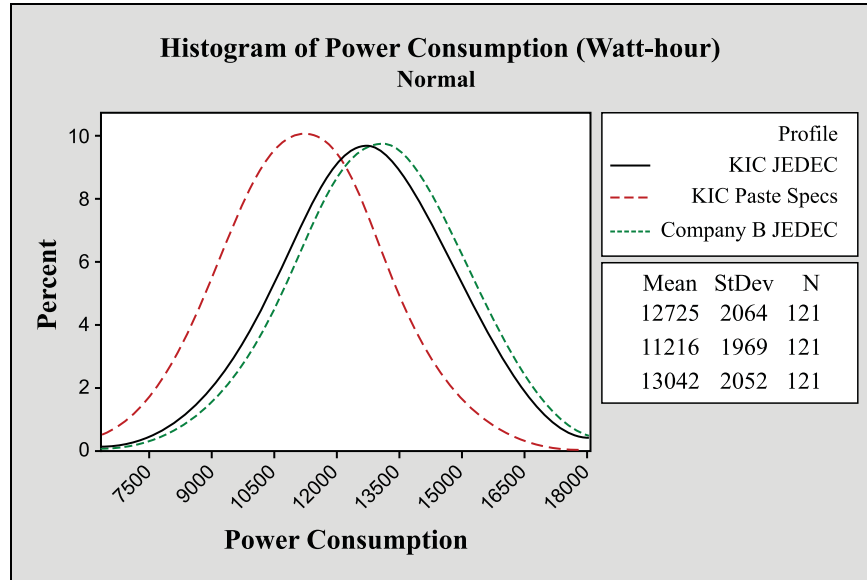


Figure 4: Mean Power Consumption Comparison – Company B

Both KIC profiles (KIC JEDEC and KIC Paste Specs) appear to be consuming less power when compared to Company B's profile, with the KIC Paste Specs being the best. This is indicated by the means (12725, 11216 and 13042 Watt-Hour), as well as the relative position of the peaks for the fitted normal distribution.

The standard deviation for Company B's profile (2052 Watt-Hour) is slightly less than the KIC JEDEC profile, but greater than the KIC Paste Specs profile (1969 Watt-Hour). This has resulted in a much steeper and tighter fitted distribution for KIC Paste Specs Profile.

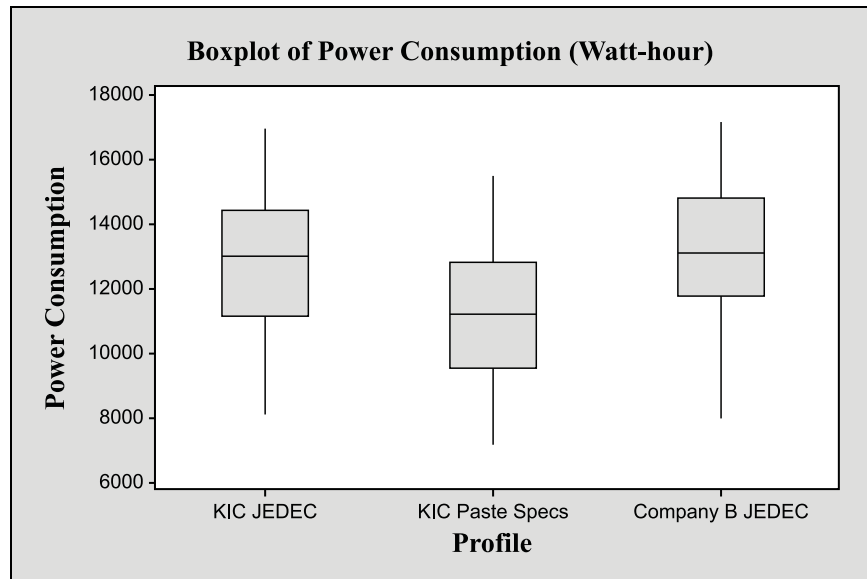


Figure 5: Boxplot for Power Consumption in Company B

The box plot comparing the profiles for Company B (Figure 5) shows that the median power consumption is higher for Company B's profile (13039.1 Watt-Hour) as compared to the KIC JEDEC (12999.1 Watt-Hour) and KIC Paste Specs (11165.7 Watt-Hour) profiles.

