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WINDOW MINI HEATING VENTILATION AND AIR CONDITIONING SYSTEMS: An Interim Report

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WINDOW MINI HEATING VENTILATION AND AIR CONDITIONING SYSTEMS

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TABLE OF CONTENTS

Page

LIST OF FIGURES v

LIST OF TABLES v

ACRONYMS AND ABBREVIATIONS vii

EXECUTIVE SUMMARY ix

INTRODUCTION 1
SCOPE 1
MARKET 1
MINI HEAT PUMP INSTALLATION 2
DATA AND METHODOLOGY 2
Hypothesis 3
The Alternate Hypothesis 3
The Test Statistic 4
Conclusion 5
Errors 5
DATA GATHERING 7
RESULTS 8
DISCUSSION AND FUTURE WORK 8
REFERENCES 9

APPENDIX A: MONTHLY PRE- AND POST-ENERGY CONSUMPTION DATA A-1

APPENDIX B: PRE- AND POST-ENERGY CONSUMPTION DATA FOR EACH DWELLING B-1

APPENDIX C: BREAKDOWN OF BEFORE AND AFTER MINI MINI HEAT PUMP INSTALLATION ENERGY CONSUMPTION C-1

LIST OF FIGURES

Page

Figure 1 Comparison of monthly energy consumption showing marginally reduced energy consumption during the cooling season but increase in energy consumption during the heating season 4

LIST OF TABLES

Page

Table 1 Pre- and post-study placement of A/C and space heaters in dwellings 3

Table 2 Months when hypothesis is acceptable 5

Table 3 Comparison of energy usage before and after window heat pump installation for each dwelling for the entire year 6

Table 4 Heating systems in each dwelling 7

ACRONYMS AND ABBREVIATIONS

A/C	air conditioning
ACHRN	Air Conditioning Heating and Refrigeration News
ADL	Arthur D. Little
BTUs	British thermal unit(s)
CDD	Cooling Degree Days
df	degrees of freedom
EIA	Energy Information Administration
HDD	Heating Degree Days
HSPF	Heating Season Performance Factor
HUD	Housing and Urban Development
n	number
PTHPs	packaged terminal heat pumps
SEER	Seasonal Energy Efficiency Ratio
s_p	pooled standard deviation
t-static	Students t-test statics
$t_{0.05}$, $t_{0.95}$	level of significance for one-tailed test. Both must be considered at 10% C.I for a two-tailed test
WAP	Weatherization Assistance Program
X_1	Average energy use with window A/C and resistance space conditioning
X_2	Average energy use with window heat pump unit only

EXECUTIVE SUMMARY

This report summarizes the work performed over the last two years on a project directed by the U.S. Department of Housing and Urban Development (HUD) to assess the savings in electrical energy by installing window mini heat pump units in single-family homes to provide cooling and heating throughout the year.

HUD funding for the study was $50,000 over a two-year period. Oak Ridge National Laboratory staff were assisted by personnel from the respective weatherization assistance program (WAP) coordinators in Texas and TXU Electric and Gas utility company.

A total of nine homes participated in this study, representing a rather small sample size for statistical analysis with acceptable degree of confidence. Hence our conclusions are tempered by this constraint of small sample size and limited resources. We could not draw a conclusion either in favor or against the window mini heat pumps. A larger sample size is recommended in future field studies.

Most houses (see Table 4) used gas heating exclusively. The fraction of the total gas consumption going towards space heating is undetermined in this study. To assess the energy input of window heat pumps on total energy usage, it is imperative to include the use of gas for space heating. When gas is available, it is generally used for cooking as well as for hot water. In this study space heating gas consumption were not measured; therefore, it was not possible to obtain a clear breakdown of the use of gas for space heating alone.

Notwithstanding the lack of conclusive evidence from this small study, one must not rush to conclusions about the benefits of window heat pumps. Technologically, window heat pumps are more energy- efficient than resistance heaters because of their ability to extract thermal energy from the environment that is freely available. That is why the coefficient of performance of a resistance heater is a maximum of one, whereas that of a heat pump is at least twice as much. The fact that the heat pump's energy efficiency characteristics could not be quantified in this study is due to many uncontrolled variables such as gas heating, preference for zone temperature control, low heat pump use, changes in occupancy, indoor temperature settings, etc. Most of the dwellings used gas heating (no portable resistance heaters). Without gas utility consumption used for heating only, it is difficult to quantify the savings in total energy due to the window mini heat pumps either during the heating season or over the whole year. During the cooling season, only two dwellings showed **substantial** energy savings by using the window heat pump instead of the A/C.

In this version of the report we have carried the analysis as far as possible noting that the existing set of data leading to the present analysis must be complemented with the non-electric load (heating gas consumption) information. We are in the process of obtaining total gas utility consumption at each dwelling and apportioning it to space heating load. An addendum to this report will address the final conclusions.

INTRODUCTION

This report summarizes the work performed over a two year period on a project directed by the U.S. Department of Housing and Urban Development (HUD) to assess the savings in electrical energy by installing window mini heat pump units to provide cooling and heating throughout the year. The assumption of the study is that mini heat pumps operate more efficiently than individual space heaters or window air conditioners, would save energy and operating costs, and therefore would be appropriate for weatherization clients.

SCOPE

This project evaluates the energy consumption before and after mini heat pump installations in nine homes in Texas. . Heat pumps for single-room or small-space application are assumed to provide an energy efficient and affordable alternative to portable electric resistance heating in residences. This technology may have particular value for weatherization clients like the elderly who may want to condition a few rooms only at the lowest cost. According to the statistical data from the early 1990's, buildings were responsible for about 35% of the total annual energy used by the United States or about 30-32 quadrillion BTUs (quads[1]) annually. Space heating accounts for around 27% of this total. In 1990, electricity use for residential space heating accounted for about 1.0 quads of energy consumption. By 1993, this had increased to 1.3 quads[2]. An Arthur D. Little (ADL) study estimated that built-in or portable room electric resistance heaters account for about half of this energy use (ADL, 1994). Mini heat pumps for single-room applications could provide an energy-and cost-saving alternative to built-in or portable electric resistance heating in the residential market and for commercial buildings (offices, hotels/motels, etc.) as well. They might be an effective retrofit solution for adding air-conditioning to homes or offices where no ductwork for air distribution exists.

