THE SOCIAL ASPECTS OF DESIGNING AN ANAEROBIC MICRODIGESTER WITH COMBINED THERMOELECTRIC HEAT AND POWER GENERATION TO CONVERT HUMAN EXCRETA TO ELECTRICITY, HEAT, METHANE AND FERTILIZER

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ABSTRACT

More than 894 million people do not have access to clean water sources and as a result, 1.6 million children die each year from diseases caused by fecal-oral contamination. Due to poor sanitation practices worldwide roughly two billion people use non-sewered or non-piped sanitation systems that often pollute the water supplies. The solution to this problem is two-fold. The first and most important part is the social aspect of the problem. This includes establishing an adoption plan for the technology in the target community to ensure it is used as intended and not abandoned or scavenged for parts or other uses. Adoption also includes affordability and practicality of the design (local manufacture), and spreading knowledge of how to improve existing sanitary practices. The second part of the solution is the actual technical design of the unit to fit the community where it is to be implemented. To better understand the social and economic aspects of a proposed unit, we interviewed rural and urban individuals in Faisalabad, Pakistan. The results of this survey were used as the basis for a modified engineering design we are currently testing. As a result of the information that was gained from the survey, a very simple engineering design of the unit was created that can be built with limited technology and is practical for the Asian subcontinent. The design is of a single modular unit that will be able to produce heat, electricity, fertilizer, and methane from human excreta. The unit is small in size so that it may fit in any location within a house to enable familial adoption, and it is also simple in design so that it only requires basic maintenance for proper use. Currently there are other more complicated systems that convert human excreta to methane gas, however this unit is unique in the sense that it can be used at the household level both safely and affordably. It is evident that the social aspects of this project, not the technical, dictate the majority of the engineering design constraints of the unit. Finally, once the unit is implemented on site, social work needs to be established to ensure the proper use of the unit and also to determine how well the engineered unit is doing on site.

INTRODUCTION

Currently there are 4.2 billion people around the world that are in need of improved sanitation (Mara, 2003). As a result millions of people worldwide are dying because of lack of clean drinking water due to human waste entering under water streams, as well as the spread of diseases caused by fecal-oral contamination. Most of the disease causing pathogens that are inside drinking water and that are passed on through drinking water are principally of fecal origin (Ashbolt et al., 2001; Hunter et al., 2002). Over 2.6 billion people worldwide live without access to a clean and safe toilet. Diarrheal diseases caused by poor sanitation kill more children than AIDS, malaria, and measles combined (Coombes, 2010). Fecal-oral diseases are a major killer today and about two children under the age of five years dies each minute due to these diseases. Diarrhea in infancy not only can lead to malnutrition, it can also lead to poor cognitive function later on in a child's life (Mara, 2003).

Water and excreta related diseases also have an effect on a countries economy. It is estimated that 360-400 billion working days were lost in developing countries due to fecal-oral diseases keeping people away from work (Pearce, 1993). It is estimated that in Pakistan alone loss of sanitation costs the country 3.9% of its GDP.

The types of water sanitation and toilets developed in North America and other industrialized nations are inadequate for developing nations. Flush toilets on average use about 70 L/person/day of water (Gleick, 1996). So for a population the size of Canada which is about 34 million people that is approximately 2.38 billion liters of water per day just to flush the toilet. This water usage is not practical in many areas, because water is very rare, and there is no infrastructure in place for piping. Also, the throne architecture developed by Thomas Crapper (1884) has been adopted in the Western world but has not been largely adopted in Eastern countries such as China, India, Pakistan, and other Eastern Asian nations. Thus, it is required that new technology to deal with handling of human excreta must be sensitive to the cultures, history, and current practice of waste handling. A Western solution is not necessarily an Eastern one.

The main purpose of the study reported here was to understand the social needs and adoption issues that will be confronted by introducing new toilet technology to people in developing nations. Often times the hardest part of implementing and introducing a new technology in a specific environment is not the actual technology but the social acceptance of the technology.

MATERIALS AND METHODS

Study Population and Setting

The survey developed for this research was conducted in five communities in the city of Faisalabad, Pakistan shown in Figure 1. Pakistan is the sixth largest country in the world by population, with a population of more than 190 million people. The median age of the citizens is 21.9 years of age with a life expectancy of about 66 years. About 36% of the population lives in urban environments, whereas the majority lives in rural environments. The major infectious diseases in Pakistan are often due to poor sanitation practices and lack of clean drinking water due to ground water contamination. Common waterborne and food related illnesses are bacterial diarrhea, Hepatitis A and E, and Typhoid Fever. Literacy within the country is equal to about 54.9% with a large disparity between men and women. Male literacy rates are equal to about 68.6% whereas female literacy rates are around 40.3%. To

better understand the economics of the country, the GDP per capita is approximately equal to $2,800 a year, which ranks 174 in the world out of 226 countries (CIA-Factbook, 2012).