Comparison between Company B (JEDEC Specs) and KIC JEDEC Specs Profiles:

Two-Sample T-Test and CI: Power Consumption, Profile

Two-sample t-Test for Power Consumption				
Profile	N	Mean	StDev	SE Mean
KIC JEDEC Specs	121	12725	2064	188
Company B (JEDEC Specs)	121	13042	2052	187

Difference = μ (KIC JEDEC Specs) - μ (Company B JEDEC Specs)
 Estimate for difference: -317
 95% upper bound for difference: 120
 t-Test of difference = 0 (vs <): t-Value = -1.20; p-Value = 0.116; DF = 239

The results of the t-Test (p-value > 0.05) indicate that the difference between the average power consumption for the two profiles is not significant. However, there is a reduction in power consumption of 2.43% (317 Watt-Hour) with the KIC recommended profile. When using the JEDEC specifications the profile difference was not statistically significant.

Comparison between Company B (JEDEC Specs) and KIC Paste Specs Profiles:

Two-Sample T-Test and CI: Power Consumption, Profile

Two-sample t-Test for Power Consumption				
Profile	N	Mean	StDev	SE Mean
KIC Paste Specs	121	11216	1969	179
Company B (JEDEC Specs)	121	13042	2052	187

Difference = μ (KIC Paste Specs) - μ (Company B JEDEC Specs)
 Estimate for difference: -1826
 95% upper bound for difference: -1399
 t-Test of difference = 0 (vs <): t-Value = -7.06; p-Value = 0.000; DF = 239

The results of the t-Test (p-value < 0.05) indicate that the difference between the average power consumption for the two profiles is significant. Furthermore, there is a reduction in power consumption of 14% (1826 Watt-Hour) with the KIC recommended profile.

Company C: Product #1 (Pb-Free)

The data analysis for the first Pb-Free product run is discussed below:

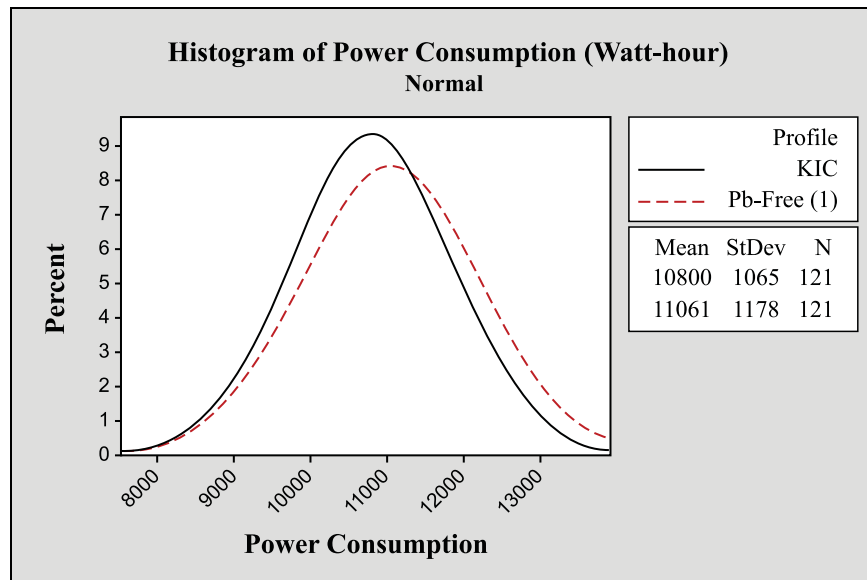


Figure 6: Mean Power Consumption Comparison – Company C Pb-Free Product 1

The KIC profile appears to be a slightly lesser power consuming than the Company C’s profile. This is indicated by the tabled means (10800 and 11061 Watt-Hour, respectively), as well as the relative position of the peaks for the fitted normal distribution. The standard deviation for Company C’s profile (1178 Watt-Hour) is greater than the KIC profile (1065 Watt-Hour). This has resulted in a shorter and wider-looking fitted distribution for company C’s profile.

