Biomass Combustion and ARI in Kiwengwa, Unguja

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Nicole Poepping: I would like to thank the wonderful cook at Pako's for making the best mchuzi na kuku I have ever eaten and everyone at home who provided encouragement and support during my time in Africa. Lastly, I would like to thank all the families who allowed us into their homes and kitchens during our time in Kiwengwa.

Eric Fournier: I would like to thank God and my Family for facilitating my dream to come to Africa (and the good people of the Bucknell University finance department for their willingness to pay for it).

Abstract:

A study was undertaken investigating the relationship between biomass cook stove usage practices in Kiwengwa, Unguja and the incidence of acute respiratory infections (ARI) amongst individuals participating in household cooking activities. In each household, the incidence of ARI was determined via semi-structured interviews conducted with the primary cooker. Additionally, measurements and observations of: biomass cook stove efficiency, stove usage behaviors, and the physical cooking environment were obtained. Statistical analysis was then performed to assess the nature and significance of relationships between variables in the three cook stove usage categories and the stated incidence of ARI within the sample households. Data regarding the incidence of ARI in the sample population was compared to records from the local dispensary detailing the number of reported cases of ARI in the entire village over the previous year.

Introduction:

This study sought to identify possible correlations between ARI, cook stove efficiency, and cooking environment in Kiwengwa. It was hypothesized that there would be strong relationships between these variables amongst household members most regularly exposed to stove particulate emissions.

In Kiwengwa, a small fishing village on the eastern coast of Unguja, cooking methods and techniques used in the domestic setting are fairly homogenous. Wood and to a lesser extent charcoal are the primary fuel types used for cooking meals inside the home. The two types of stove most commonly in use, albeit with some variation in size, were found to be the basic three stone fire (wood burning) and metal charcoal stoves with clay lined combustion chambers. Cooking activities occupy approximately 3 hours per day for the primary cook of each household, most often the wife, and her young children, who either assist in cooking activities or remain in the cooking environment for extended periods of time.

Extensive daily use of stoves in a closed environment coupled with the use of wood or charcoal fuel has shown to increase the risk of many health conditions, especially respiratory illnesses, in household members exposed to stove pollutants (Ezzati et al, 2000). In similar rural communities in Kenya and Tanzania, high levels of child mortality and adult ARI have been linked to cooking activities, specifically the use of wood and charcoal in enclosed spaces (Schellenberg et al; 2002). In the Kilombero region of Kenya, child mortality rates reached 20% in 2002 and ARI was cited as a causal factor in nearly 40% of those deaths (Schellenberg et al; 2002). In Tanzania, similar results were found although the child mortality rate was lower than that observed in Kenya. Furthermore, a three year study conducted in the central region of Kenya surveying women and children’s health and found a strong correlation between ARI and cooking conditions (Ezzati, 2000). Due to the similarities in cooking conditions and fuels used in these study areas and the village of Kiwengwa, it is likely that ARI is also a significant health risk for young children and women in Kiwegnwa.

Background Information

Indoor air pollution from the combustion of biomass cooking fuels is the leading cause of upper respiratory illnesses worldwide (Ezzati, 2000). More than 6% of the global burden of disease and mortality are caused by acute respiratory infections (ARI) which are directly linked to exposure to pollutants from domestic biomass fuels, mostly in developing nations (Ezzati et al, 2001). Women, especially those responsible for cooking, and their young children are most heavily exposed to high levels of these pollutants which are concentrated primarily in indoor cooking spaces (Bruce et al., 2000).

In the developed world, biomass fuels have been abandoned in favor of cleaner more efficient alternatives such as natural gas and electricity, however poverty remains a primary barrier to the adoption of these fuels in developing nations. This, along with high population growth rates in many developing nations, has lead to the increasing use of biomass fuels amongst the poor, and the slow pace of development in many of these countries suggests that biomass fuels will continue to be used for many decades (Bruce et al., 2001).