The population of Faisalabad is approximately equal to 2.8 million; this is the third largest metropolis in Pakistan located in the province of Punjab. The climate can see extremes ranging from a maximum temperature of 50 °C during the summer months to a minimum of -2°C in the winter. The mean maximum and minimum temperature in the summer months range between 39 to 27°C whereas in the winter they range between 17°C and 6°C (It's Pakistan, 2012). Over 91 million people in Pakistan live without improved sanitation (UNICEF & WHO, 2012). Thus, Pakistan is an ideal target nation for new technology to safely handle human excreta. To conduct the survey, a researcher (capable of speaking Urdu) was sent to Faisalabad, Pakistan in November 2011.

Figure 1: Map of Pakistan with the city of Faisalabad highlighted above (CIA Factbook, 2008).

Sampling Procedure

The survey consisted of 20 simple to answer questions that were written in Urdu which is the local language used for reading and writing in Faisalabad. The survey was translated by the researcher that was sent out to Faisalabad, and it was typed in Urdu and individually given out to each participant. Ethics approval from the University of Calgary was granted to carry out the survey. The survey was distributed among middle class families of Faisalabad, and no more than one survey per household was given out. The participants that took the survey were literate and the survey was completed in privacy without any influence of the researcher. The age of the participants ranged between 4 and 70+.

Prior to conducting the survey we had performed a sample size calculation. Assuming we wanted to determine the responses for 91,000,000 Pakistan citizens without access to proper hygiene, with 95% confidence with a confidence interval of 8% we would need a sample size of 150. We surveyed 196 people (154 male, 42 female), giving us a confidence interval of 7% (results presented as percent of population are +/- 7%).

Questionnaire

The following is a list of the 20 questions that were asked in the survey.

1. What is your gender?
2. What is your age?
3. Do you live in the city or the village?
4. What is the name of your city or village?
5. How many people live in your household?
6. What type of toilet do you use?
7. Typically how many times a day do you defecate?
8. How many hours a day is electricity unavailable in your home?
9. How many hours a day is gas unavailable in your home?
10. If you had a toilet that creates electricity, gas and fertilizer without any ongoing cost would you use it?
11. If no why?
12. Would you be willing to purchase this type of toilet?
13. If no why?
14. What is the reasonable cost of this type of toilet?
15. If you had one electronic device that you cannot live without what would it be?
16. If you had one device that runs on gas that you cannot live without what would it be?
17. How many animals do you have in your house? And what types?
18. What do you do with the animal waste?
19. What do you do with your kitchen scraps like fruit and vegetable peels?
20. Additional comments?

Out of all of the surveys that were distributed 196 were returned and analyzed.

RESULTS AND DISCUSSION

Demographics and Baseline Data

The following sections highlight the results of the survey. Figure 2 shows the number of people living in each household for both the city and the village. As can be seen the average family size of people living in a household is typically larger than that found in North America. This is because the family is living as an extended family often with grandchildren and grandparents in the house. Also, on average each woman gives birth to about 3 children, as compared to countries like Canada and the United States it is 1.59 to 2.09 children per mother (CIA Factbook, 2012). There is no significant difference between the number of people living in each household in the city or the village as shown in Figure 2.