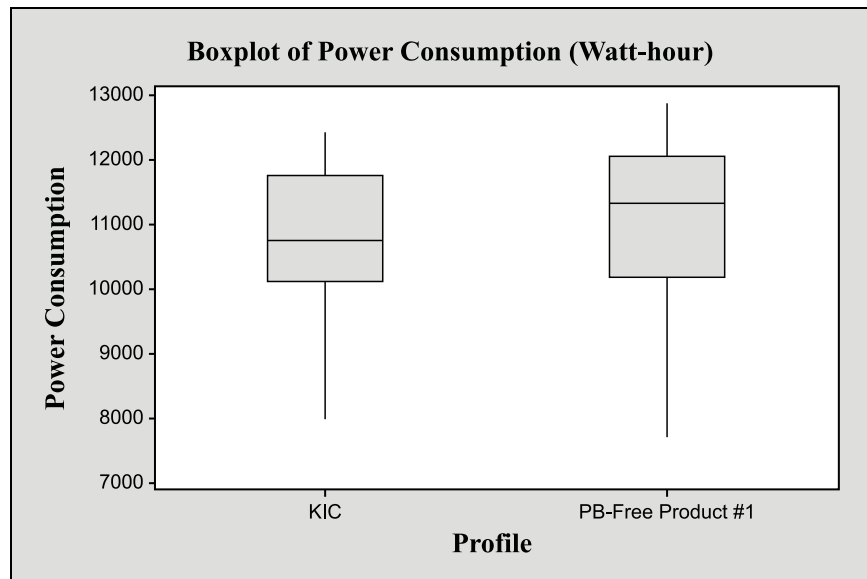


Figure 7: Boxplot for Power Consumption in Company C for Pb Free Product 1

The box plot shown in Figure 7 reveals higher power consumption for Company C’s profile (11328.5 Watt-Hour) as compared to KIC profile (10766.4 Watt-Hour).

Two-Sample T-Test and CI: Power Consumption, Profile

Two-sample t-Test for Power Consumption

Profile	N	Mean	StDev	SE Mean
KIC	121	10800	1065	97
Company C (Product #1)	121	11061	1178	107

Difference = μ (KIC) - μ (Company C Product #1)

Estimate for difference: -261

95% upper bound for difference: -22

t-Test of difference = 0 (vs <): t-Value = -1.81; p-Value = 0.036; DF = 237

The results of the t-Test (p-value < 0.05) indicate that the difference between the average power consumption for the two profiles is significant. There is a reduction in power consumption of 2.36% (261 Watt-Hour) with the KIC recommended profile.

Company C: Product #2 (Pb-Free)

The data analysis for the second Pb-Free product run is discussed below:

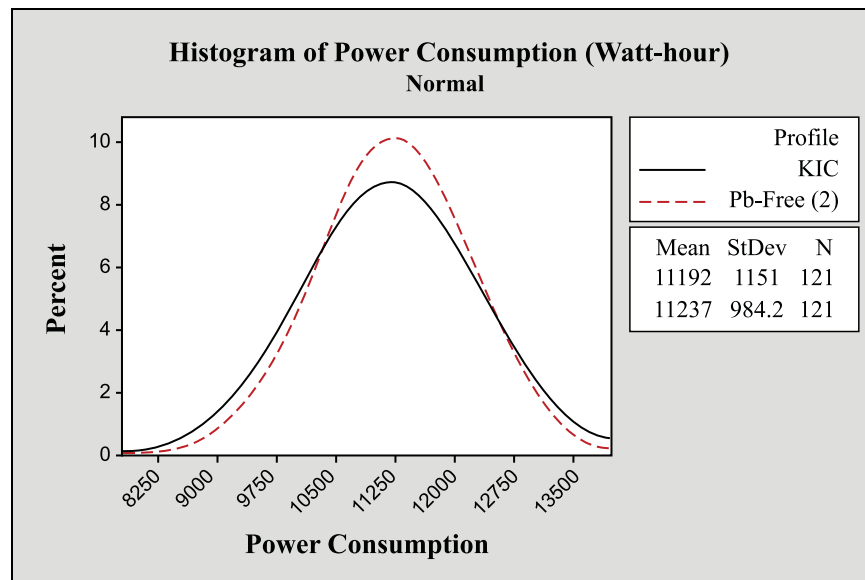


Figure 8: Mean Power Consumption Comparison – Company C Pb Free Product 2

The KIC profile appears to be a slightly lesser power consuming than the Company C's profile. This is indicated by the means in the table (11192 and 11237 Watt-Hour, respectively), as well as the relative position of the peaks for the fitted normal distribution. However, the standard deviation for Company C's profile (984.2 Watt-Hour) is slightly less than the KIC profile (1151 Watt-Hour). This has resulted in a shorter and wider-looking fitted distribution for KIC profile.