MARKET

Of a total of 5.7 million air conditioning and heat pump units sold in the U.S in 1996 (Air Conditioning Heating and Refrigeration News (ACHRN);1997), heat pumps accounted for 1.1 million units. The number of installed heat pump units in U.S residences has risen from 7 million in 1990 to almost 10 million in 1996. Single-room heat pump products presently have only a very small share of the U.S market. There are two principal system types in the category—ductless mini split heat pumps and packaged terminal heat pumps (PTHPs). A large potential market exists for minisplit-type systems as a retrofit measure in residences. As of 1993 Energy Information Administration (EIA) (1995) there were about 7 million homes that relied upon built-in electric resistance heaters as the primary heating system. Geographically, these were spread around the country as follows: 17% in the Northeast Census Region, 20% in the Midwest, 27% in the South, and 36% in the West. Of these 7 million homes, about 69%

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[1] 1 quad=10^{15} BTUs (1.055 x 10^{18} Joules)

[2] Table 31 (EIA) and Table 5.14 (EIA 1995b) give values of 0.3 quads and 0.41 quads for 1990 and 1993, respectively, consumed at the residence. Using an average efficiency for generation transmission, and distribution of electricity of 31% (EIA 1996a) gives total energy consumption of 1.0 and 1.3 quads for 1990 and 1993, respectively.

were located in areas with 4000 or more heating degree days (HDD). Approximately another 14 million homes used built-in or portable resistance heaters for part of their heating needs (about 55% in areas with over 4000 HDD). Another 5 million homes use oil-fired hydronic heating systems primarily in the Northeast region (Maine, New Hampshire, Vermont, Rhode Island, Connecticut, New York, Pennsylvania, and New Jersey). Potentially, window mini heat pumps could replace several of these units if they provide the convenience at a reasonable cost.

MINI HEAT PUMP INSTALLATION AND COSTS

Two different mini heat pumps were installed at nine separate dwellings in Texas. The mini heat pump units are, Amana Model #MC18M33PCEH, rated at 18,000 BTU/h (1.5 tons), 10 SEER unit at $689.00 each and Amana Model # MC12M32PCEH, rated at 12,000 BTU/h (1 ton), 10 SEER at $633.00 each. Installation cost in Grayson County, Texas was $100 for each mini heat pump. Installations in Corsicana, Texas were $250 per installation. An additional $100 was charged for each occurrence of moving the 230VAC connection, installing a new breaker and upgrading the wire, if needed. A licensed electrician working with Alpine Air was responsible for the electrical hookups. The point of contact person was Larry L. Bailey, (903) 891-9154. The total cost of installations was $6656.00. The average cost of installation per house was $740.

Other people assisting in the weatherization program were:

Mark Bullard, Weatherization Assistance Program (WAP) Program Manager, (903) 813-3532 and Art Kampschafer, WAP Program Coordinator (903) 872-2401. Andrea Sander (214) 812-6966 and Brad Johnson (214) 875-2538 with Texas Utilities were other participants in the project.

The dwellings where the mini heat pumps (window units) were installed are numbered from 2087 through 2096. Some of the dwellings contained a window A/C unit operated on 120V or on 240V, and some also had portable electric space heaters. Existing A/C and space heating equipment is denoted by the prefix, Pre. During this study, the window A/C units were removed and replaced with the window heat pump units. Some dwellings also augmented their space heaters. Table 1 "maps" the preexisting equipment (Pre) and the equipment after the window heat pumps were installed (Post). The x marks indicate no equipment.

DATA AND METHODOLOGY

Before installing window heat pumps, the energy consumed by the window A/C and by resistance space heaters in each dwelling was collected in daily intervals for a period of one year from July 2000 through June 30, 2001. This set of data formed the baseline case. The CCD and the HDD data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) website. After the window A/C units were replaced with window heat pumps, the energy consumption was again collected for the window heat pump and any resistance heater that the dwelling wanted to use or had installed to supplement heating needs.

Table 1. Pre- and Post-Study Placement of A/C and Space Heaters in Dwellings.

	Window A/C 120V		Window A/C 240V		Window Heat Pump		Portable Heater	
Premise	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
2087	1	1			X	1	2	3
2088	1				X	1		1
2090			1		X	1		
2091	1	1	1		X	1		
2092	1		1		X	1	3	1
2093	1	1	1		X	1		1
2094	2	1	1		X	1		
2095	1		2		X	1		
2096			1		X	1		1

CCD and HDD were also collected. In essence, the data from each dwelling consists of HDD, CDD and the total energy used for A/C and space heating before and after window heat pump installation. Since the HDD and CDD for the baseline case (window A/C + resistance space heating) are different from the period pertaining the replacement window heat pumps, the energy usage is referenced to the HDD and CDD measured for the baseline period. In this way the comparison of the difference in energy consumption in the study becomes consistent.

Fifteen-minute data collected during each day was finally aggregated to the monthly figures tabulated in Table 2. In this way, the monthly energy consumption before and after replacement of window A/C units with window heat pumps for each dwelling can be compared after the energy consumption figures have been normalized to the CCDs and HDDs measured for the pre-installation period (1 year).

A bar chart comparing the monthly energy consumption before and after replacing the window A/C units with the window heat pump units is shown in Figure 1where the aggregate electricity consumption from all nine dwellings before and after mini heat pump installation is shown month-wise. At a glance, the relative heights of the two bars for each month depicts the change in the aggregate electricity consumption due to the mini heat pumps

