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Evaluation of heat pumps usage and energy savings in residential buildings

Nehad Elsawaf[1], Tarek Abdel-Salam [2], Leslie Pagliari[3]

[1] Department of Economics, Helwan University, Cairo, Egypt.
[2]Department of Engineering, East Carolina University, Greenville, NC 27858, USA.
[3]Department of Technology Systems, East Carolina University, Greenville, NC 27858, USA.

Abstract
The residential housing sector is a major consumer of energy in most countries around the world. In the United States the residential sector consumes about 21 % of the energy and about 35% of the electricity production. Of the total energy consumption per house hold about 33% is consumed for space heating. This study evaluates the energy consumption in residential houses during the heating season. The main objective of the study is to test the effectiveness of using heat pumps for space heating in eastern North Carolina. Data for the current study were collected from four cities in eastern North Carolina. The collected data which includes surveys and actual energy consumption (gas and electrical) were analyzed using statistical methods. Results show that houses with heat pumps as the main source of heating have the lowest energy consumption and the lowest energy intensity (energy per unit area of the house). Houses with electrical furnaces have the highest energy consumption and the highest energy intensity ratios.

Keywords: Heating; Heat pumps; Residential homes.

1. Introduction
The global surge in energy prices as well as the increase in the level of pollutants and harmful emissions; the green house effects have forced policy makers around the world to promote more effective means to achieve energy efficiency and energy conservation. While the two concepts have been widely acknowledged in the energy and economic policy literature, there is a clear distinction between the two. Energy efficiency refers to the adoption of a specific technology that reduces the overall energy consumption without changing the relevant behavior of consumers [1]. Energy conservation, on the other hand, depends on behavioral shifts in consumer behavior to voluntarily lower consumption [2]. Policy makers try to target the two dimensions simultaneously when designing effective energy policies. In many cases, energy efficiency improvement is set as an environmental target with strong assumptions on the rationality of end users ad their responsiveness to price signals in the energy market [1]. Although energy literature has outlined several factors and parameters (economics, social and institutional) that affect consumer behavior in relation to end use energy demand and consumption, the economic rationality in energy use and the energy savings potential still emerge as the strongest drivers towards adopting energy efficiency improvement. If an energy price increase is persistent, it's likely to significantly affect energy efficiency adoption, as consumers replace older capital equipment and firms

have incentives to develop new products and processes [3]. In the USA and in many other countries of the world, the domestic/ residential sector has been highlighted as an area with considerable potential for improved energy efficiency [4].

The residential housing sector is a major energy consumer in most countries. In the United States, this sector uses approximately 21 EJ (Exa=10^{18}) of site energy per year. This amounts to approximately 20% of all energy used in the nation. Moreover, American households consumed fully 35% of all national electricity production (3,660 billion kWh) and strongly depend on natural gas for heating [5-7]. Further, supplying energy to the residential sector in the U.S. generates fully 18% of its greenhouse gas emissions. Despite improvements in refrigerator, furnace efficiency, and insulation technologies as well as on-going improvements to building codes related to energy, many Americans' lifestyle changes have put higher demands on heating and cooling resources. The average U.S. home size has increased significantly, from 139 m^2 in 1970 to 214 m^2 in 2005 [8]. The two-person household in a large home has become more common, as has central air conditioning: 23% of households had central air conditioning in 1978 and that figure rose to 55% by 2001. Also, miscellaneous electric end-uses in households has been rapidly expanding since 2000, largely offsetting efficiency gains in the conventional end-uses of heating, cooling and water heating [7]. The present work focuses on determining the efficacy of using heat pumps as the main source of heating in eastern North Carolina residential homes.

2. Data collection and overview of the sample

The data used in this study and described below is taken from a larger sample obtained through a research project that evaluates an energy efficiency program at eastern North Carolina [8]. Applicable utilities supplied energy consumption data consistent with customer release. Since the electric providers were not gas providers in some cases, participants were asked to authorize release of gas consumption records as applicable. These authorizations were forwarded to appropriate gas providers in order to obtain records for the project. Data were collected by means of survey and analyzed using statistical methods of comparison. The data points came from four cities in eastern North Carolina. Survey forms were developed, trialed and sent by mail to a selected sample of homes in four cities over a period of seven months. The survey mailings included a cover letter describing the purpose, energy use acquisition authorization letter and a self-addressed, stamped return envelope. Following the survey mailing, many recipients were contacted via telephone to encourage participation, minimize non-response and explain survey questions in order to maximize survey data validity. Survey questions were developed from the U.S. Department of Energy's residential energy consumption survey [9]. The questionnaire contained eleven sections covering the household characteristics, energy usage, fuel type, and house characteristics. These sections of the questionnaire are summarized in Table1. A summary of the data used in this study is presented below to give an overview of the analyzed sample.