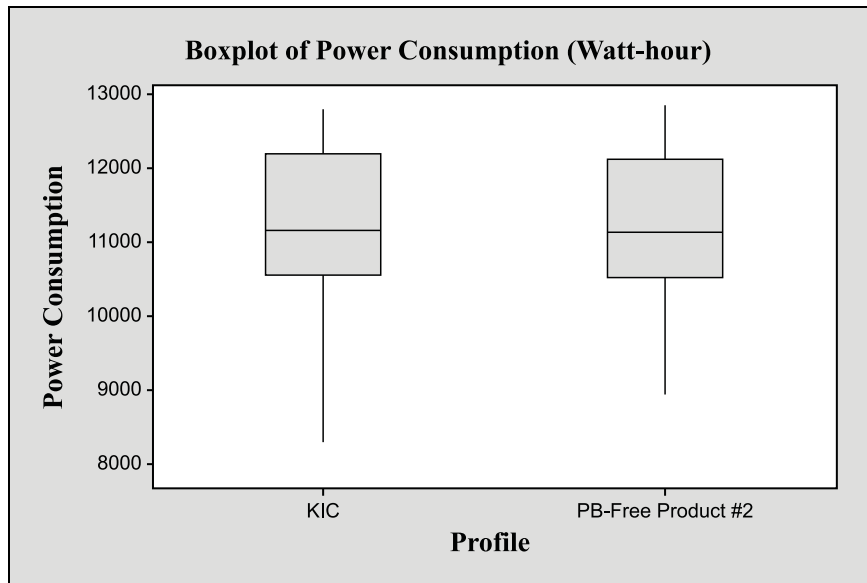


Figure 9: Boxplot for Power Consumption in Company C Pb Free Product 2

Median power consumption in both the profiles (Figure 9) is almost the same suggesting not much difference in the power consumption between the two profiles.

Two-Sample T-Test and CI: Power Consumption, Profile

Two-sample t for Power Consumption				
Profile	N	Mean	StDev	SE Mean
KIC	121	11192	1151	105
Company C (Product #2)	121	11237	984	89

Difference = μ (KIC) - μ (Company C Product #2)

Estimate for difference: -45

95% upper bound for difference: 182

t-Test of difference = 0 (vs <): t-Value = -0.33; p-Value = 0.372; DF = 234

The results of the t-Test (p-value > 0.05) indicate that the difference between the average power consumption for the two profiles is not significant. There is minimal reduction in power consumption (45 Watt-Hour) with the KIC recommended profile.

Company C: Product #3 (Sn-Pb)

The data analysis for a Sn-Pb product run is discussed below:

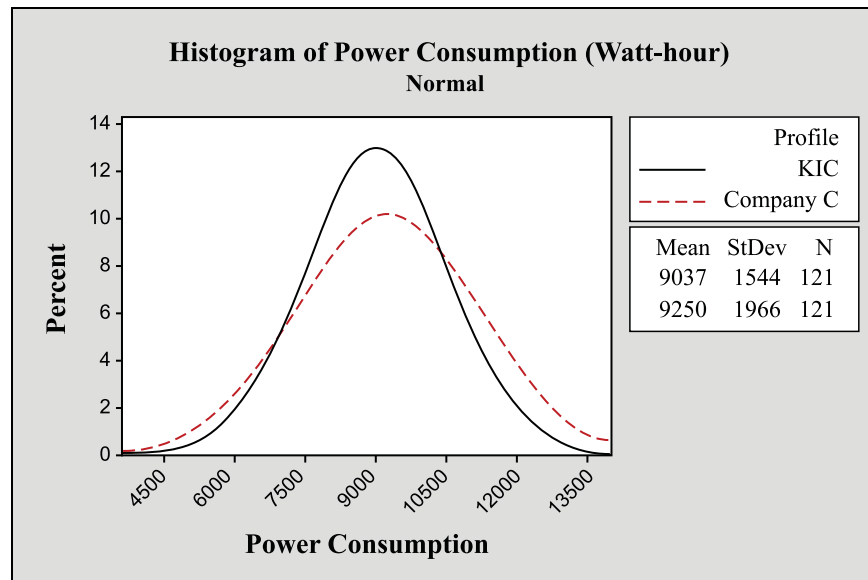


Figure 10: Mean Power Consumption Comparison – Company C Sn-Pb Product

The KIC profile appears to be a lesser power consuming profile than the Company C's profile. This is indicated by the tabled means (9037 and 9250 Watt-Hour, respectively), as well as the relative position of the peaks for the fitted normal distribution. The standard deviation for Company C's profile (1966 Watt-Hour) is greater than the KIC profile (1544 Watt-Hour). This has resulted in a shorter and wider-looking fitted distribution for company C's profile.