Currently, more than two billion people rely on biomass fuels as the primary source of domestic energy (Ezzati, 2000). In addition to the grave implications for increased environmental destruction associated with the continued use of biomass fuels there will also be significant negative impacts on the health of those being regularly exposed to the emissions from their combustion. The most common health conditions associated with exposure to biomass emissions are acute upper respiratory infections (AURI), acute lower respiratory infections (ALRI). This association, coupled with the prevalent use of biomass fuels worldwide has prompted several NGOs and the World Health Organization to carry out new health initiatives to determine effective preventative measures that could potentially reduce exposure to these pollutants (Bruce et al; 2000).

Still, very little research has been conducted attempting to correlate levels of indoor air pollution to the incidence of respiratory illnesses in the domestic setting. Studies involving outdoor air pollution in densely populated areas are prevalent, but these tend focus on chronic low-level exposure to particulate matter, which are problems primarily in large cities and developed countries. This represents a critical gap in our understanding of the role of exposure to biomass pollutants as a causal agent of ARI, especially since approximately 80% of total global exposure to particulate matter occurs indoors in developing countries (Ezzati, 2000).

To better understand the relationship between cook stove usage, indoor air pollution, and ARIs, further research must be done to determine how the operation and design of stoves influence their performance in terms of efficiency. This data coupled with analysis of local health conditions is needed to increase awareness and, more importantly, aid in the development of preventative measures to reduce the negative health effects of indoor air pollution.

Health effects of exposure to indoor air pollutants

Acute respiratory infections (ARI) are the most common physiological response to exposure to emissions from indoor biomass combustion (Ezzati et al, 2001). ARIs are divided into acute lower respiratory infections (ALRI) and acute upper respiratory infections (AURI) (See appendix A).

> *Acute lower respiratory infections*- These infections are isolated to the lungs, the bronchi, the trachea, and the larynx. Bronchitis, pneumonia, and broncho-pneumonia are the most commonly reported ALRIs.
>
> *Acute upper respiratory infections*- These infections are isolated to the pharynx, the tonsilar glands, the eustachian tube, the nasal cavities, and the sinuses. Colds and sinus infections are the most commonly reported AURIs.

Limited evidence also shows there is an increased incidence of other health conditions such as lung disease, asthma, lung cancer, tuberculosis, cataracts, and blindness in women and children regularly exposed to indoor air pollutants. However further research is necessary to narrow the number of possible causal factors of these conditions.

Study Area:

The study was carried out in the village of Kiwengwa on the Island of Unguja (see image on right). Unguja is located between 5° 43" and 6° 29" south of the Equator, and 39° 11" and 39° 36" east of the Prime Meridian. It is approximately 40 kilometers off the coast of Tanzania mainland and with a total area of 1658 square kilometers is the largest island within the Zanzibar Archipelago. The capital of Zanzibar, Zanzibar Town, is located on the western coast of Unguja. The main industries in Unguja are fishing, spice farming, and tourism.

Kiwengwa is a small fishing town located in the north B District of Unguja Island. It consists of three loosely segregated villages- Kairo, with a population of 161 people, in the north, Gulioni, with a population of 477 people, in the center and the largest village, and Kumbaurembo, with a population of 541 people, in the south (Masudi, 2006 census data). Our research project was conducted in the largest of the three villages, Kumbaurembo which has 245 males and 296 females of which 58% are adults and 42% are children (Masudi, 2006 census data). The primary occupation for men in Kumbaurembo is artisenal near-shore fishing although a small percentage are private for-hire drivers, work in the surrounding hotels, or are farmers. Most women are housewives and some also collect seaweed, cook for business, and clean at the hotels in addition to their household duties. Thirty one, or 32%[1], of the households in Kumbaurembo were surveyed, and ARI health profiles for 168 people in Kumbaurembo were acquired during the period of April 14th- May 5th, 2007.