Table 1. List of survey sections

1	Household characteristics
2	Basic housing characteristics
3	Kitchen appliances
4	Other appliances
5	Water heating
6	Space heating
7	Air conditioning
8	Quality of construction
9	Solar orientation
10	Home design
11	Miscellaneous

2.1 Overview of household characteristics

When the sample is classified by the method of heating (see Figure1), approximately 27% of the homes are using heat pumps, 33% are using gas heating, 11 % are using electrical furnaces, and 29% are using combined methods for heating. The average size of the household in the selected sample for both the test (homes that use heat pumps) and the control (homes that use other methods for heating) groups is found to be almost the same and equals three persons per house. The maximum number of occupants in the sample is six persons and the minimum number is two persons.

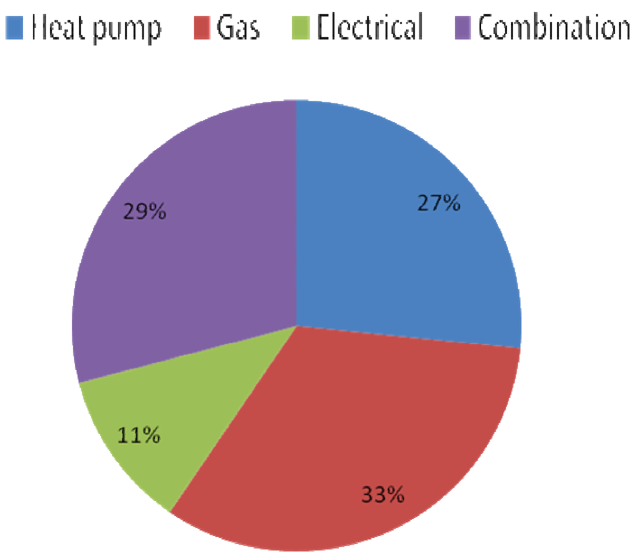

Figure 1. Classification of the sample based on the heating method

For the purpose of the study, the residences in the sample were divided into three categories based on floor area: small size (less than 140m^2), medium size (between 140 and 205 m^2) and large size (more than 205 m^2). As shown in Figure 2, the percentages of the house sizes in the test group are 54%, 40%, and 6 % for large, medium and small homes respectively and the percentages of the house sizes in the control group are 33%, 62%, and 5% for large, medium and small homes respectively. The percentages of 1-4 years old, 5-8 years old and 9-12 years old homes in the control group sample are 40% , 46 % and 14 % respectively (see Figure 3), and for the test group homes 52% are 1-4 years old , 38% are 5-8 years old and 10% are 9-12 years old.

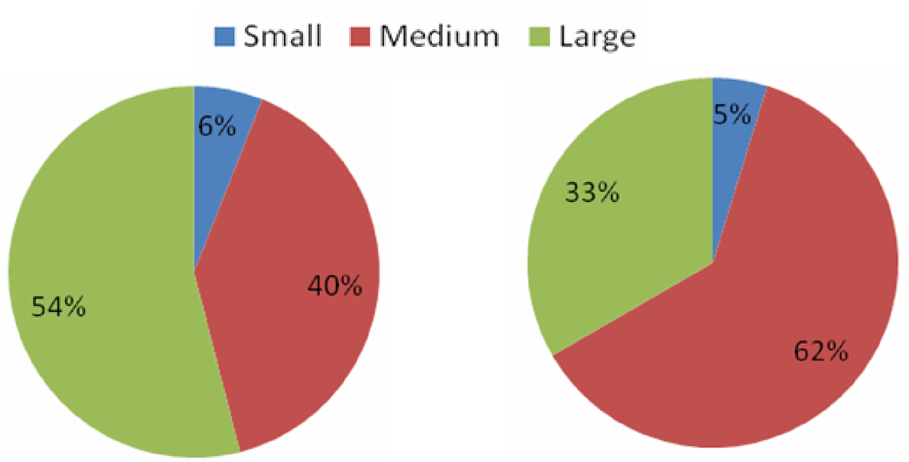

Figure 2. House size distribution in the sample for (a) Test group (b) Control group.