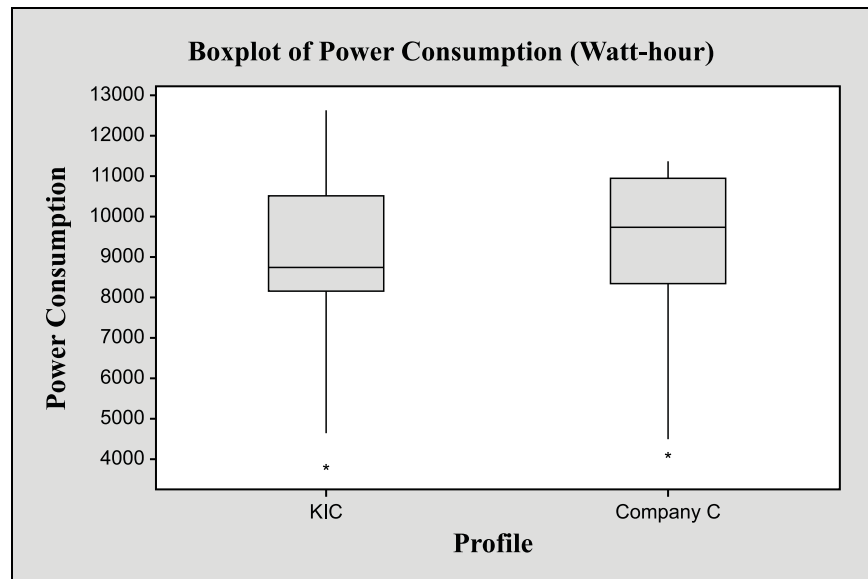


Figure 11: Boxplot for Power Consumption in Company C Sn-Pb Product

Median power consumption is higher for Company C's profile (9731.28 Watt-Hour) as compared to KIC profile (8739.35 Watt-Hour)

Two-Sample T-Test and CI: Power Consumption, Profile

Two-sample t for Power Consumption

Profile	N	Mean	StDev	SE Mean
KIC	121	9037	1544	140
Company C (Product #3)	121	9250	1966	179

Difference = μ (KIC) - μ (Company C Product #3)

Estimate for difference: -213

95% upper bound for difference: 162

t-Test of difference = 0 (vs <): t-Value = -0.94; p-Value = 0.175; DF = 227

The results of the t-Test (p-value > 0.05) indicate that the difference between the average power consumption for the two profiles is not significant. However, there is a reduction in power consumption of 2.3% (213 Watt-Hour) with the KIC recommended profile.

