

Statistical Consulting Report

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Water Removal from Pan

The objective of this research was to test whether or not water can be removed from the wall cavity under different pressures, with and without insulation and air cooler.

The factors in the experiment were as follows:

Pressure Readings (three levels): **30, 20, 10** psi

Insulation (two levels): **Yes/No**

Air cooler (two levels): **Yes/No**

A controlled amount of water (285 ± 5 g) was placed inside a holding pan and the following measurements were recorded:

- Initial weight of wall (no water)
- Weight of pan + water
- Weight of wall + water
 - Hourly measurements of wall + water (1 – 4 hr)
- Final weight of pan + water

Research Questions

Looking at the amount of water lost hourly as well as total (pan and wall):

1. Is there a difference in water removal with and without the air cooler at respective pressure readings?
 - a. With and without insulation?
 - b. Are there hourly differences?
2. Is there a difference in the total amount of water removed from the pan versus the total amount of water removed from the wall?
 - a. With and without insulation
 - b. With and without air cooler

I am more interested in showing the total loss from the pan versus the total loss from the wall.

Comments

The response variable is Pan_final_gr.

The authors cleverly recorded the initial wall and initial pan weights, which can be used as covariates in analysis of variance to test the effects of factors on water removal.

A linear model can be fit to the response variable to tests the following hypotheses:

Pressure differences are not different for water removal ($H_0: \mu_1 = \mu_2 = \mu_3 = 0$)

Insulation does not affect water removal ($H_0: \mu_1 = \mu_2 = 0$)

Air Cooler does not affect water removal ($H_0: \mu_1 = \mu_2 = 0$)

The model is

$$y_{ijkl} = \mu + \beta X + I_{ij} + P_i + I_j + A_k + PI_{ij} + PA_{ij} + IA_{ij} + PI_{ij} + e_{ijkl}$$

y_{ijkl} is the l th observation of the i th pressure, j th insulation and k th air cooler;

μ is the overall mean;

X is the covariate (initial pan weight)

β is the coefficient of the covariate

P_i is the i th pressure effect ($i=1,2,3$), $E(P) = 0$;

I_j is the j th Insulation effect ($j=1,2$), $E(I) = 0$;

A_k is the k th Air cooler effect ($k=1,2$), $E(A) = 0$;

PI_{ij} is i th pressure by j th insulation interaction;

PA_{ik} is i th pressure by k th air cooler interaction;

IA_{jk} is i th insulation by j th air cooler interaction;

e_{ij} is random error associated with l th observation of the i th pressure, j th insulation and k th air cooler with the expectations of $\sim NID(0, \sigma^2)$.

SAS GLM procedure (SAS 9.2) can be used to test the hypotheses outlined above.

```
ods graphics on;
proc glm data=pan ;
class Pressure Insulation Aircooler ;
model pan_final_gr = pan_in_gr    pressure  Insulation  aircooler
                        pressure*insulation pressure*AirCooler
                        insulation*aircooler ;
means pressure Insulation aircooler /tukey ;
means pressure*Insulation pressure*AirCooler insulation*aircooler/tukey ;
run;
ods graphics off;
```

The output from is given below:

The GLM Procedure

Class Level Information

Class	Levels	Values
Pressure	3	PSI10 PSI20 PSI30
Insulation	2	Insulation NoInsulation
AirCooler	2	AirCooler NoAircooler

Number of Observations Read 144
 Number of Observations Used 144

Dependent Variable: Pan_final_gr

Sum of Source	DF	Squares	Mean Square	F Value	Pr > F
Model	10	53985.66435	5398.56643	102.46	<.0001
Error	133	7007.40565	52.68726		
Corrected Total	143	60993.07000			

R-Square 0.885111 Coeff Var 2.698916 Root MSE 7.258599 Pan_final_gr Mean 268.9450

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pressure	2	5829.22320	2914.61160	55.32	<.0001
Insulation	1	43538.99560	43538.99560	826.37	<.0001
AirCooler	1	91.01160	91.01160	1.73	0.1910
Pressure*Insulation	2	3138.58320	1569.29160	29.79	<.0001
Pressure*AirCooler	2	421.71387	210.85693	4.00	0.0205
Insulation*AirCooler	1	953.16271	953.16271	18.09	<.0001
Pan_in_gr	1	12.97417	12.97417	0.25	0.6205

The F tests in above output show that the main effects of Pressure and Insulation are highly significant, while the effect of AirCooler was not. All two-way interactions were also significant. Thus, although Air cooler main effect is not significant, it should be kept in the model to have hierarchical models. The Pressure*Insulation interaction effect is highly significant with a Pr value of <0.0001.