2.2. Overview of Energy Consumption

After investigating the energy consumption trends of the sample, it is found that house with heat pumps consume the lowest energy. Figure 4 shows the average monthly consumption of energy during the heating season in MJ. It can be seen that the lowest energy consumption is for those homes which only use heating pumps. The maximum energy consumption is found to be for those homes which use electrical furnaces for heating. The energy consumption of those houses is about 2.1 of the energy consumption for homes with heat pumps. The energy consumptions for homes with gas and homes with a combination method of heating are 1.9 and 1.6 times the consumption of house with heat pumps.

To further understand the energy consumption trends of the groups, the average monthly energy consumption for each house is divided by its heated area to obtain the energy intensity ration in kJ/m^2 As shown in Figure 5 the lowest energy intensity energy consumption still for the heat pumps group and the maximum energy intensity is for those homes with electrical furnaces (2.6 times the energy intensity ratio of the heat pumps group). The energy intensity for homes with gas and homes with combination method of heating are 1.7 and 1.9 times the consumption of house with heat pumps.

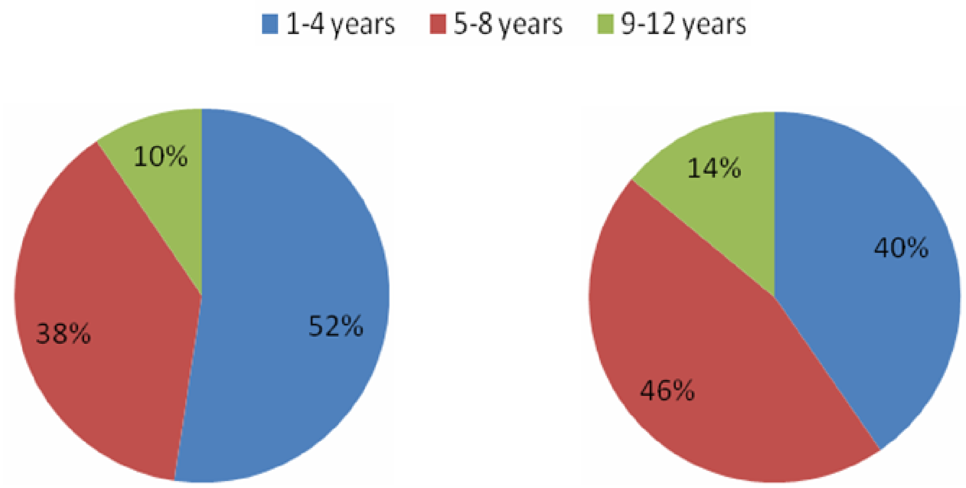

Figure 3. Number of years since construction for (a) Test group (b) Control group.