Comparison between the Average Power Consumption for different companies

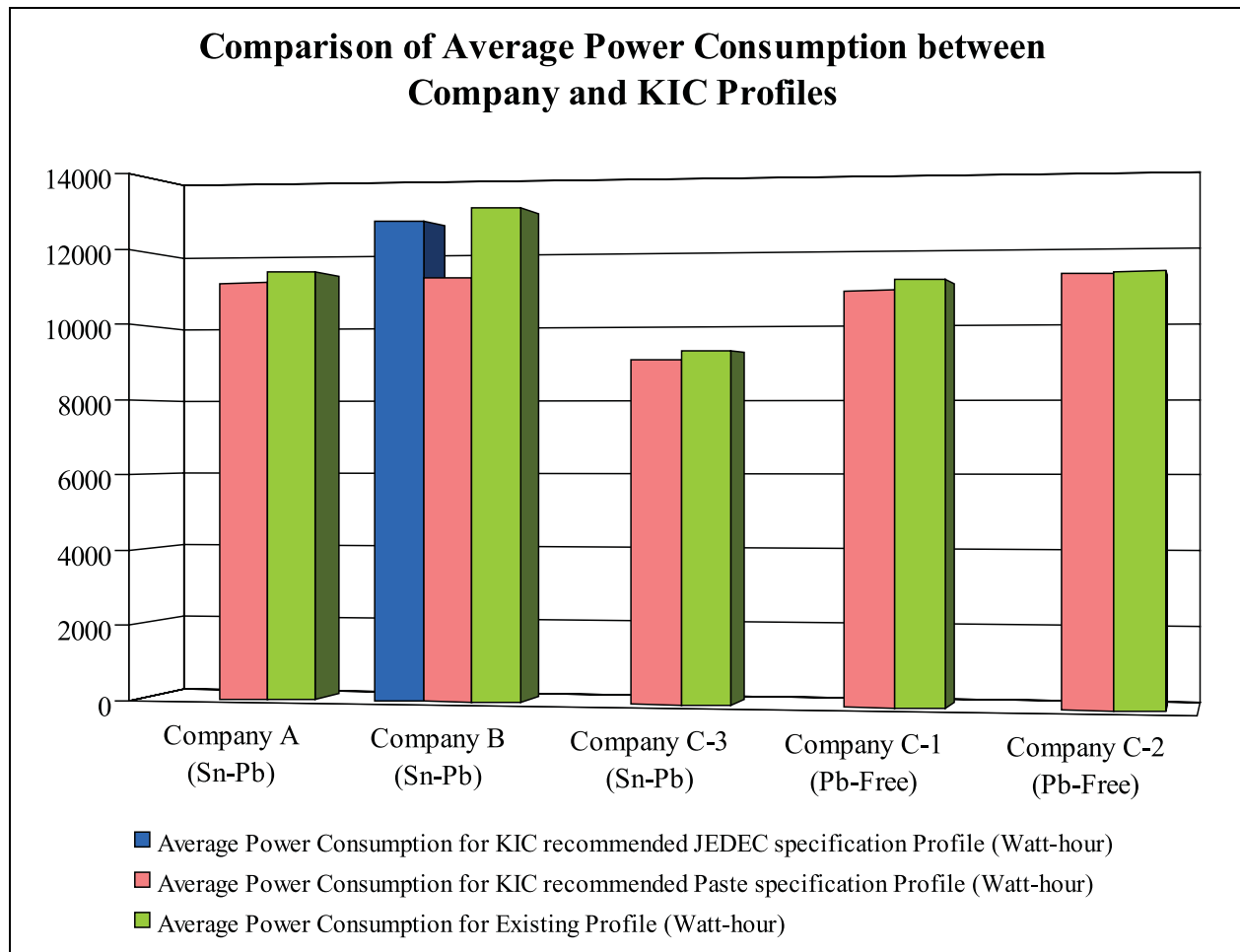


Figure 12: Comparison of Mean Power Consumption for All Profiles

In all cases, the KIC recommended profiles have lower power consumption than the existing company profiles.