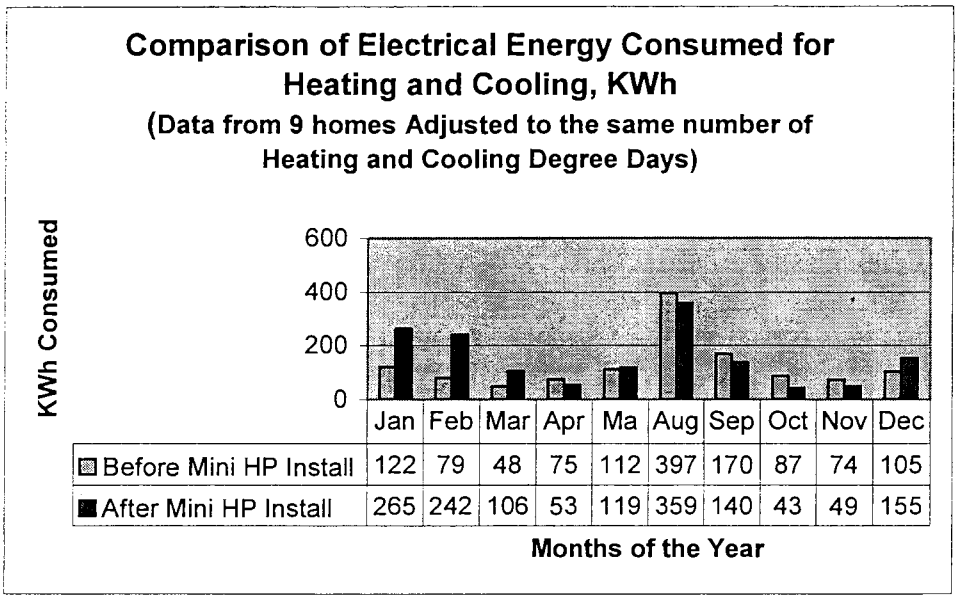
In order to draw conclusions from the energy consumption shown in Figure 1, a more rigorous statistical evaluation of the data is needed. This is done below using the students t-test as the test statistic.

Hypothesis

The null hypothesis is that for the month-to-month comparison, the average energy usage for the pre- and post-installation of window heat pumps remains the same.

The Alternate Hypothesis

The alternate hypothesis is that the post-installation energy consumption may be greater or less than the pre-installation energy consumption.



	Jan	Feb	Mar	Apr	Ma	Aug	Sep	Oct	Nov	Dec
Before Mini HP Install	122	79	48	75	112	397	170	87	74	105
After Mini HP Install	265	242	106	53	119	359	140	43	49	155

Figure 1. Comparison of monthly energy consumption showing marginally reduced energy consumption during the cooling season but increase in energy consumption during the heating season. Data for June and July are not plotted to avoid the period of installation of the mini HPs.

The Test Statistic

The test statistic is the students t-test. The degree of freedom depends on the number of data points taken. If the cell under the kWh heading in any of the tables in Appendix A is blank, it signifies that data was not reported. If the cell contains zero, then the energy used is actually zero. For example, in the winter months, the energy used by the window A/C should be zero because there is no need for cooling during the winter.

The student's t-test is given by

$$t = \frac{(X_1 - X_2)}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

The prefix 1 and 2 relate to the pre- and post-window heat pump installation, respectively. The student's t-test is designated as t, at a specified confidence interval (C.I), s_p is the pooled standard deviation of the pre-and post energy consumption data, and n_1 and n_2 are the number of data points in the post- and pre-cases. The averaged monthly energy consumption are X_1 and X_2. The C.I. is taken at the 90% level. This means that we are 90% confident in drawing a conclusion whether the difference in the mean energy consumption (X_1 - X_2) is significant or not.

Conclusion

The t-test statistic from the data was compared against tabulated data. If the t-test statistic fell within the t-test figures from tabulated data, the null hypothesis is accepted. If the t-test statistic falls outside the t-test figures from tabulated data, the null hypothesis is rejected and the alternate hypothesis is accepted. Whether the difference in the averages of the pre- and post-window installations is significant or not is determined by the t-test statistic.

Errors

A Type I error is if we conclude there *is* a difference between the pre- and post energy consumption when in reality there is *not*. In this case we will be biased towards concluding that the window heat pump does save energy when in fact it does not. The chance of such an incorrect conclusion is limited to 10%.

The results of the average monthly energy usage before and after installation of the window heat pumps are summarized in Table 2.

Table 2. Months when hypothesis is acceptable.

	Accept Hypothesis: The monthly energy consumption are similar (no significant difference)	Accept Alternate Hypothesis: There is a difference in the energy consumption	
	$X_1 \sim X_2$	$X_1 > X_2$	$X_1 < X_2$
January	x		
February	X		
March	X		
April	X		
May	X		
August	X		
September	X		
October		x	
November	x		
December	x		

From Table 2 we see that only for the month of October we see more energy used (statistically) by the window A/C and space resistance heaters. Therefore, the window heat pump shows a significant energy saving only in October ($X_2 < X_1$). In all other months where data is available, the average energy is statistically comparative. This is due to the large standard deviations observed in the data. The large standard deviations are attributed to a reading of zero reported before weatherization. Also, many houses used gas heating during winter months, yet gas consumption was not measured. Therefore, although on an absolute basis the energy used during the cooling season with the window heat pump unit is less than for the case of the window A/C unit as shown in Figure 1 and Appendix A, on a statistical basis, we can conclude with 90% certainty that only in the month of October the window heat pump (plus portable heater) units performed significantly better with respect to energy usage.

A similar statistical analysis is performed for the data set broken down by dwelling to

ascertain if any seasonal trends exist between dwellings. This data is shown in Appendix B: Pre- and Post-Energy Consumption Data for each Dwelling. The null hypothesis in this case is that there is no significant difference in energy consumption for each dwelling when the A/C window is replaced with window heat pumps. The alternate hypothesis is that there is difference in energy consumption for each dwelling. The energy consumption with window A/C may be greater or smaller than the energy consumption with window heat pump units. Table 3 summarizes the results for the data in Appendix B.

Table 3. Comparison of energy usage before and after window heat pump installation for each dwelling for the entire year

Dwelling	Before (KWh)	After (KWh)	Before-After (KWh)
2087	301	390	-80
2088	62	64	-2
2090	263	111	152
2091	350	172	178
2092	128	204	-76
2093	83	204	-121
2094	185	106	79
2095	72	98	-26
2096	71	80	-9

Table 3 shows that in the case of three dwellings, 2090, 2091, 2094, the total electric energy usage is reduced after the window heat pump unit is installed. However, the standard deviations of energy usage for each dwelling for the whole year is quite large, and therefore, on a statistical basis we conclude with 90% confidence that the difference between the energy consumption figures before and after window heat pump installation is not significant. There is a 10% chance that we may have made an error. The erroneous conclusion would be to conclude that there is a difference in energy consumption when in reality there is not.