Kiwengwa was chosen as the site for this study because in terms of size, socio-economic development, and the fuel types in use, it is similar to ARI study sites from Kenya and the Tanzanian mainland. This is significant because cook stove related ARI are also likely to be prevalent in Kiwengwa due to these similarities. Furthermore, Kiwengwa is demographically similar to the large number of small villages dotting Unguja's eastern coast. This ensures that the data sets produced as well as any conclusions made have relevance for other rural communities in coastal Unguja.

[1] Calculated by using the average household size for Tanzania, 5.5, and dividing the total population of Kumbaurembo by 5.5 and using that number, 98 houses, to determine the percentage of households surveyed for this study. This method was used because the number and location of households is constantly influx due to new construction and abandonment of old dwellings.

Methodology:

Data was gathered to determine the strength and nature of relationships between the incidence of ARIs and

1.) stove efficiency

2.) cooking behaviors

3.) cooking environment

Measurements of Stove Performance

To obtain quantitative measurements of the thermal efficiency of the stoves being used by our interview respondents, water boiling tests were performed in accordance with the internationally recognized standard procedure designed by experts from the Shell Foundation's Household Energy and Health Program (appendix B). The exact procedure to be used for this portion of our study was taken from the Water Boiling Test Procedure, Version 1.5 (August 20, 2004) (appendix B. One of the three tests described in the procedure, "The Simmer Test," was eliminated for the sake of the time demands being made of the interview respondents. Also, "The Simmer Test" was included as a measurement of the fuel consumption rating for the stoves being tested and because this is not a focus of the research question, its omission was justified. In addition to the basic test procedure the Shell Foundation group has also made available an exhaustive Excel spreadsheet with input fields for calculating different metrics using the data gathered in the test. Also, there is ready made data collection sheet which neatly organizes observation fields based on the chronology of the testing procedure and the specific layout of the calculation spreadsheet (Appendix G).

Justification

The decision to examine stove efficiency is grounded in the well established chemical principle that higher levels of particulate emissions are associated with the incomplete combustion of biomass fuels [i.e. low thermal efficiency] (appendix C). Additionally, this procedure is ideally suited to the necessities of the research environment for many reasons.

1. The test has been designed in such a way that it can be conducted in the field using minimal supplies while still controlling for all of the critical variables governing such a complex thermodynamic system as a biomass cook stove.
2. There are no requirements regarding the technical expertise of the researcher.
3. It is internationally recognized as a standard methodology and thus is valuable in the sense that any data obtained through its use can be compared to data gathered in other similar studies being conducted around the globe.

Observation of Physical Cooking Environment

Using a tape measure, data was obtained regarding:

1. The interior volume and surface area of the structure immediately housing the cook stove (i.e. a room)
2. The presence of a chimney and the surface area of its opening.
3. The presence of any windows or doors and their surface area.

These individual measurements were used as an attempt to estimate of the level of air exchange in the structure. Then this data was compared to data regarding the incidence levels of ARI amongst the interview subjects.

Justification

The concentration of emissions from a stove and thus the potential risk for developing ARI can vary widely based on the physical layout of the cooking environment. The more restricted the air flow to the room or structure housing the cook stove, the greater the concentration of stove emissions being inhaled by individuals participating in cooking. Therefore, these estimates of air exchange could potentially be a mitigating factor in the incidence of cook stove related ARI within the household.

Observation of Cooking Behaviors

Direct observation of cooking techniques such as proximity to the stove while cooking, and frequency of bending over the fire (the location of the highest concentration of particulate matter) was carried out at each household during one meal time, either lunch or dinner depending on the time of the visit to the home. A checklist was developed which included the most commonly observed suspected risk increasing behaviors. (appendix D) Additional space was also provided for other suspected risk increasing behaviors observed that were not previously considered, of which three such behaviors were added to the permanent checklist. The duration of time each household member was engaged in each suspected risk increasing behavior was recorded on the checklist. These were then totaled put into two categories: suspected high risk behaviors, and suspected at risk behaviors, for analysis purposes. These behaviors include:

Suspected high risk behaviors:

1A) Use of a hazardous material as ignition source for charcoals or tinder (Examples include: disposable plastic bags, plastic bottles, and other miscellaneous flammable garbage items)

1B) Placing one's face within 1-3 feet of the flame during ignition and using the mouth to physically stoke the ignition source via blowing

2A) Placing one's face within 1-3 feet of the flame while manipulating the fuel source to increase heat output (defined as physically moving/shaking coals or fuel wood to shake off spent ashes)

2B) Placing one's face within 1-3 feet of the flame while stirring or simmering of foodstuffs using a hand utensil

3A) Collection and disposal of ash in an unhealthful manner (any sort of behavior causing excessive quantities of the particulate spent fuel/ash materials to become airborne)

4B) Use of two or more stoves simultaneously

4C) Use of hazardous materials throughout cooking activities (Examples include: coconut husks, plastics, and other miscellaneous flammable garbage items)

Suspected at risk behaviors:

4A) Sitting within 1-3 feet of the flame (Examples include watching fire, cutting of vegetables and other miscellaneous behaviors occurring close to the fire)

The corresponding abbreviations for each risk behavior will be used throughout the rest of the paper.

Justification

The health effects of exposure to indoor air pollutants is related not only to the type and pollution level in the air but also the exposure level (i.e. the time spent breathing in the polluted air) (Bruce et al., 2000). Exposure refers to, "the concentration of pollution in the immediate breathing environment during a specified period of time" (Ezzati, 2000). An example of a risk increasing behavior, in the sense that it would cause one individual to inhale excess stove emissions over another, might be blowing on tinder rather than fanning it during the lighting process. To address this, a comprehensive checklist of other such risk increasing cooking behaviors was developed and used while observing the interview respondents cook. A quantitative measurement of the number of behaviors rather than qualitative descriptions of their perceived harmfulness allowed statistical analyses relating this phenomenon the incidence of ARI in the sample group to be carried out.

Interviews

An interview was conducted with the members of the household most often engaged in cooking activities (see appendix E for interview questions) to determine household members' exposure to the cook stove while in use and the frequency of ARI in all household members. The interview was conducted in the home of the interviewees, most often before cooking tasks were carried out. Average time spent in cooking environment per day was determined for each member of the household along with the frequency of ARI in each household member in the past year. This information was obtained individually from each household member except for young children, for whom the parents provided the appropriate information. Questions regarding ARI diagnosis were obtained from the World Health Organization's protocol for the clinical diagnosis for ARI (See Appendix F. Information regarding the names, ages, and sex of household members was provided primarily by the wife in the household, who was also most often the primary cook of the household.

Justification

The interview provided critical information regarding cooking times, duration of cooking activities, household members involved in cooking, and frequency and duration of ARIs amongst members of the household. Because people in developing countries often do not report medical conditions to formal treatment centers due to various financial, cultural, and/or religious beliefs the interview was vital to determine the number of stated ARI in each household. Furthermore, the interview provided information about other behaviors or cooking activities that occur in addition to daily meal preparation. An example of this would be cooking foods for sale at local markets or shops.

Analysis of dispensary health records

Medical records regarding conditions associated with ARIs were obtained from the local dispensary to determine the number of reported cases of ARIs in the last year in Kiwengwa.

Justification

This element of the study was included not only to compare the number of ARI cases reported at the dispensary to the data collected from the semi-structured interview but also to assess local understanding of the sources and treatment options for ARI symptoms.

Ethics Statement:

Prior to their participation in our study interview subjects were made known of the following policies regarding the following rights.