Comparison between the Std Dev of the Power Consumption for different companies

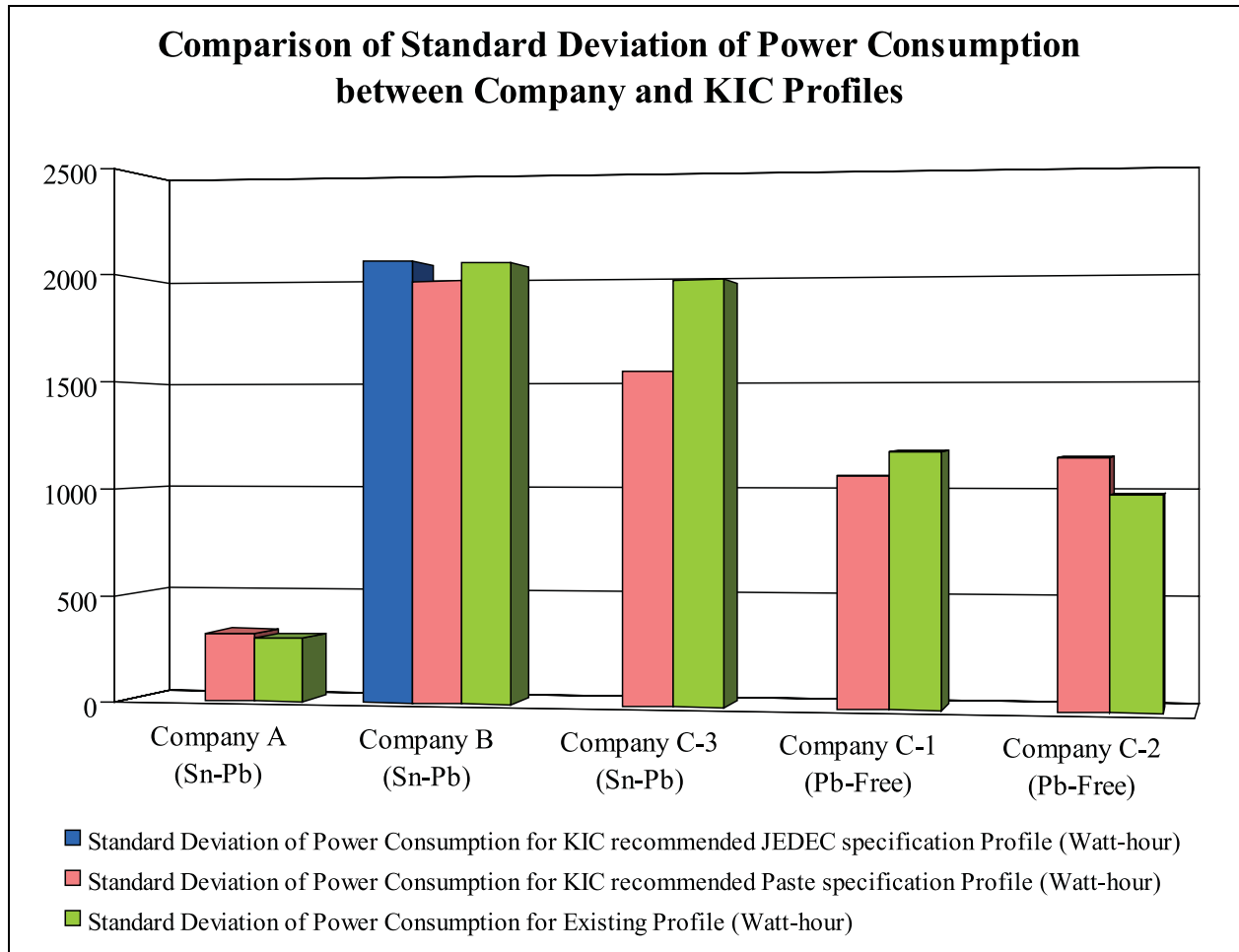


Figure 13: Comparison of Std. Dev. of Power Consumption for All Profiles

Moreover, the Standard Deviation of Power Consumption for all KIC Profiles is lesser than the existing company profiles.

Issues faced during Experimentation

Company A

- The oven could not stabilize at the set points recommended by KIC Navigator due to its limitations (interference of the adjacent zone). Due to this limitation, the minimum set point for the first zone had to be restricted to 110°C, even though the KIC software recommended 71°C.
- For this site, one of the recent updates for the Beta version of the software was not available as KIC sent it later.

Company C

- The software experienced a bug that predicted the same set points as the original.

Conclusions

- The recipes recommended by the new KIC Navigator feature have been observed to have either reduced the power consumption when compared existing recipe or maintained it the same. This is shown in the figure below (Figure 14):

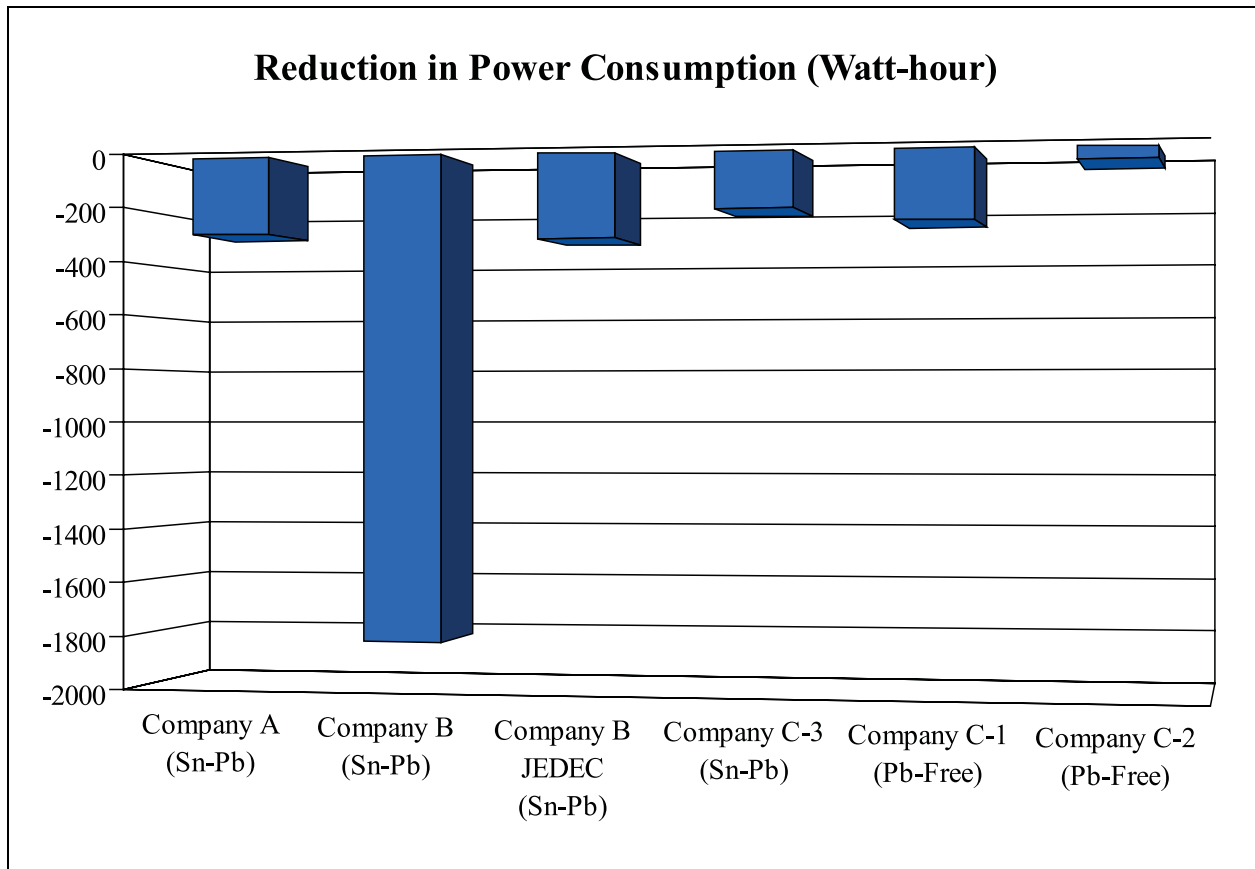


Figure 14: Power Consumption Reduction for all Profiles

- Furthermore, it is also observed that in most cases, the percentage reduction in power consumption is 2% or higher, as shown in the figure below (Figure 15):