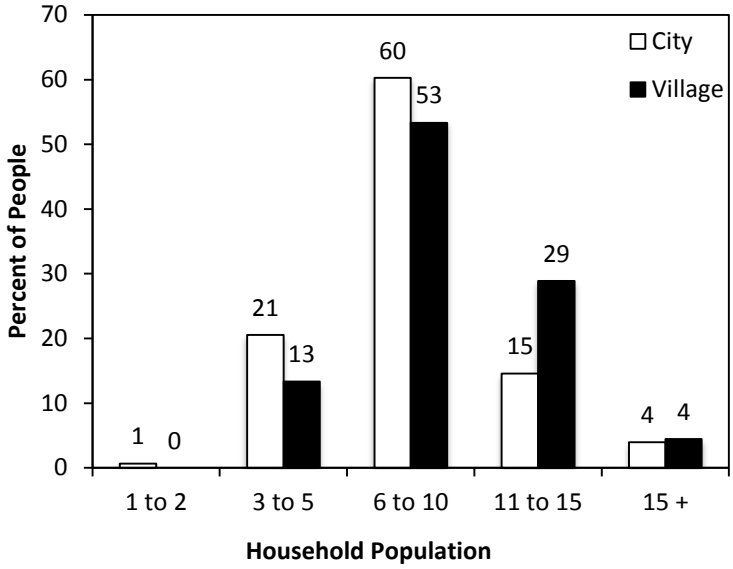

Figure 2: The percent of respondents that stated how many people are living in their home answering the question: Q5: How many people live in your household? (n = 96 responses).

Figures 3 and 4 below show the number of defecations per day for males and females. As shown in Figure 3 most individuals defecate 2 to 3 times daily, also the number of defecations per day between males and females is also approximately the same. This is valuable information that can be used to size out a toilet for this region.

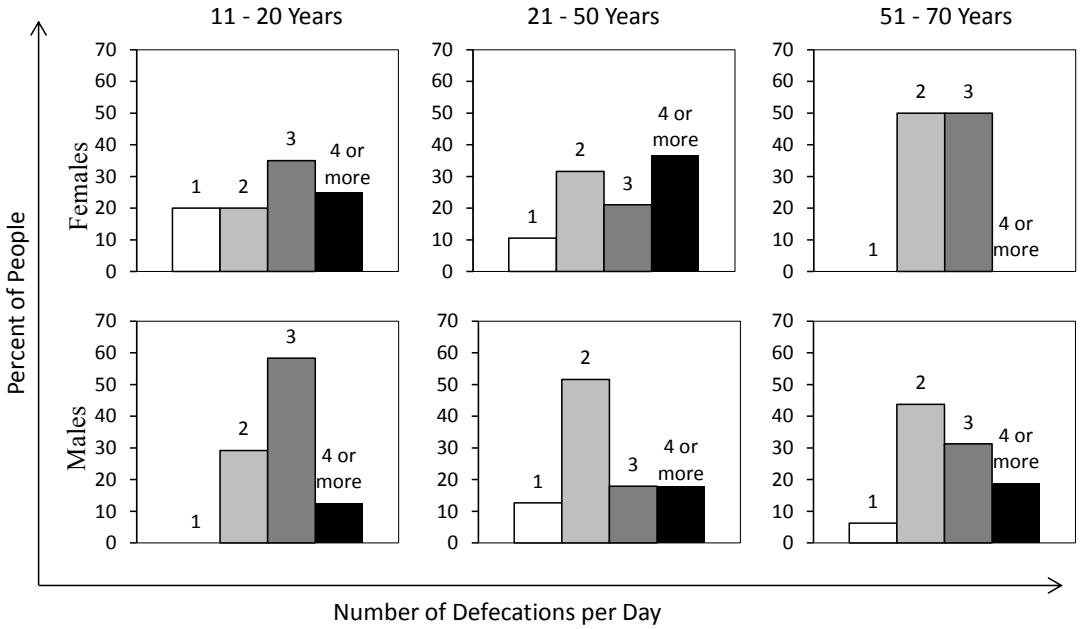

Figure 3: The percent of respondents that answered to the number of defecations per day for males and females between the age of 11 and 70 years answering to the question: Q7: Typically how many times a day do you defecate? (n = 151 responses).

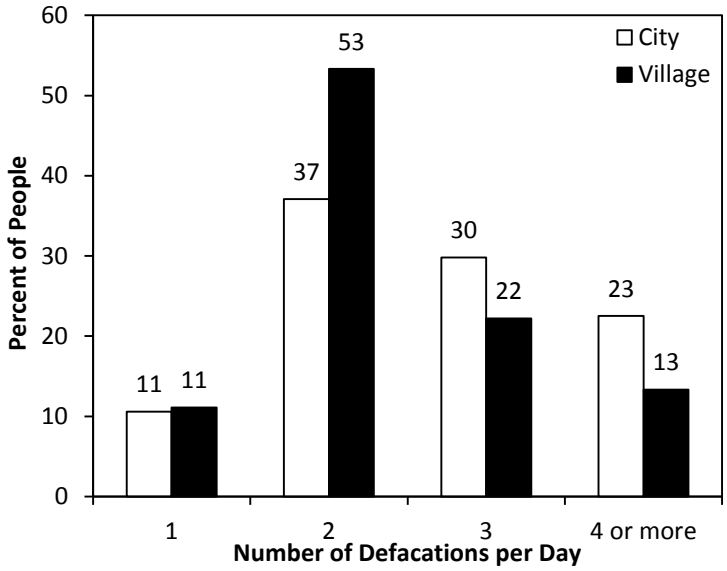

Figure 4: Percent of respondents that answered to the number of defecations per day for people living in the city and village answering to the question: Q7: Typically how many times a day do you defecate? (n = 196 responses).