The next step is look at the multiple range to see which levels of a factor are different from each other and how the levels interacts with other factors.

Tukey's Studentized Range (HSD) Test for Pan_final_gr

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	133
Error Mean Square	52.68726
Critical Value of Studentized Range	3.35203
Minimum Significant Difference	3.5119

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Pressure
A	277.300	48	PSI10
B	267.660	48	PSI20
C	261.875	48	PSI30

The Tukey grouping shows that under PSI30, water removal from the pan is the most efficient, followed by PSI20 and PSI10.

Tukey's Studentized Range (HSD) Test for Pan_final_gr

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	133
Error Mean Square	52.68726
Critical Value of Studentized Range	2.79726
Minimum Significant Difference	2.3929

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Insulation
A	286.333	72	Insulation
B	251.557	72	NoInsulation

Having no insulation is more efficient in water removal than with insulation.

Tukey's Studentized Range (HSD) Test for Pan_final_gr

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha 0.05
 Error Degrees of Freedom 133
 Error Mean Square 52.68726
 Critical Value of Studentized Range 2.79726
 Minimum Significant Difference 2.3929

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	AirCooler
A	269.740	72	NoAircooler
A	268.150	72	AirCooler

Multiple range tests with interactions

Level of Pressure	Level of Insulation	N	-----Pan_final_gr-----		-----Pan_in_gr-----	
			Mean	Std Dev	Mean	Std Dev
PSI10	Insulation	24	288.833333	2.7293361	297.691667	0.94658042
PSI10	NoInsulation	24	265.766667	15.8626350	297.833333	1.49394915
PSI20	Insulation	24	285.333333	4.0288812	296.333333	3.47245893
PSI20	NoInsulation	24	249.986667	4.9414895	298.186667	1.25423341
PSI30	Insulation	24	284.833333	6.6572397	298.333333	0.96308682
PSI30	NoInsulation	24	238.916667	4.9926613	298.616667	1.00505966

Since interactions are significant, comparing different pressures with Insulation and without insulation makes more sense than comparing the main effects of pressure. The above means shows that when pressure is combined with insulation, the best results (water removal) can be obtained by having PSI30+No Insulation. The pan weight with and without insulation under PSI30 is 284.8 and 238.9, respectively. This is about 46 gram difference. On the other hand the main effect of PSI30 was only 261.87 g.