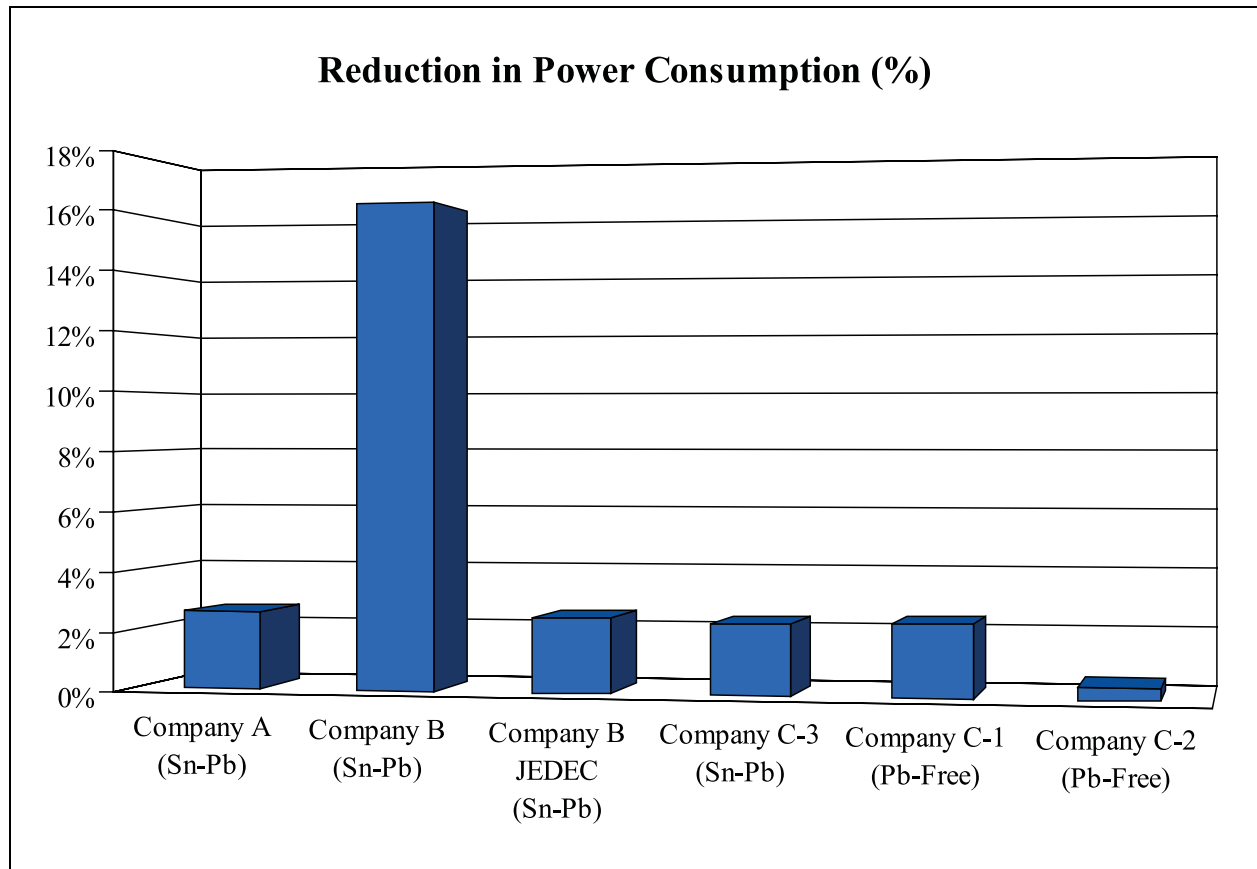


Figure 15: Percentage Reduction in Power Consumption

- The new Navigator Power option has the capability to generate a reduced power consumption recipe without compromising the productivity and the quality of the output.
- The software provides the flexibility to incorporate the restrictions offered by the reflow oven
- The updated software version has a large solder paste menu (both Sn-Pb and Pb-Free) to select from. This feature automatically feeds the solder paste specifications.