Figure 5 below shows the methods used for capture of human excreta. For both city and village dwellers it can be seen that preference to a squat toilet, displayed in Figure 6, is given over a sitting (Western throne) toilet. After talking with the participants in the survey it is clear that because the social norm is to use a squat toilet participants also feel that it is more sanitary because no body parts come into physical contact with the toilet.

It is estimated that in Pakistan over 40 million people still practice open defecation. About 4% of the urban population and 34% if the rural population practice open defecation (UNICEF and WHO, 2012), and this is a huge sanitary problem. The data presented in this study shows that approximately 25% of village dwellers and < 2% of city dwellers practice open defecation.

When survey participants were asked whether they would use a toilet that created electricity, gas, and fertilizer, the response was unanimously yes (data not shown). People were very responsive to the idea and they were actually quite surprised that a toilet could produce so many useable things.

Also, another very important point is that people in this area do not use toilet paper to clean themselves as they use the toilets. Due to cultural and religious practices they use water to clean themselves after they have used the toilet to defecate or urinate. However, when water is unavailable then they often resort to leaves or mud.

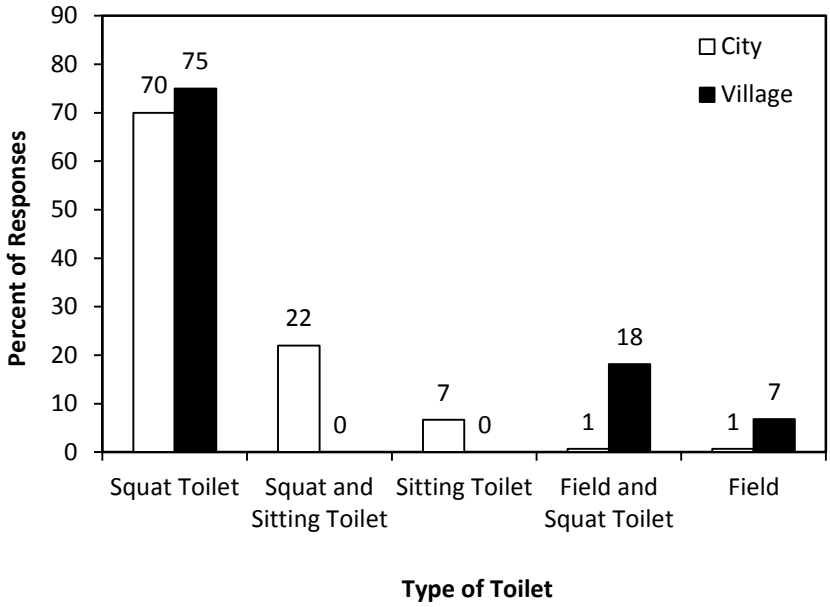

Figure 5: Percent of respondents answering to the method of human waste disposal for the city and village answering to the question: Q6: What type of toilet do you use? (n = 194 responses).

Figure 6: Typical squat toilet in Pakistan.

The average household income for low income families is less than 100 Canadian dollars a month to about 1,000 Canadian dollars for upper middle class families. About one-fifth (22%) of the population lives below the poverty line. The income disparity is quite large and the upper class can make up to several hundred to a few thousand Canadian dollars a month. Figure 7 below shows the amount of money the participants are willing to pay for such a toilet if it were to be sold. This gives an indication of the value perceived for the toilet.