A breakdown of the before- and after- mini heat pump installation energy consumption figures provides additional insight in to the energy usage structure at each dwelling (Appendix C). Dwellings 2088, 2090, 2091, 2093, 2094 and 2095 show no portable resistance heating (zero kWh) under the column, "portable heaters" indicating that in the winter months, (January=1, February=2, etc.) these dwellings used gas heating and not portable resistance heaters. During the summer months, dwellings 2090 and 2094 show a sharp *decrease* in energy consumption after the A/C is replaced with the window heat pump. The sharp drop in air-conditioning energy use is difficult to rationalize because the cooling coefficient of performance (COP) of a heat pump is comparable to that of an A/C unit. However, in the remaining dwellings, the A/C energy usage was comparative to the window heat pump energy usage as expected.

It would be advantageous to know the total gas usage from the gas utility billing information to include the gas space heating energy and then compare the total before- and after-window heat pump installation energy consumption data. However, the data on gas usage for heating alone is not readily available. Another possible explanation of the discrepancy in the energy usage during the cooling season mentioned above is to look at the indoor temperature settings. The CDD data alone is not a valid variable because the energy usage is dependent on

the inside temperature settings and the degree of weatherization in the respective dwellings. Table 4 lists the type of heating in each dwelling showing that most houses used gas and not portable resistance heaters to heat their homes.

Table 4. Heating Systems in each Dwelling.

	Heating Method	
Dwelling	**Gas furnace(s)**	**Electric heater(s)**
2087		2
2088	1	2
2090	1	
2091	2	
2092	2	
2093	2	
2094	3	
2095	3	
2096	1	

DATA GATHERING

This study uses Single Point End-use Energy Disaggregation (SPEED) recorders and their accompanying computer server and software, which together comprise the Nonintrusive Appliance Load Monitoring System (NIALMS).[3] SPEED is a whole-house electric end-use monitoring system that allows the collection of appliance-specific load data without entering customer homes or installing meters on specific appliances. SPEED/NIALMS is a product of Enetics Inc. (www.enetics.com).

SPEED/NIALMS takes advantage of the fact that each appliance type that uses electric power has a unique profile in both watts and reactive volt-amps (VARs). The SPEED recorders, which can be installed behind an existing electric meter in less than 20 minutes, detects watts, VARs, and on/off sequences of the electrical equipment used in a house. The recorder samples the incoming current and voltage (including phase angle) 2,000 times per second. It looks for edge transitions to determine exactly when a particular electric appliance turns on and off. It calculates and stores the date and time of each edge event, along with voltage, current, and real and reactive power. The recorder transmits information on the characteristics of these "edge" (on/off) events remotely, over standard voice-quality telephone lines, to a dedicated computer server. An algorithm is used to cluster the edges, create pairs of clusters (i.e., on and off edges), calculate consumption intervals, and assign intervals to appliance models.

[3] The prototype for SPEED/NIALMS, which was originally developed by the Massachusetts Institute of Technology in the 1980's, was field tested by EPRI and seven utility partners in the mid-1990s. The EPRI report on this field test showed that SPEED/NIALMS is 90-95% accurate for most appliances.

While it is possible to collect information on numerous end uses with traditional load monitoring, it requires attaching small electric meters to a large number of circuits or appliances. Thus, traditional methods of monitoring numerous electric end uses are likely to require considerably more effort to install, more site visits, and more tolerance, patience and cooperation from the households in the study than the nonintrusive SPEED/NIALMS monitoring system. SPEED/NIALMS monitoring offers a number of advantages over conventional metering strategies. Some of its most important advantages include:

- ease of installation and redeployment,
- its nonintrusive nature which causes no inconvenience for clients,
- its ability to detect appliances that are added or removed from the household's inventory of working equipment, and
- its ability to deliver extensive and accurate information (including total electric consumption, loads for large numbers of electric end-uses, and indoor temperature) for the time periods of interest.

Once it is in place, the SPEED/NIALMS equipment continues to send data remotely for as long as one wishes to monitor the house.

RESULTS

- The limited data shows that at the 90% confidence level, there is no statistical difference in the total energy usage during cooling and heating seasons on a monthly basis. The chance of error in this conclusion is 10%.
- The data shows that at the 90% confidence level, there is no statistical difference in energy usage for each dwelling over the entire period of 1 year covering all four seasons. The chance of error in this conclusion is also 10%.
- Dwellings 2090 and 2094 show a sharp **decrease** in air-conditioning energy consumption.

DISCUSSION AND FUTURE WORK

- The sample size in this study was too small. Only nine dwellings were considered.
- The degree of weatherization in each dwelling is assumed to be the same, but this is not known for sure.
- No blower door test was performed.
- It is not known if any weatherization was done between the time the window A/C units were removed and the window heat pumps were installed.
- Eight of the nine dwellings used gas heating in the winter. This biases the results against the window heat pumps, because resistance space heating is low while the window heat pump uses energy for space heating and therefore records energy usage.
- Dwellings relied on zone space heating as opposed to centralized heating further complicating data analysis from a small number of samples.
- Energy usage is also behavior dependent. Some residents may set the thermostat at higher temperatures than others.
- It would have been worthwhile to collect energy usage in terms of indoor and outdoor temperatures as the heat energy loss of a building envelope is directly dependent on this temperature difference instead of relying on HDDs and CDDs

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APPENDIX A: MONTHLY PRE- AND POST-ENERGY CONSUMPTION DATA.