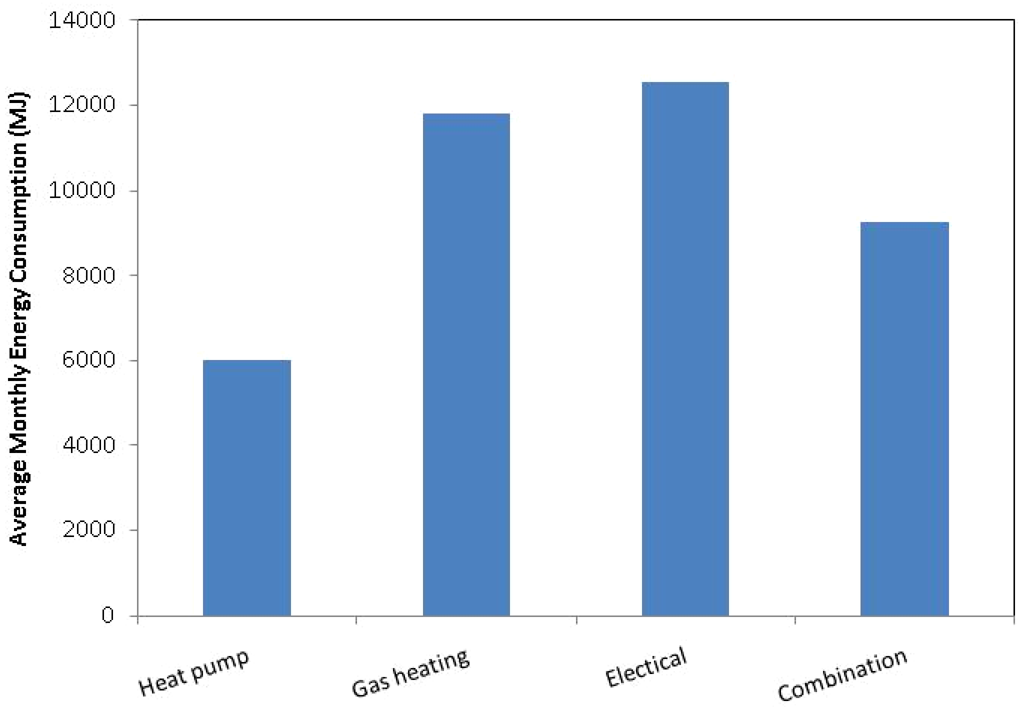

Figure 4. Average-monthly energy consumption for the different groups.

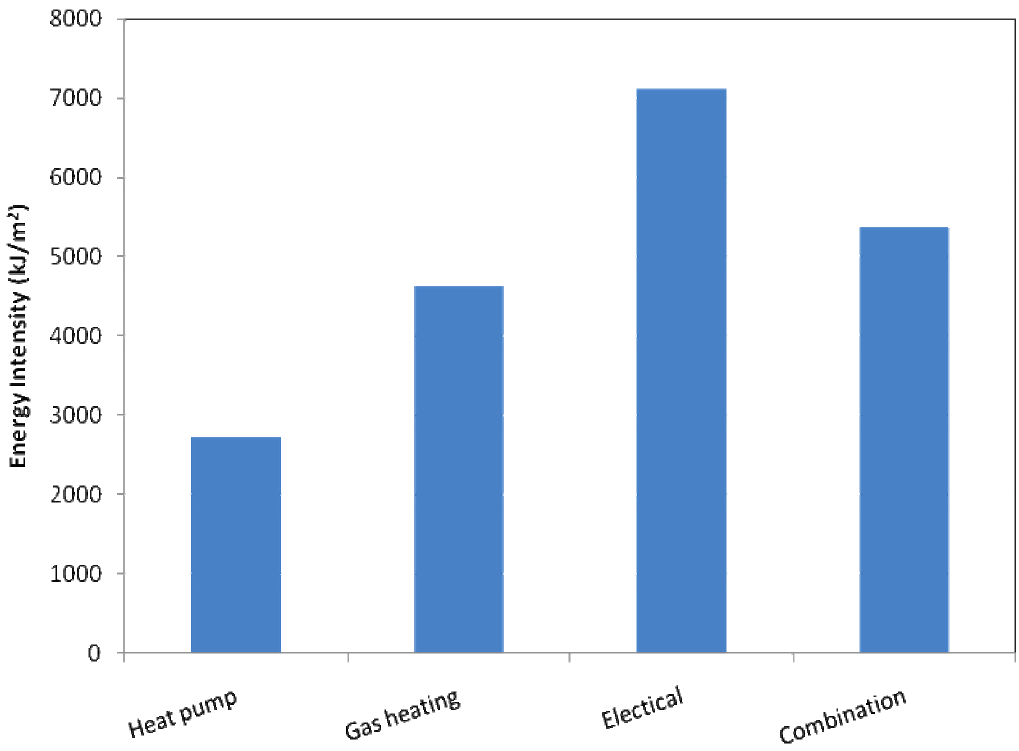

Figure 5. Average-monthly energy intensity for the different groups.

3. Results Analysis and Discussion

3.1 Comparisons of Heat Pump and Electrical Furnace Heating

Comparisons of two methods of heating (heat pump and electrical furnace) are conducted for a number of homes in this study based on the actual energy consumption data. In this section results for one of these homes will be presented. Figure 6 shows the monthly energy intensity during the heating season for a house with electrical furnace and compares it with the energy intensity when using a heat pump. The house is classified as a one-story, 3-bedroom, small size house with a heated area of 116 m^2. The house has one 10 kW (3 tons of refrigeration) heat pump unit with SEER of 13. The average household size is 2 persons and the heating temperature inside the house is adjusted to 70^{o}F during the heating months. The house originally has an electrical furnace and retrofitted to heat pump. The figure shows the same trend for the two methods of heating. The energy consumption is higher in the case of Electrical furnace use (dashed line). The average reduction of the energy intensity during the heating season is found to be about 25% which support the previous results from the sample.