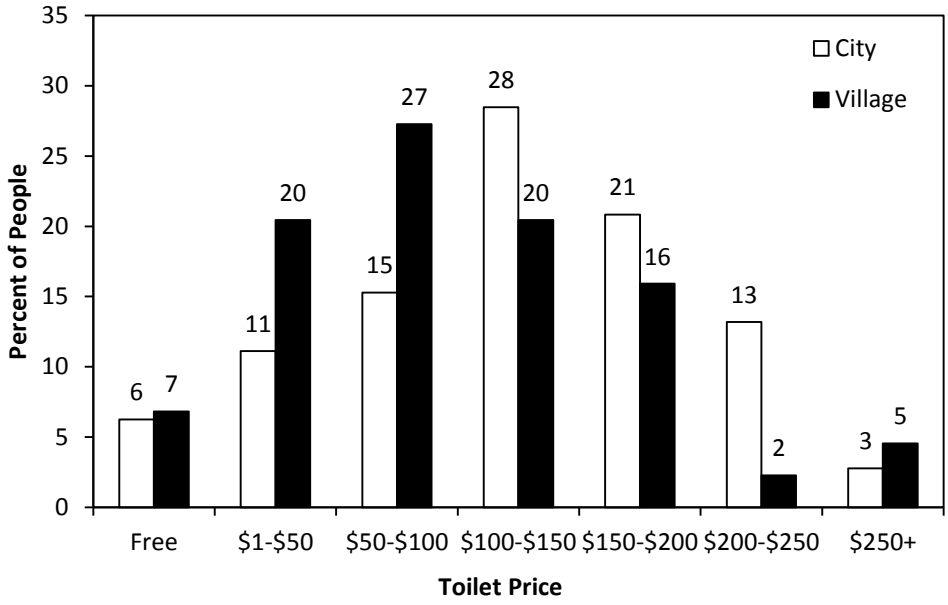

Figure 7: Percent of people answering to the price in Canadian dollars people are willing to pay for the toilet answering to the question: Q14: What is the reasonable cost of this type of toilet? (n = 188 responses).

Although both electricity and gas is widely available in the city, as seen in Figures 8 and 9, each day, electricity and gas supplies are shutdown for several hours. The cause for this is a shortage of resources in the country as well as political problems within the area. However, as shown in Figure 8, gas is often unavailable in the villages. The gas line infrastructure is not in place to allow gas into the more remote areas. Here the locals are dependent on using cow patties and other sources of fuel to cook their food and warm their houses in the winter.

Figures 9 and 11 reveal which electrical or gas appliance they cannot afford to live without. For electrical devices basics, the house fan and motor for the water pump were at the top of the list. Most of the homes in Faisalabad use underground water sources thus requiring a water motor to pump the water from underground aquifers to a container on the roof or higher up where it can be later used. For gas appliances, as shown in Figure 11, a gas stove was the main device that people could not live without since it provides them with the ability to cook food.

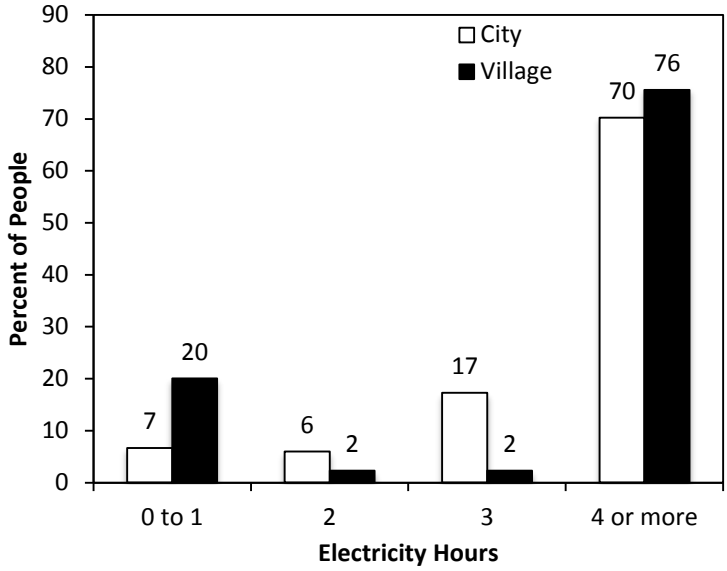

Figure 8: Percent of people answering to the number of hours each day electricity is unavailable in the home answering to the question: Q8: How many hours a day is electricity unavailable in your home? (n = 196 responses).