		January		
		$(HDD+CDD)_{before}$	550	
		$(HDD+CDD)_{after}$	658	
		Before		After
				Adjusted
		Kwh	Kwh	Kwh
	2087	688	984	822.5
	2088	0	185	154.6
	2090	0	202	168.8
	2091		4	3.3
	2092	285	556	464.7
	2093	0	532	444.7
	2094	0	0	0.0
	2095	0		
	2096	0	73	61.0
Avg.		121.62		265.0
Std. Dev.		249.63		289.0
sample size, n		8		8
df		14		
90% C. I	$\alpha = 0.10$			
s_p	270			
$t_{0.050}$	-1.761			
$t_{0.950}$	1.761			
t-test	-1.062			
Conclusion:	accept null hypothesis			

		February		
		$(HDD+CDD)_{before}$	502	
		$(HDD+CDD)_{after}$	546	
		Before	After	
				Adjusted
		Kwh	Kwh	Kwh
	2087	517	688	633
	2088	0	276	254
	2090	0	0	0
	2091		8	7
	2092	116	646	594
	2093	0	394	362
	2094	0	1	1
	2095	0		
	2096	0	96	88
Avg.		79.125		242
Std. Dev.		181.5		263.6
sample size, n		8		8
df		14		
90% C. I	$\alpha = 0.10$			
s_p	226.3			
t0.050	-1.761			
t0.950	1.761			
t-test	-1.443			
conclusion:	accept null hypothesis			

March

$(HDD+CDD)_{before}$	377
$(HDD+CDD)_{after}$	317

	Before	After	Adjusted
	Kwh	Kwh	Kwh
2087	288	238	283
2088	0	48	57
2090	7	0	0
2091		4	5
2092	57	205	244
2093	0	178	212
2094	18	4	5
2095	0		
2096	15	36	43
Avg.	48.1		106
Std. Dev.	98.8		119.3
sample size, n	8		8

df	14
90% C. I	$\alpha = 0.10$
s_p	109.5
t0.050	-1.761
t0.950	1.761
t-test	-1.057
conclusion:	accept null hypothesis

April

$(HDD+CDD)_{before}$ 224

$(HDD+CDD)_{after}$ 156

	Before	After	Adjusted
	Kwh	Kwh	Kwh
2087	116		
2088	0	6	9
2090	127	55	79
2091		52	75
2092	30	20	29
2093	27	60	86
2094	168	42	60
2095	105		
2096	26	23	33

Avg.		74.9	52.9
Std. Dev.		61.3	29.6
sample size, n		8.0	7.0
df	13		
90% C. I	$\alpha = 0.10$		
s_p	49.3		
t0.050	-1.771		
t0.950	1.771		
t-test	0.861		
conclusion:	accept null hypothesis		

May

$(HDD+CDD)_{before}$	251	
$(HDD+CDD)_{after}$	323	

	Before	After	Adjusted
	Kwh	Kwh	Kwh
2087	54		
2088	0	33	26
2090	254	275	214
2091		167	130
2092	2	134	104
2093	44	95	74
2094	339	189	147
2095	127		
2096	77	183	142

Avg.		112.1	119.4
Std. Dev.		122.9	59.7
sample size, n		8.0	7.0
df	13		
90% C. I	$\alpha = 0.10$		
s_p	98.9		
t0.050	-1.771		
t0.950	1.771		
t-test	-0.14311		
conclusion:	accept null hypothesis		

		August		
		$(HDD+CDD)_{before}$	606	
		$(HDD+CDD)_{after}$	608	
		Before		After
				Adjusted
		KWh	KWh	KWh
	2087	179	416	414.6
	2088	251	95	94.7
	2090	823	454	452.5
	2091	797	311	310.0
	2092	181	349	347.9
	2093	300	388	386.7
	2094	481	639	636.9
	2095	293	284	283.1
	2096	268	307	306.0
Avg.		397		359.16
Std. Dev.		250.22		146.11
sample size, n		9		9
df				
90% C. I		$\alpha = 0.10$		$\alpha = 0.10$
sp	205			
t0.050	-1.746			
t0.950	1.746			
t-test	0.392			
conclusion:	accept null hypothesis			

		September		
		$(HDD+CDD)_{before}$	287	
		$(HDD+CDD)_{after}$	428	
		Before	After	
				Adjusted
		KWh	KWh	KWh
	2087	92	160	107
	2088	103	41	27
	2090	450	262	176
	2091	86	223	150
	2092	83	206	138
	2093	176	267	179
	2094	356	380	255
	2095	64	140	94
	2096	119	202	135
Avg.		169.9		140
Std. Dev.		137.9		63.2
sample size, n		9		9
df	16			
90% C. I	$\alpha = 0.10$			
s_p	107.2			
$t_{0.050}$	-1.734			
$t_{0.950}$	1.734			
t-test	0.131			
conclusion:	accept null hypothesis			

October

$(HDD+CDD)_{before}$	287
$(HDD+CDD)_{after}$	428

	Before	After	Adjusted
	KWh	KWh	KWh
2087	152	175	117
2088	5	12	8
2090	204	77	52
2091	168	63	42
2092	89	36	24
2093	18	56	38
2094	126	63	42
2095	4	46	31
2096	17	46	31
Avg.	87		43
Std. Dev.	78		31
sample size, n	9		9
df	16		

90% C. I	$\alpha = 0.10$
s_p	60
$t_{0.050}$	-1.746
$t_{0.950}$	1.746
t-test	2
conclusion:	accept alternate hypothesis

November

$(HDD+CDD)_{before}$	224		
$(HDD+CDD)_{after}$	363		
	Before	After	
			Adjusted
	KWh	KWh	KWh
2087	304	371	229
2088	2	0	0
2090	102	14	9
2091		0	0
2092	104	36	22
2093	0	219	135
2094	72	0	0
2095	0	62	38
2096	7	11	7
Avg.	73.9		48.9
Std. Dev.	103.7		80.0
sample size, n	8		9
df	15		
90% C. I	$\alpha = 0.10$		
s_p	88.9		
$t_{0.050}$	-1.753		
$t_{0.950}$	1.753		
t-test	0.578		
conclusion:	accept null hypothesis		

December

$(HDD+CDD)_{before}$ 495

$(HDD+CDD)_{after}$ 530

	Before	After	Adjusted
	KWh	KWh	KWh
2087	620	509	475
2088	0	74	69
2090	25	59	55
2091		0	
2092	181	283	264
2093	0	341	318
2094	11	1	1
2095	0	36	34
2096	0	20	19
Avg.	104.6		154.5
Std. Dev.	217.2		175.6
sample size, n	8		8

df	14
90% C. I	$\alpha = 0.10$
s_p	197.5
$t_{0.050}$	-1.761
$t_{0.950}$	1.761
t-test	-1.009
conclusion:	accept null hypothesis