3.2. Statistical Analysis of the Data

This paper utilizes several statistical research methods targeted at establishing differences in energy consumptions between homes that have utilized and relied on heat pumps as their main heating source (test group) and homes that have relied on other heating alternatives such as gas, electricity and a combination of the latter two(control group). Samples were collected from both populations, by means of survey data and analyzed using both univariate and multivariate statistical analysis. Our research hypothesis (H_1) is stated as follows:

H_1: Residential use of heat pumps provides significant energy savings over alternative heating sources during the heating season in Eastern North Carolina.

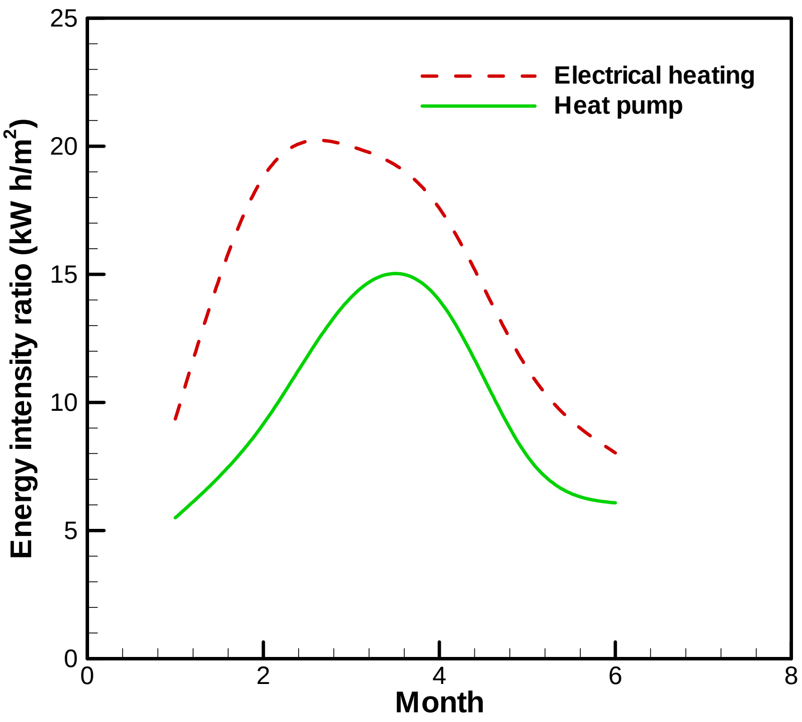

Figure 6. Monthly energy consumption comparison for a medium size house with electrical furnace and heat pump.

3.2.1. Univariate Analysis

The univariate analysis shows the significance of means test for some energy specification variables as well as for the average energy consumption variables during the heating season between the test group (homes that rely on heat pumps) and the control group (homes that rely on alternative sources) for a sample of homes in four different cities in Eastern North Carolina, USA. The significance of means test is conducted by the One Way Analysis of Variance method (ANOVA). The energy specification variables include both, home and household characteristics that are consistent with the energy efficiency program specifications. These variables include the following; House size, Number of occupants, Number of Stories, Years since construction, house orientation and heating temperature. These variables are expected to influence the size of energy consumption in general and are calculated as follows; House size takes three values 1, 2, and 3 for small, medium and large homes respectively. Number of occupants represents the total number of persons that live in the house. Number of stories takes values 1, 2 and 3. House orientation is the number of windows facing south. Heating temperature is average adjusted air temperature in the house, measured in ^{o}F.

Energy consumption during the heating season is calculated using two variables; Average monthly energy consumption and average monthly energy intensity. Average monthly energy consumption is the actual average consumption of all homes in kJ. Average monthly energy intensity is the actual average monthly consumption of each house normalized by the area of the house in kJ/m^2. Normalizing by the area of the house allows us to better control for the effect of house size in the subsequent analysis.

In all statistical analysis to follow, only homes with complete gas, electricity and heat pump data are included and considered (i.e., no missing data). This resulted in a sample size of 82 homes. Results of the ANOVA analysis are shown in Tables 2 and 3 can be summarized as follows: In Table 2, results show that most of the homes in our sample, are medium sized homes. The mean size for the control group sample was 2.62 versus 2.28 mean size for the test group sample. This result indicates that homes that rely on other heating sources (control group) are slightly larger in size than homes that rely on heating pumps (test group). The mean difference is statistically significant at the 95% confidence level.