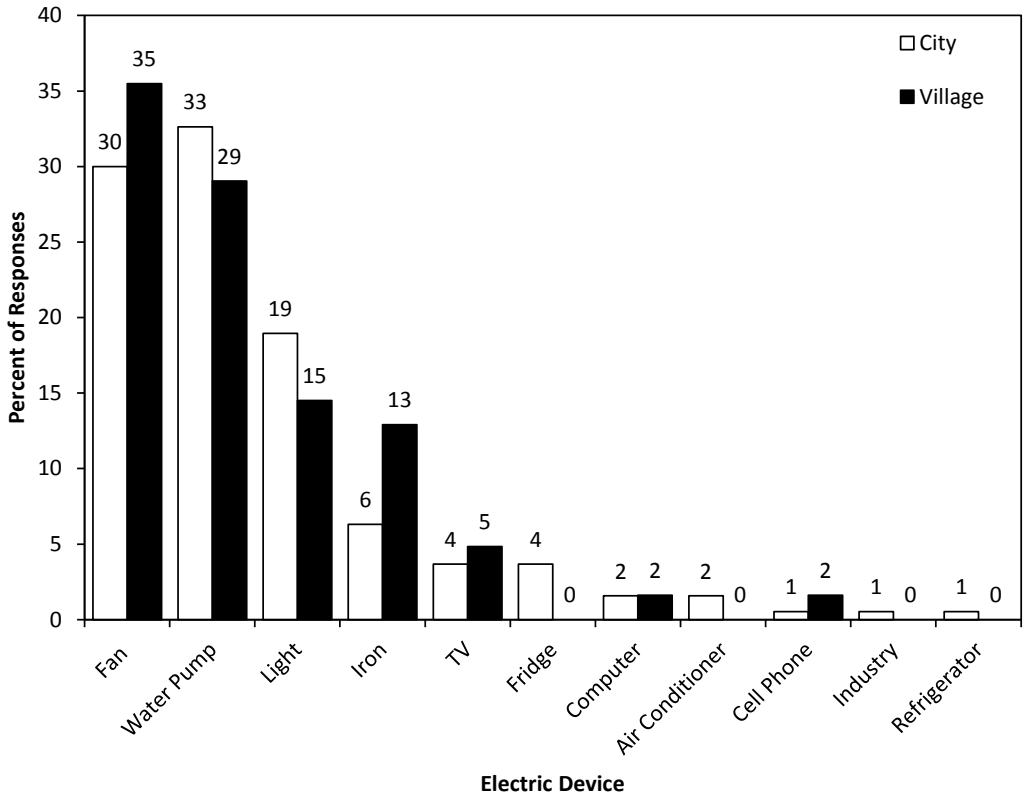

Figure 9: The percent of respondents listing a particular electrical device that they wrote down answering the question: Q15: If you had one electronic device that you cannot live without what would it be? (n= 252 responses).

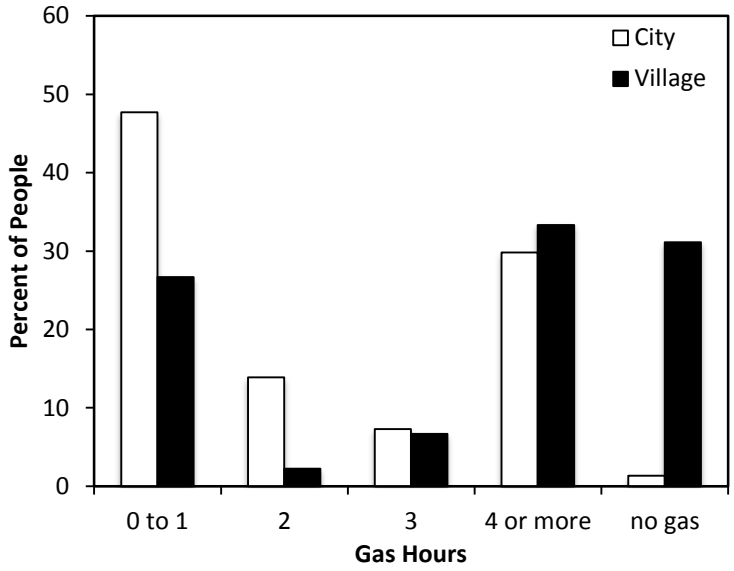

Figure 10: Percent of people answering to the number of hours each day gas is unavailable in the home answering to the question: Q9: How many hours a day is gas unavailable in your home? (n = 196 responses).