APPENDIX B: PRE- AND POST-ENERGY CONSUMPTION DATA FOR EACH DWELLING

Dwelling 2087

Month	Before HDD	Before CDD	Before HDD+CDD	Before Aggregate Electricity Consumed (resistance heat+A/C)	After HDD	After CDD	After HDD+CDD	After Aggregate Electricity Consumed (resistance heat +HP)	After Adjusted Aggregate Electricity Consumed (resistance heat +A/C)
				Kwh				Kwh	Kwh
Jan	546	4	550	688	658	0	658	984	822.5
Feb	501	1	502	517	546	0	546	688	632.6
Mar	362	15	377	288	305	12	317	238	283.0
Apr	67	157	224	116					
May	15	236	251	54					
Aug	0	606	606	179	0	608	608	416	414.6
Sep	4	283	287	92	0	428	428	160	107.3
Oct	90	86	176	152	100	93	193	175	159.6
Nov	196	28	224	304	356	7	363	371	228.9
Dec	484	11	495	620	529	1	530	509	475.4
Avg.				301					390
Std. Dev.				230					246
sample size, n				10					8
df	16								
90% C. I	$\alpha = 0.10$								
sp	237.0								
t0.050	-1.746								
t0.950	1.746								
t-test	-0.7961								
conclusion:	accept null hypothesis								

Dwelling 2088

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C)	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP)	Adjusted Aggregate Electricity Consumed (resistance heat +HP)
				Kwh				Kwh	Kwh
Jan	546	4	550	0	658	0	658	185	154.6
Feb	501	1	502	0	546	0	546	276	253.8
Mar	362	15	377	0	305	12	317	48	57.1
Apr	67	157	224	0	48	108	156	6	8.6
May	15	236	251	0	2	321	323	33	25.6
Jun					0	411	411	60	0.0
Jul	0	670	670	319			0		
Aug	0	606	606	251	0	608	608	95	94.7
Sep	4	283	287	103	0	428	428	41	27.5
Oct	90	86	176	5	100	93	193	12	10.9
Nov	196	28	224	2	356	7	363	0	0.0
Dec	484	11	495	0	529	1	530	74	69.1
Avg.				62					64
Std. Dev.				115					79
sample size, n				11					11
df	20								
90% C. I	$\alpha = 0.10$								
sp	99								
t0.050	-1.86								
t0.950	1.86								
t-test	-0.0474								
conclusion:	accept null hypothesis								

Dwelling 2090

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C) Kwh	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP) Kwh	Adjusted Aggregate Electricity Consumed (resistance heat +HP) Kwh
Jan	546	4	550	0	658	0	658	202	169
Feb	501	1	502	0	546	0	546	0	0
Mar	362	15	377	7	305	12	317	0	0
Apr	67	157	224	127	48	108	156	55	79
May	15	236	251	254	2	321	323	275	214
Jun			0		0	411	411	373	0
Jul	0	670	670	906					
Aug	0	606	606	823	0	608	608	454	453
Sep	4	283	287	450	0	428	428	262	176
Oct	90	86	176	204	100	93	193	77	70
Nov	196	28	224	102	356	7	363	14	9
Dec	484	11	495	25	529	1	530	59	55
Avg.				263					111
Std. Dev.				327					137
sample size, n				11					11
df	20								
90% C. I	$\alpha = 0.10$								
sp	251								
t0.050	-1.725								
t0.950	1.725								
t-test	1								
conclusion:	accept null hypothesis								

Dwelling 2091

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C)	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP)	Adjusted Aggregate Electricity Consumed (resistance heat +HP)
				Kwh				Kwh	Kwh
Jan					658	0	658	4	4
Feb					546	0	546	8	8
Mar					305	12	317	4	4
Apr					48	108	156	52	52
May					2	321	323	167	167
Jun					0	411	411	51	51
Jul	0	670	670	753					
Aug	0	606	606	797	0	608	608	311	310
Sep	4	283	287	86	0	428	428	223	150
Oct	90	86	176	168	100	93	193	63	57
Nov					356	7	363	0	0
Dec					529	1	530	0	0
Avg.				350					172
Std. Dev.				389					128
sample size, n				3					3
df	4								
90% C. I	$\alpha = 0.10$								
sp	290								
t0.050	-2.312								
t0.950	2.312								
t-test	0.753								
conclusion:	accept null hypothesis								

Dwelling 2092

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C)	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP)	Adjusted Aggregate Electricity Consumed (resistance heat +HP)
				Kwh				Kwh	Kwh
Jan	546	4	550	285	658	0	658	556	465
Feb	501	1	502	116	546	0	546	646	594
Mar	362	15	377	57	305	12	317	205	244
Apr	67	157	224	30	48	108	156	20	29
May	15	236	251	2	2	321	323	134	104
Jun					0	411	411	145	0
Jul	0	670	670	277					
Aug	0	606	606	181	0	608	608	349	348
Sep	4	283	287	83	0	428	428	206	138
Oct	90	86	176	89	100	93	193	36	33
Nov	196	28	224	104	356	7	363	36	22
Dec	484	11	495	181	529	1	530	283	264
Avg.				128					204
Std. Dev.				93					199
sample size, n				11					11
df	20								
90% C. I	$\alpha = 0.10$								
sp	155								
t0.050	-1.725								
t0.950	1.725								
t-test	-1.147								
conclusion:	accept null hypothesis								

Dwelling 2093

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C) Kwh	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP) Kwh	Adjusted Aggregate Electricity Consumed (resistance heat +HP) Kwh
Jan	546	4	550	0	658	0	658	532	445
Feb	501	1	502	0	546	0	546	394	362
Mar	362	15	377	0	305	12	317	178	212
Apr	67	157	224	27	48	108	156	60	86
May	15	236	251	44	2	321	323	95	74
Jun					0	411	411	152	0
Jul	0	670	670	350					
Aug	0	606	606	300	0	608	608	388	387
Sep	4	283	287	176	0	428	428	267	179
Oct	90	86	176	18	100	93	193	56	51
Nov	196	28	224	0	356	7	363	219	135
Dec	484	11	495	0	529	1	530	341	318
Avg.				83					204
Std. Dev.				131					152
sample size, n				11					11
df	20								
90% C. I	$\alpha = 0.10$								
sp	142								
t0.050	-1.725								
t0.950	1.725								
t-test	-2.008								
conclusion:	accept alternate hypothesis								
	X2 > X1								