1.) Interview subjects have the initial right to refuse to participate in the study, to decline to participate in any specific portion of the study, as well as the right to terminate their participation completely at any point after the study has begun.
2.) The identities of all interview subjects will be concealed in the final publication of all research products to be produced from the study. The only individuals to whom their identities will be made available will be ourselves (the researchers) and the SIT academic advisor, Benjamin Miller.
3.) The identities of any individuals other than the interview subjects themselves who may be discussed during the interview will also remain completely anonymous in the final research products.
4.) Any health records obtained from the local village dispensary will remain confidential
5.) All interview subjects will be guaranteed access to any published works that are produced using data gathered from their participation in the study. This can be accomplished by visiting the local village dispensary where copies of the study will be made available or by visiting the SIT library of Independent Study Projects in Stone Town.

Results:

Cook Stove Performance: General Data

In-house tests of cook stove performance were carried out according to a procedure developed by the Shell Foundation's Household Energy and Health Program (appendix B). The tests involved the boiling of two separate pots of water, with explicit procedural restrictions on such practices as charging and stoking the fire. The margin of error for weighed materials was +/- 5 grams, +/- 0.1 degrees Celsius for all temperature measurements, and +/- 5 seconds for all time recordings.

Four different stove types were tested according to this procedure. Below is a listing of their names and respective abundances.

Stove Type	**Abundance**
3 Stone Fire	23
Raised Iron Platform	4
Metal Charcoal Stove with Clay Lined Combustion Chamber	2
Kerosene Stove	2

Using a calculation spreadsheet developed by the same Shell team, the raw data from each of the four stove types was converted into the following metrics of stove performance:

Metrics	**Units**	**Label**
Wood consumed (moist)	g	fcm
Net change in char during test	g	Dcc

Equivalent dry wood consumed	g	Fcd
Water vaporized from all pots	g	Wcv
Effective mass of water boiled	g	Wcr
Time to boil Pot	min	Dtc
Thermal efficiency	--	Hc
Burning rate	g/min	Rcb
Specific fuel consumption	g/liter	SCc
Temp-corrected specific consumption	g/liter	SCTc
Firepower	watts	FPc

The following is a summary of descriptive statistics for the data collected in the individual tests (2 per household with 31 households). For the charcoal and kerosene stoves (4 total) the only performance metric which was able to be calculated was thermal efficiency. This is because the data collection and calculation sheets used during testing were specifically designed to accommodate the observation of solid biomass fuel combustion in which all combustion materials could be captured and measured. Because of the nature of the fuel source for kerosene stoves (a liquid) and the design of the charcoal stoves (which prevented the collection of char) it was impossible to calculate the other performance metrics.

A test to determine whether the data for each of these variables conformed to a normal distribution was conducted. All were found to be normally distributed at the 90% confidence level and thus compliant with the assumptions implicit to the parametric statistical tests to be presented in the analysis section.

Descriptive Statistics: Fcm, DCc, Fcd, Wcv, Wcr, DTc, Hc, Rcb, SCc, SCTc, FPc

Variable	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Fcm	797.8	45.5	334.6	85.0	498.8	850.0	1041.3	1455.0
DCc	125.9	10.6	78.2	5.0	68.8	115.0	176.3	315.0
Fcd	512.9	33.9	249.3	129.0	290.5	498.0	724.3	1027.0
Wcv	83.35	9.87	72.53	5.00	33.75	67.50	110.25	350.00
Wcr	4154	163	1196	325	4421	4676	4811	5203
DTc	12.981	0.772	5.675	7.000	10.000	12.000	15.000	44.000
Hc	0.2090	0.0177	0.1396	0.0800	0.1200	0.1600	0.2450	0.9000
Rcb	41.50	2.67	19.63	13.00	24.50	40.50	55.25	93.00
SCc	120.59	6.48	47.61	43.00	79.50	116.50	162.50	221.00
SCTc	123.37	6.59	48.41	44.00	81.00	121.00	168.50	224.00
FPc	12772	820	6024	3967	7496	12521	17028	28647

Of these different metrics of stove performance, the one which was focused on the most going into our statistical analysis was Hc (stove thermal efficiency). As presented in the table, the mean thermal efficiency for all four stove types was found to be 20.09%. The average time boil was found to be 12.98 minutes with a mean firepower of 12,772 watts.