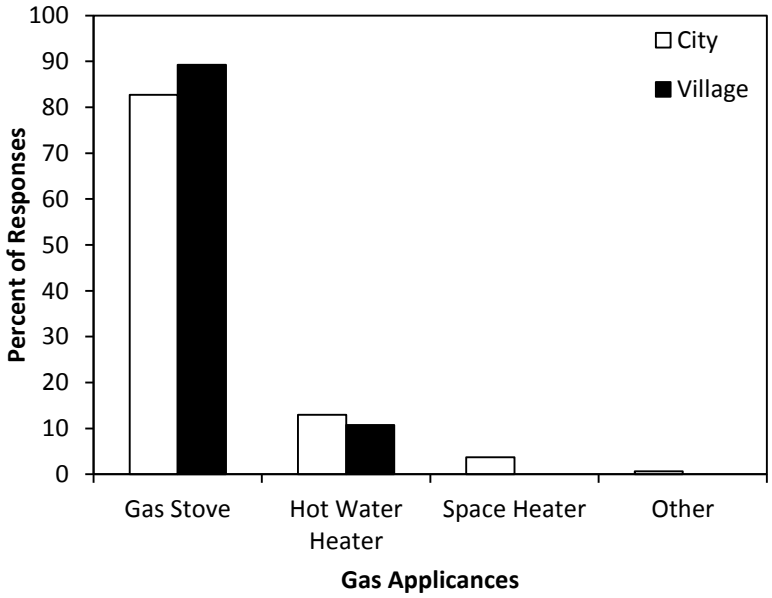

Figure 11: The percent of respondents listing a particular electrical device that they wrote down answering the question: Q15: If you had one electronic device that you cannot live without what would it be? (n = 191 responses).

Figure 12 shows the types of animals that are owned by people living in the city and the village. Also shown in the bottom plot is that the majority of city dwellers do not have animals, whereas a majority of the people living within the villages do have animals. The majority of the animals in the region are goats, water buffalo and cows. Both of these animals provide milk for the people and are still used in farming in rural areas.

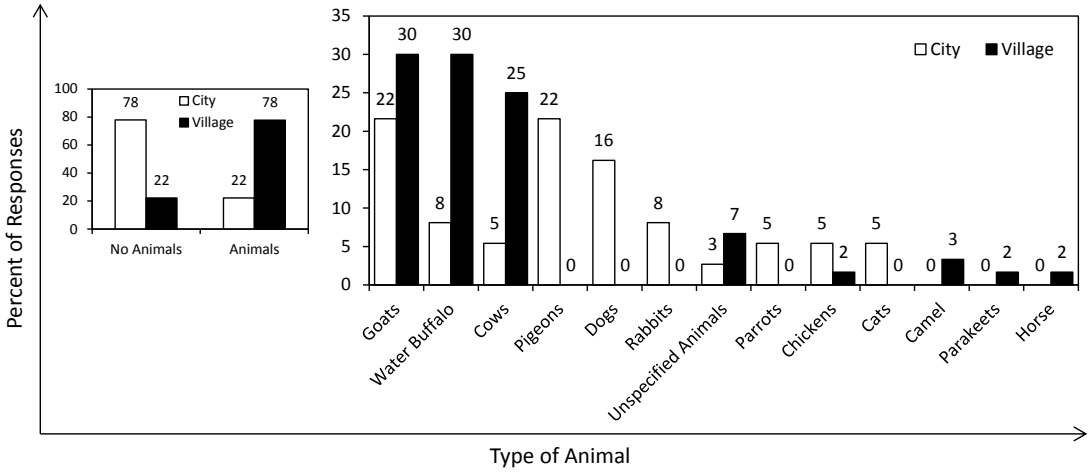

Figure 12: The percent of respondents that have animals in the city and the village that they wrote down answering to the question: Q16: How many animals do you have in your house? (n = 194 responses) and what types? (n = 97 responses).

Most of the waste in urban environments is put away into the landfill sites or is burned. However, in the rural environment the animal waste is used as fertilizer in the field or made into cow patties, illustrated in Figure 13, for fuel to cook their food or heat their homes in the winters. The end use of animal waste is presented in Figure 14. Figure 15 displays the major uses of kitchen organic wastes. The results show that the majority of it is disposed into garbage sites. A much larger amount is used as fertilizer in the village versus that in cities.

Figure 13: Cow patties, cow and water buffalo manure used to make cow patties that are dried out and used as fuel in rural environments.