Dwelling 2094

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C)	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP)	Adjusted Aggregate Electricity Consumed (resistance heat +HP)
				Kwh				Kwh	Kwh
Jan	546	4	550	0	658	0	658	0	0
Feb	501	1	502	0	546	0	546	1	1
Mar	362	15	377	18	305	12	317	4	5
Apr	67	157	224	168	48	108	156	42	60
May	15	236	251	339	2	321	323	189	147
Jun			0		0	411	411	479	0
Jul	0	670	670	462					
Aug	0	606	606	481	0	608	608	639	637
Sep	4	283	287	356	0	428	428	380	255
Oct	90	86	176	126	100	93	193	63	57
Nov	196	28	224	72	356	7	363	0	0
Dec	484	11	495	11	529	1	530	1	1
Avg.				185					106
Std. Dev.				190					194
sample size, n				11					11
df	20								
90% C. I	$\alpha = 0.10$								
sp	192								
t0.050	-1.725								
t0.950	1.725								
t-test	0.967								
conclusion:	accept null hypothesis								

Dwelling 2095

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C)	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP)	Adjusted Aggregate Electricity Consumed (resistance heat +HP)
				Kwh				Kwh	Kwh
Jan	546	4	550	0					
Feb	501	1	502	0					
Mar	362	15	377	0					
Apr	67	157	224	105					
May	15	236	251	127					
Jun									
Jul	0	670	670	380					
Aug	0	606	606	293	0	608	608	284	283
Sep	4	283	287	64	0	428	428	140	94
Oct	90	86	176	4	100	93	193	46	42
Nov	196	28	224	0	356	7	363	62	38
Dec	484	11	495	0	529	1	530	36	34
Avg.				72.2					98
Std. Dev.				126					106
sample size, n				5					5
df	8								
90% C. I	$\alpha = 0.10$								
sp	117								
t0.050	-1.86								
t0.950	1.86								
t-test	-0.352								
conclusion:	accept null hypothesis								

Dwelling 2096

	Before				After				
Month	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +A/C)	HDD	CDD	HDD+CDD	Aggregate Electricity Consumed (resistance heat +HP)	Adjusted Aggregate Electricity Consumed (resistance heat +HP)
				Kwh				Kwh	Kwh
Jan	546	4	550	0	658	0	658	73	61
Feb	501	1	502	0	546	0	546	96	88
Mar	362	15	377	0	305	12	317	36	43
Apr	67	157	224	26	48	108	156	23	33
May	15	236	251	77	2	321	323	183	142
Jun					0	411	411	209	0
Jul	0	670	670	266					
Aug	0	606	606	268	0	608	608	307	306
Sep	4	283	287	119	0	428	428	202	135
Oct	90	86	176	17	100	93	193	46	42
Nov	196	28	224	7	356	7	363	11	7
Dec	484	11	495	0	529	1	530	20	19
Avg.				71					80
Std. Dev.				104					89
sample size, n				11					11
df	20								
90% C. I	$\alpha = 0.10$								
sp	97								
t0.050	-1.725								
t0.950	1.725								
t-test	-0.212								
conclusion:	accept null hypothesis								

APPENDIX C: BREAKDOWN OF BEFORE AND AFTER MINI HEAT PUMP INSTALLATION ENERGY CONSUMPTION

		<----------Before----------						<----------After----------					
premise	month #	HDD	CDD	A/C kWh	Portable Heaters kWh	Heat Pump kWh	Aggregate Energy kWh	HDD	CDD	A/C kWh	Portable Heaters kWh	Heat Pump kWh	Aggregate Energy kWh
2087	1	546	4	7	680	0	688	658	0	0	684	299	984
2087	2	501	1	22	494	0	517	546	0	0	447	241	688
2087	3	362	15	14	274	0	288	305	12	0	33	205	238
2087	4	67	157	9	107	0	116	48	108	0	1	15	16
2087	5	15	236	8	46	0	54						
2087	7	0	670	175	19	0	193						
2087	8	0	606	161	18	0	179	0	608	81	1	334	416
2087	9	4	283	71	21	0	92	0	428	1	3	156	160
2087	10	90	86	1	151	0	152	100	93	0	71	104	175
2087	11	196	28	0	304	0	304	356	7	0	219	153	371
2087	12	484	11	0	620	0	620	529	1	0	345	163	509
2088	1	546	4	0	0	0	0	658	0	0	139	46	185
2088	2	501	1	0	0	0	0	546	0	0	244	32	276
2088	3	362	15	0	0	0	0	305	12	0	25	23	48
2088	4	67	157	0	0	0	0	48	108	0	0	6	6
2088	5	15	236	0	0	0	0	2	321	0	0	33	33
2088	6							0	411	0	0	60	60
2088	7	0	670	319	0	0	319						
2088	8	0	606	251	0	0	251	0	608	0	0	95	95
2088	9	4	283	103	0	0	103	0	428	0	0	41	41
2088	10	90	86	5	0	0	5	100	93	0	0	12	12
2088	11	196	28	2	0	0	2	356	7	0	0	0	0
2088	12	484	11	0	0	0	0	529	1	0	48	26	74

		<----------Before----------						<----------After----------					
premise	month #	HDD	CDD	A/C kW h	Portable Heaters kWh	Heat Pump kWh	Aggregate Energy kWh	HDD	CDD	A/C kW h	Portable Heaters kWh	Heat Pump kWh	Aggregate Energy kWh
2087	1	546	4	7	680	0	688	658	0	0	684	299	984
2087	2	501	1	22	494	0	517	546	0	0	447	241	688
2087	3	362	15	14	274	0	288	305	12	0	33	205	238
2087	4	67	157	9	107	0	116	48	108	0	1	15	16
2087	5	15	236	8	46	0	54						
2087	7	0	670	175	19	0	193						
2087	8	0	606	161	18	0	179	0	608	81	1	334	416
2087	9	4	283	71	21	0	92	0	428	1	3	156	160
2087	10	90	86	1	151	0	152	100	93	0	71	104	175
2087	11	196	28	0	304	0	304	356	7	0	219	153	371
2087	12	484	11	0	620	0	620	529	1	0	345	163	509
2088	1	546	4	0	0	0	0	658	0	0	139	46	185
2088	2	501	1	0	0	0	0	546	0	0	244	32	276
2088	3	362	15	0	0	0	0	305	12	0	25	23	48
2088	4	67	157	0	0	0	0	48	108	0	0	6	6
2088	5	15	236	0	0	0	0	2	321	0	0	33	33
2088	6							0	411	0	0	60	60
2088	7	0	670	319	0	0	319						
2088	8	0	606	251	0	0	251	0	608	0	0	95	95
2088	9	4	283	103	0	0	103	0	428	0	0	41	41
2088	10	90	86	5	0	0	5	100	93	0	0	12	12
2088	11	196	28	2	0	0	2	356	7	0	0	0	0
2088	12	484	11	0	0	0	0	529	1	0	48	26	74
2090	1	546	4	0	0	0	0	658	0	0	0	202	202
2090	2	501	1	0	0	0	0	546	0	0	0	0	0