Observations of Physical Cooking Environment: General Data

Measurements of the physical structure housing the stove were gathered for each of the 31 households which participated in the study. From this data the following calculations were made.

Data Category	**Units**
Total interior surface area	m^2
Percentage of total interior surface area being exposed to ventilation	%
Total interior volume	m^3

These variables were used as proxies for the estimation and comparison of air exchange levels for each of the structures housing the cook stoves.

A descriptive summary of this data is presented below. And once again, the distributions of these variables were tested for normalcy and all were found to be normally distributed at a 90% confidence level.

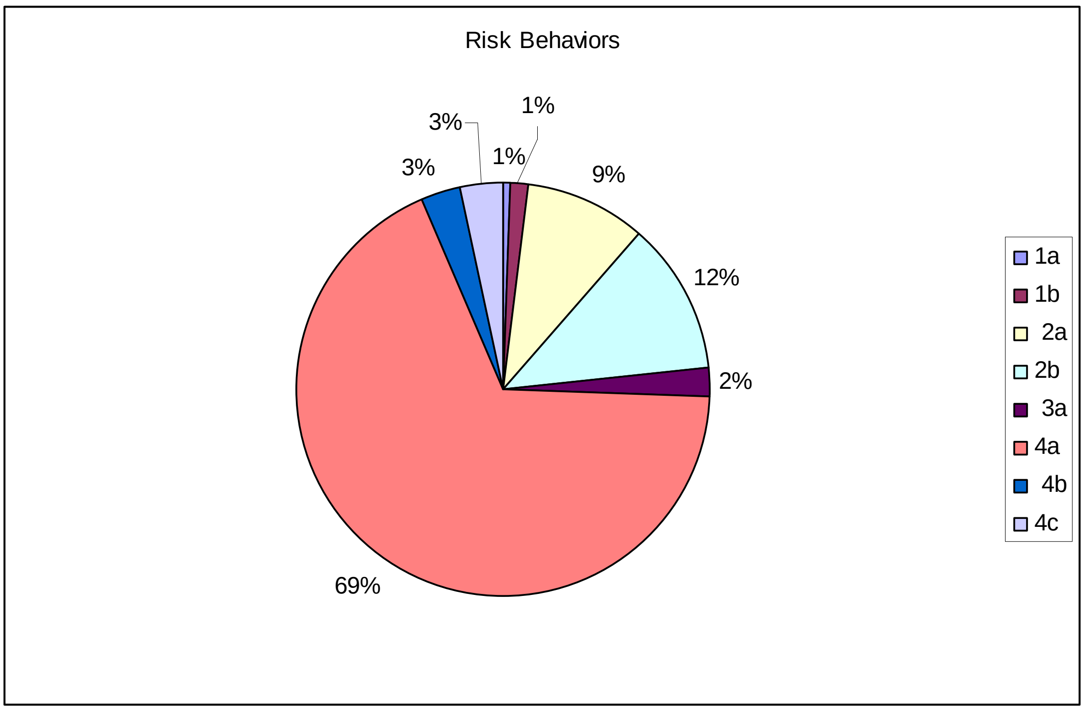
Descriptive Statistics: Percent of Total, Interior Volume , SA Total (m^2)

```
Variable                   Mean  SE Mean  StDev  Minimum     Q1  Median     Q3
Percent of Total Surface  18.82     1.44   8.02     9.18  14.17   16.43  21.89
Interior Volume (m^3)     12.14     1.13   6.32     4.96   6.69   10.66  15.51
SA Total (m^2)            25.98     1.41   7.87    15.14  21.11   24.34  30.78

Variable                  Maximum
Percent of Total Surface    43.57
Interior Volume (m^3)       35.00
SA Total (m^2)              51.00
```

The mean value for total interior surface area was found to be 25.98 m^2, the mean percentage of total surface area open to ventilation was 18.82 %, and the mean interior volume was 12.14 m^3. No houses observed in our study were found to have a chimney in the physical structure housing the stove.