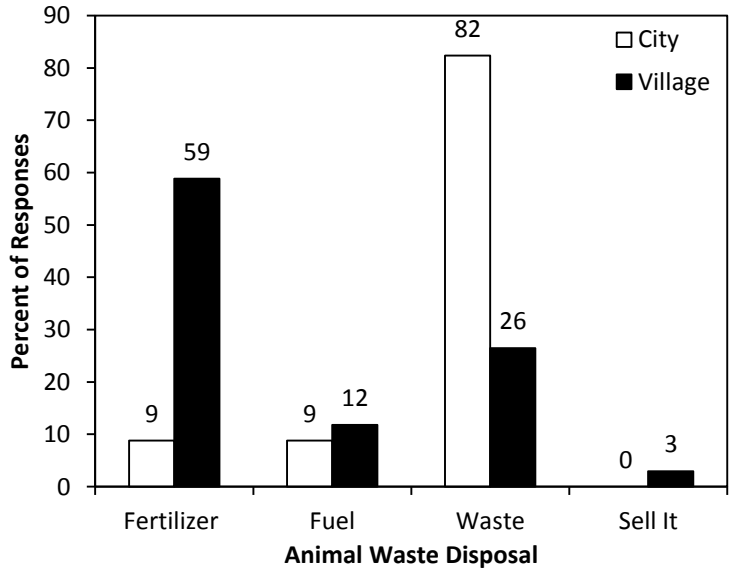

Figure 14: The percent of respondents listing a method of animal waste disposal that they wrote down answering the question: Q18: What do you do with the animal waste? (n = 68 responses).

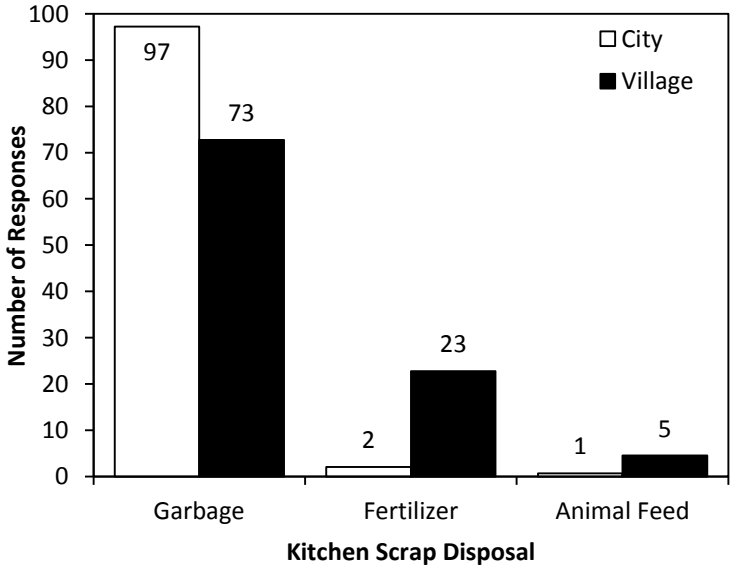

Figure 15: The percent of respondents listing a method of kitchen scarp disposal that they wrote down answering the question: Q19: What do you do with your kitchen scraps like fruit and vegetable peels? (n = 190 responses).

Out of the survey participants only 5% commented in writing. These 5% unanimously agreed that a toilet system that generated biogas, water, electricity, and fertilizer would be beneficial for the country and population, and there is a great need for this technology in the area, due to electricity and gas shortages.

CONCLUSIONS

The conclusions of the study are as follows:

1. The survey respondents appear to believe that a toilet technology that produces biogas, water, electricity, and fertilizer would be beneficial. All respondents unanimously agreed that they would want to use such a toilet.
2. Given the majority of respondents use squat-style toilets, the toilet technology must use this form of toilet.
3. About 78% of village dwellers have animals as compared to only 22% of the city dwellers. The most common types of animals as found in this study were goats, water buffalos and cows.
4. The majority of rural respondents indicated that they use animal wastes for fuel and fertilizer whereas respondents from the city stated that they put most of it to garbage.
5. For both rural and city respondents, gas stoves was the most needed fuel-based appliance in the household whereas a fan and water pump were the most needed of electrical appliances. Nearly 30% of respondents from the rural areas suggested that they have no access to gas supplies.
6. Nearly 30% of respondents, both rural and city, indicated that they have 4 or more hours per day without gas supplies. Nearly 70% of respondents, both rural and city, stated that they have 4 or more hours per day without electricity. This suggests that there is a market for these resources.
7. The largest fraction of city dwellers indicated that they would pay between CAD$100 and $150 for a toilet capable of generating biogas, electricity, water, and fertilizer. The largest fraction of rural dwellers indicated that they would pay between CAD$50 and $100 for such a toilet.
8. Nearly 97% of the kitchen scraps are disposed of in the garbage in the city, and only 73% of kitchen scraps are disposed of in the village, the remainder are used as fertilizer or fed to the animals.

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