2090	3	362	15	7	0	0	7	305	12	0	0	0	0
2090	4	67	157	127	0	0	127	48	108	0	0	55	55
2090	5	15	236	254	0	0	254	2	321	0	0	275	275
2090	6							0	411	0	0	373	373
2090	7	0	670	906	0	0	906						
2090	8	0	606	823	0	0	823	0	608	0	0	454	454
2090	9	4	283	450	0	0	450	0	428	0	0	262	262
2090	10	90	86	204	0	0	204	100	93	0	0	77	77
2090	11	196	28	102	0	0	102	356	7	0	0	14	14
2090	12	484	11	25	0	0	25	529	1	0	0	59	59
2091	1							658	0	4	0	0	4
2091	2							546	0	8	0	0	8
2091	3							305	12	4	0	0	4
2091	4							48	108	35	0	16	52
2091	5							2	321	26	0	141	167
2091	6							0	411	15	0	36	51
2091	7	0	670	753	0	0	753						
2091	8	0	606	797	0	0	797	0	608	175	0	136	311
2091	9	4	283	86	0	0	86	0	428	194	0	28	223
2091	10	90	86	163	0	0	163	100	93	49	0	14	63
2091	11							356	7	0	0	0	0
2091	12							529	1	0	0	0	0
2092	1	546	4	0	285	0	285	658	0	0	362	194	556
2092	2	501	1	0	116	0	116	546	0	0	521	126	646
2092	3	362	15	0	57	0	57	305	12	0	107	98	205
2092	4	67	157	0	30	0	30	48	108	0	0	20	20
2092	5	15	236	2	0	0	2	2	321	0	0	134	134
2092	6							0	411	0	0	145	145
2092	7	0	670	277	0	0	277						
2092	8	0	606	181	0	0	181	0	608	0	0	349	349
2092	9	4	283	82	1	0	83	0	428	0	0	206	206
2092	10	90	86	0	89	0	89	100	93	0	0	36	36

2092	11	196	28	0	104	0	104	356	7	0	1	34	36
2092	12	484	11	0	181	0	181	529	1	0	130	152	283
2093	1	546	4	0	0	0	0	658	0	0	255	277	532
2093	2	501	1	0	0	0	0	546	0	0	160	234	394
2093	3	362	15	0	0	0	0	305	12	0	0	178	178
2093	4	67	157	27	0	0	27	48	108	0	0	60	60
2093	5	15	236	44	0	0	44	2	321	39	0	56	95
2093	6							0	411	91	0	61	152
2093	7	0	670	350	0	0	350						
2093	8	0	606	300	0	0	300	0	608	0	0	388	388
2093	9	4	283	176	0	0	176	0	428	0	0	267	267
2093	10	90	86	18	0	0	18	100	93	0	0	56	56
premise	month #	HDD	CDD	A/C kW h	Portable Heaters kWh	Heat Pump kWh	Aggregate Energy kWh	HDD	CDD	A/C kW h	Portable Heaters kWh	Heat Pump kWh	Aggregate Energy kWh
2093	11	196	28	0	0	0	0	356	7	0	0	219	219
2093	12	484	11	0	0	0	0	529	1	0	6	336	341
2094	1	546	4	0	0	0	0	658	0	0	0	0	0
2094	2	501	1	0	0	0	0	546	0	0	0	1	1
2094	3	362	15	18	0	0	18	305	12	1	0	3	4
2094	4	67	157	168	0	0	168	48	108	24	0	17	42
2094	5	15	236	339	0	0	339	2	321	109	0	80	189
2094	6							0	411	322	0	158	479
2094	7	0	670	462	0	0	462						
2094	8	0	606	481	0	0	481	0	608	405	0	234	639
2094	9	4	283	356	0	0	356	0	428	263	0	116	380
2094	10	90	86	126	0	0	126	100	93	43	0	20	63
2094	11	196	28	72	0	0	72	356	7	0	0	0	0
2094	12	484	11	11	0	0	11	529	1	0	0	1	1
2095	1	546	4	0	0	0	0	658	0	0	0	73	73

2095	2	501	1	0	0	0	0						
2095	3	362	15	0	0	0	0						
2095	4	67	157	105	0	0	105						
2095	5	15	236	127	0	0	127						
2095	7	0	670	380	0	0	380						
2095	8	0	606	293	0	0	293	0	608	0	0	284	284
2095	9	4	283	64	0	0	64	0	428	0	0	140	140
2095	10	90	86	4	0	0	4	100	93	0	0	46	46
2095	11	196	28	0	0	0	0	356	7	0	0	62	62
2095	12	484	11	0	0	0	0	529	1	0	0	36	36
2096	1	546	4	0	0	0	0	658	0	0	61	12	73
2096	2	501	1	0	0	0	0	546	0	0	78	18	96
2096	3	362	15	0	0	0	0	305	12	0	13	23	36
2096	4	67	157	26	0	0	26	48	108	0	0	23	23
2096	5	15	236	77	0	0	77	2	321	0	0	183	183
2096	6							0	411	0	0	209	209
2096	7	0	670	266	0	0	266						
2096	8	0	606	268	0	0	268	0	608	0	0	307	307
2096	9	4	283	119	0	0	119	0	428	0	0	202	202
2096	10	90	86	17	0	0	17	100	93	0	0	46	46
2096	11	196	28	7	0	0	7	356	7	0	0	11	11
2096	12	484	11	0	0	0	0	529	1	0	0	20	20

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