Observation of Cooking Behaviors: General Data

Observations of cooking behaviors were made throughout an entire cooking session, from the lighting of the fire to the disposal of the ashes. Cooking time varied greatly, from 25-255 minutes. To ensure cooking behaviors between households were comparable and to account the wide range of cooking times, percentages of each behavior were used. The following are the average percentages of the duration of cooking behaviors in each household. They are based on the data acquired at each of the thirty one homes in which cooking behaviors were observed.



Of these suspected risk behaviors the most common behavior was 4A, outlined as sitting 1-3 feet within the fire. This was not only the most common behavior of the primary cook in the household, but was also a frequent behavior of those aiding the primary cook and young children, who were either carried on the cooks back or sat near the cook throughout the duration of the cooking period. 2A and 2B are also common cooking behaviors and were observed in every household except those which used kerosene stoves, as there is no need to adjust the fuel source (i.e. rustle the coals or wood) and the heat is distributed evenly enough that stirring can be kept to a minimum.

Observing the cooking behaviors at each household also provided valuable information regarding groups of people most often engaged in cooking activities. After our observations were completed three target groups that were suspected to have a greater risk of acquiring ARI from cooking related activities were established. These target groups were:

1) children ages 1-10
2) women ages 18-40
3) women ages 41+

These groups were suspected to have a greater risk of acquiring ARI for several reasons. Young children too young for school often spent time assisting the primary cook with various cooking tasks, putting them at greater risk of prolonged exposure to indoor air pollutants from cook stove usage. This coupled with widespread malnourishment of children in Kumbaurembo and the well established fact that children have weaker immune systems than adults makes it highly probable that these children would be more susceptible to ARI.

Young to middle aged women surveyed for this study generally spent the most time in the cooking environment actively engaged in cooking as they were most often the primary cooks in the household. Prolonged exposure to pollutants due to their cooking activities likely put them at greater risk of contracting health conditions associated with indoor air pollution. Older women were analyzed separately as a point of reference for younger women in the other target group, and because they took on a less active role than younger women in the cooking process but were often present during the duration of cooking activities. The following is a table showing the percentages of people from each target group seen engaged in suspected risk behaviors[2]:

Behavior	Children 0-10	Females 18-40	Females 40+
1A	0	28%	50%
1B	20%	48%	17%

[2] These percentages were determined by taking the number of people from each target group who we *actually observed* in the cooking environment, and not by the estimated average time spent in cooking environment per day.

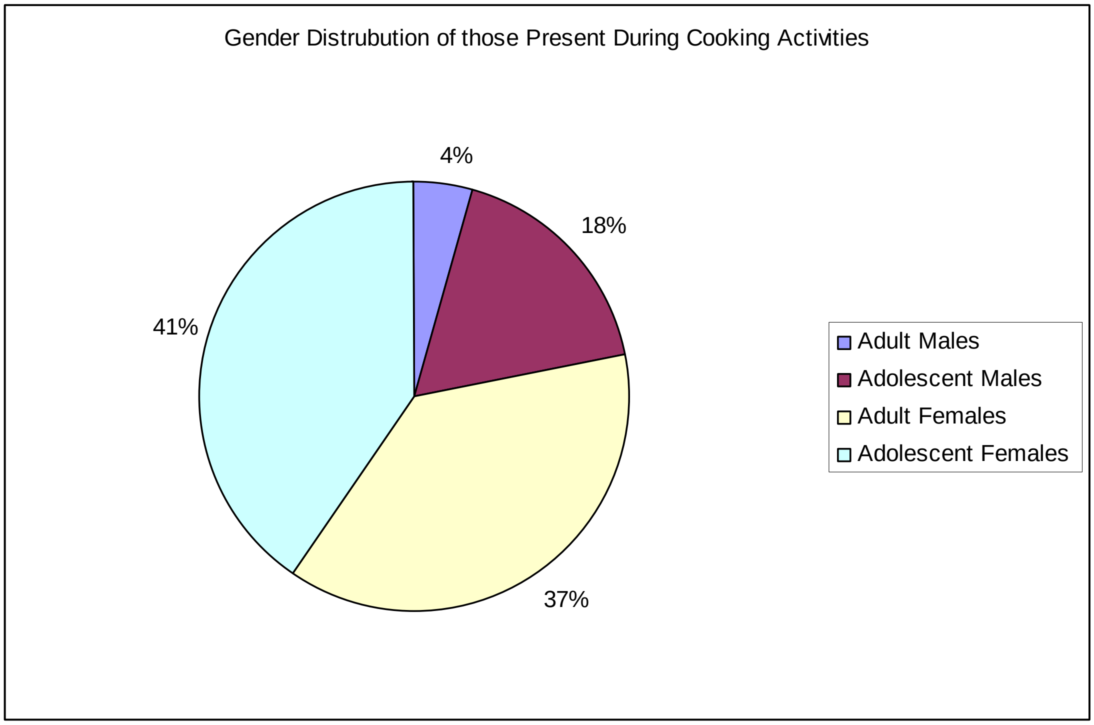
2A	70%	76%	100%
2B	60%	92%	90%
3A	10%	64%	50%
4A	100%	100%	100%
4B	0%	12%	0%
4C	30%	48%	33%