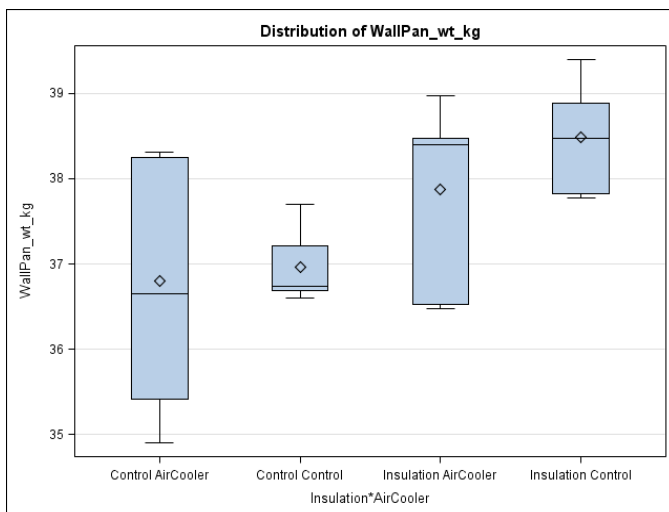
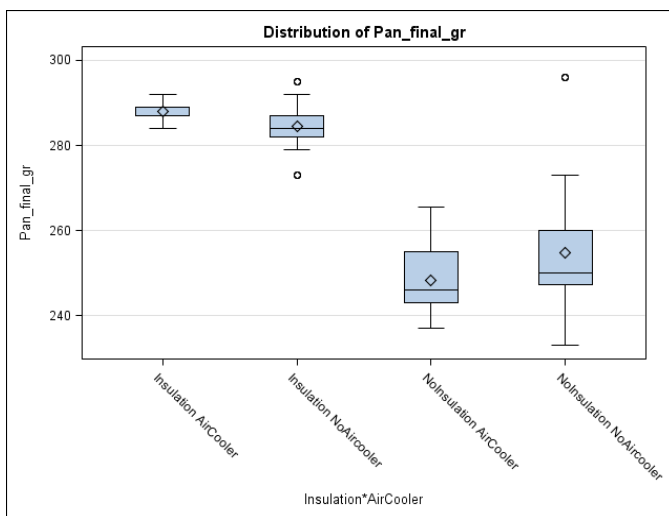
Level of Pressure	Level of AirCooler	N	-----Pan_final_gr-----		-----Pan_in_gr-----	
			Mean	Std Dev	Mean	Std Dev
PSI10	AirCooler	24	274.100000	16.3733612	298.191667	1.06338944
PSI10	NoAircooler	24	280.500000	15.7231483	297.333333	1.27404411
PSI20	AirCooler	24	267.833333	21.6567424	296.833333	3.74939609
PSI20	NoAircooler	24	267.486667	14.9474752	297.686667	0.99261038
PSI30	AirCooler	24	262.516667	23.7545724	298.616667	0.81382974
PSI30	NoAircooler	24	261.233333	24.5786522	298.333333	1.12931941

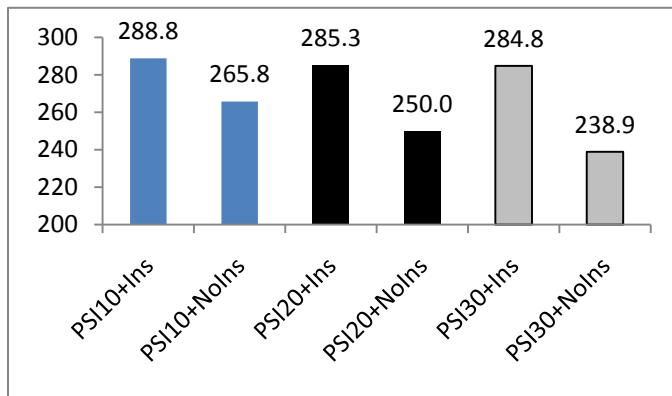
In above output, having air cooler or not is significant only when the air pressure is PSI10. If the pressure is low (PSI10) then having air cooler will have a significant impact on water removal. However, air cooler does not have an effect when the pressure is greater (PSI20 and PSI30).

Level of Insulation	Level of AirCooler	N	-----Pan_final_gr----- Mean	Std Dev	-----Pan_in_gr----- Mean	Std Dev
Insulation	AirCooler	36	288.111111	2.3637474	297.016667	2.98606286
Insulation	NoAircooler	36	284.555556	6.2538877	297.888889	1.11554670
NoInsulation	AirCooler	36	248.188889	8.7207397	298.744444	1.07449508
NoInsulation	NoAircooler	36	254.924444	18.6575608	297.680000	1.27985713

Comparing insulation levels with and without Air Cooler shows significant interactions. When there is no insulation, Air Cooler is more efficient in water removal. The difference between Yes and No air cooler when there was no insulation was $254.92 - 248.19 = 6.735$ g.

Using charts to examine the main effects and their interactions





The interaction of pressure and insulation

The relative difference between having insulation and not having insulation is not the same across different pressures. The effect of insulation is the greatest when the pressure is PSI30. If a wall is insulated, the pressure should be greater than PSI10 (e.g., PSI20 and PSI30) in order to see a significant water removal. However, we did not see significant difference between PSI20 and PSI30 when the wall is insulated.