The mean number of occupants is higher in the control group than the test group, indicating that homes that rely on alternative heating methods usually have larger households. This result, however is not statistically significant.

Table 2: One way ANOVA analysis of house characteristics.

	Mean Heat Pumps (1)	Mean Other Heating Methods (2)	Mean difference (1-2)	P-Value
House size	2.28	2.62	-0.35	0.015**
Number of occupants	2.73	2.80	-0.07	0.827
Number of stories	1.57	1.82	-0.25	0.072*
Years since construction	4.61	5.63	-1.02	0.132
House orientation	4.5	5	-0.5	0.481
Heating temperature	70.76	69.60	1.16	0.082*

* denotes statistical significance at the 10% level, ** denotes statistical significance at the 5% confidence level.

The mean number of stories is higher in the control group than the test group , indicating that homes that rely on alternative heating methods tend to have more stories (i.e. bigger) than the homes that rely on heat pumps. This result is statistically significant at the 90% confidence level. Results, further show that the mean number of years of constructions and the mean number of windows facing South in the control group is higher than those in the test group, however this result is not statistically significant.
Finally, results in Table 2 show that the average adjusted air temperature (heating temperature) in the control group is significantly lower than that in the test group, indicating that homes that rely on heat pumps (test group) are warmer than those that rely on alternative sources of energy. This result is significant at the 90% confidence level.
In Table 3, the mean difference in energy consumption between the two groups is directly measured. Results show that the average monthly energy consumption during the heating season is higher in the control group than in the test group. This result is statistically significant at the 99% confidence level. The result indicates that homes that rely on heat pumps as a main source of energy consume less energy and are thus more energy efficient than residential homes that rely on alternative sources of heating energy. Furthermore, results in Table 3 show that the average monthly energy intensity is higher in the control group than the test group. This result is also significant at the 99% confidence level. This result is even more important as it proves that the homes with heat pumps are more energy efficient even after controlling for house size and despite the fact that these homes have fewer windows facing South and have a significantly higher heating temperature (as discussed above in Table 2).

Table 3: One way ANOVA analysis of energy consumptions.

	Mean Heat Pump (1)	Mean Other Heating Methods (2)	Mean difference[1] (1-2)	P-Value
Average monthly energy consumption during the heating season	6006377	10910618	-4904241	000***
Average monthly energy intensity during the heating season	57203	303659	-246456	000***

*** denotes statistical significance at the 1% confidence level.

Overall, results of the univariate analysis support the hypothesis that residential homes that use heat pumps are more energy efficient and achieve higher energy savings in their monthly energy consumption than their counterparts who rely on alternative sources of heating.

3.2.2. Multivariate Analysis

In this section, a multivariate framework is used to directly test the hypothesis that the use of heat pumps has resulted in energy savings over alternative heating sources during the heating season in the residential sector of Eastern North Carolina. Reduction in levels of energy consumption is usually an indication of energy savings. Energy consumption is proxied by two variables; the average monthly energy consumption and the average monthly energy intensity during the heating seasons (discussed and measured in the previous section).

In this multivariate framework, an Ordinary Least Squares (OLS) regression is conducted on the overall sample of 164 homes that rely on heat pumps as well as other alternative heating sources. In order to be able to document a relationship, we need to control for the effects of other possible variables that might influence the level of energy consumption in the residential sector.

The control variables used in the multivariate framework are the energy specification variables that have been defined and discussed earlier. We control for House size (HSIZE), Number of occupants (NOCCUP), Number of stories (NSTOR), Years Since Construction (CONSTYR), House Orientation (ORIENT) and Heating Temperature (HEATEMP). Table 4 presents the results of the following OLS regression. In Panels A and B of the table, we report regressions using each of the energy consumption variables, as the dependent variable respectively as shown in Equation 1.

$$ECONSUMP_i = \beta_0 + \beta_1 \text{ LN HSIZE}_i + \beta_2 \text{ NOCCUP}_i + \beta_3 \text{ NSTOR}_i + \beta_4 \text{CONSTYR}_i + \beta_5 \text{ORIENT}_i + \beta_6 \text{ HEATEMP}_i + \beta_7 \text{ HPUMP} + \epsilon_i \quad (1)$$

For i = 1 to N, where N is the number of homes in the overall sample, and LN HSIZE is the natural log of the House Size variable.

The variable of interest in this model is heat pump (HPUMP). This is the independent variable that we use to test the energy savings hypothesis. HPUMP is a dummy variable that takes the value of 1 if the home relies on heat pumps, as the main source of heating, and zero, if the home relies on other alternative heating sources.

Results in Table 4 strongly support the research hypothesis. The results can be summarized as follows:

In Panel A, using the average monthly energy consumption during the heating season (ECONSUMP) as the dependent variable, the coefficient of the heat pump dummy (HPUMP) is negative and significant at the 99% confidence level, indicating, that the use of heat pumps reduced the monthly average energy consumption in the sample.

The coefficient for the natural log of House size (LN HSIZE) was positive and significant at the 95% confidence level. As predicted, the larger the house, the higher its energy consumption levels and vice versa.

The Coefficient for most of the control variables came out with the same expected signs, where average monthly consumption increases with the increase in the # of occupants , the number of stories in the house. The coefficient for NOCCUP and NSTOR was positive and significant at the 95% confidence level. The coefficient for House orientation (ORIENT) and heat temperature (HEATEMP) came out with the expected signs, but were not statistically significant.

Results in Panel B also strongly support the research hypothesis. When using the average monthly heating intensity as another dependent variable to proxy for energy consumption, the Coefficient for HPUMP was also negative and significant at the 99% confidence level.

Overall, results in Table 4 provide a strong support to the hypothesis that residential homes in Eastern North Carolina that relied on heat pumps as a main source of heating during the heating season were able to significantly reduce their monthly energy consumption, thus save more on their energy bills, more than their counterparts that relied on alternative energy sources. Results from the multivariate analysis also reinforce the research findings in the univariate analysis section discussed earlier.

Table 4: Mutlivariate analysis of energy savings.

Dependent variable; ECONSUMP		
Independent Variables	Panel A	Panel B
Constant	451.1	448.1
	(0.299)	(0.6303)
LN HSIZE	509.3	592.4
	(2.164)**	(1.180)**
NOCCUP	1749	465.5
	(1.345)**	(1.954)**
NSTOR	1596	111.2
	(1.326)**	(2.00)**
CONSTYR	-1264	-3.260
	(-0.619)	(-0.03)
ORIENT	-1201	-198.3
	(-0.341)	(-0.741)
HEATEMP	5977	134.6
	(0.584)	(1.036)
HPUMP	-3380	-2880
	(-2.618)***	(-4.720)***
F value	4.740	4.916
P value	0.000***	0.000***
R^2	0.322	0.326
Adj R^2	0.251	0.260

4. Conclusions

This study evaluates the energy consumption for residential homes in four cities at eastern North Carolina. The main objective of the study is to compare the energy consumption for homes with different methods of heating. Data was collected using surveys in addition to actual energy consumption data form utility bills. Analysis of the actual energy consumption showed that homes with heat pumps as the only method of heating have the lowest energy consumption and the lowest energy intensity ratios. In addition, data was analyzed using descriptive statistics, univariate analysis and multivariate analysis. Results of the univariate analysis and multivariate analysis support the hypothesis that residential homes that use heat pumps are more energy efficient and achieve higher energy savings in their monthly energy consumption than their counterparts who rely on alternative sources of heating.

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Nehad H. Elsawaf is an Assistant Professor of Economics at Helwan University, Cairo Egypt. She received her Bachelor's and Master's Degree in Economics at the American University in Cairo. She received her Ph.D. in International Finance from Old Dominion University, USA. Her research interests are in the areas of energy economics, risk management and the operations of multinational enterprises.

Tarek M. Abdel-Salam is an Associate Professor of Engineering at East Carolina University. He received his Ph.D in Mechanical Engineering from Old Dominion University, Norfolk, Virginia, USA. His research interests include renewable energy, energy management, wind energy, solar energy and, fuel injection and alternative fuels.

Leslie R. Pagliari is an Associate Professor in the Department of Technology Systems and Associate Dean of Academic Affairs at the College of Technology and Computer Science, East Carolina University. Her research focus is in effective logistical strategies, quality management, and STEM initiatives. She holds an MS in Occupational Safety and a PhD in Engineering Management. She is active in the Council of Supply Chain Management Professionals, the Eastern Carolina Safety and Health Board, and the Association for operation management.