It was observed that every person in each target group was engaged in behavior 4A, or sitting one-three feet within the fire. However, young and old women were more often engaged in other behaviors compared to children, suggesting a more active role in kitchen activities amongst adult women. Still, of all three target groups, women 18-40 were generally the most involved in perceived risk behaviors.

Interviews: General Data

Of those who spent time in the cooking environment each day, 78% were female and 22% percent were male. Of the 22% of males who spent time in the cooking environment, 80% were young children and 20% were adult males. Of the 78% of females who spent time in the cooking environment, 58% were female adolescents and 48% were adult women. The following is a general gender distribution for those who are present during cooking activities[3]:

[3] This gender distribution was determined by using data regarding the average time spent in cooking environment, which was obtained for every member of each household visited. Data from observed cooking behaviors was not used.



It is clear that females were more often present during cooking activities, whether as the primary cook or as an assistant to the primary cook, than males. Of the males that were present during cooking activities, the adolescent males were most often infants or toddlers who were unable to play outside the home and the adult males were all fishermen that helped cook fish for lunch at home.

To gain a better understanding of what groups spent the most time in the cooking environment, it is also important to look at average time spent in cooking environment amongst various demographic groups. As the previous graph made clear, mostly children and women were present in the cooking environment each day therefore the focus groups used in the previous section also prove relevant here. The following is a table of average time spent in cooking environment amongst the three established focus groups.

Group	Average Time Spent in Kitchen/Day
Children 0-10	35 minutes/day
Females 18-40	155 minutes/day
Females 41+	77 minutes/day

The table clearly indicates that females 18-40 spent twice as much time in the cooking environment as the other two focus groups, with children spending the least amount of time in the cooking environment. Many women in the 18-40 focus group indicated several reasons for the long duration of time spent in the cooking environment. These included lack of ability to store food (therefore needing to keep the fire going until members of the household arrived to eat), the use of locally harvested rice which takes longer to cook than store bought rice, the need to nurse young children during cooking activities, serving meals that have many separately cooked components, and using wood with a high moisture content.

Using the same focus groups, average ARI per person per year was determined:

Group	Average Number of ARI/Person/Year
Children 0-10	1.32
Females 18-40	1.15
Females 41+	0.81

Children were found to have the highest frequency of ARI amongst the three focus groups with females 41+ have the lowest frequency of ARI. One woman noted that her ARI were likely due to exposure to chemicals at her other job, otherwise no alternative explanations were provided for ARI.

Dispensary Records: General Data

Records regarding the number of ARI cases in the past year were obtained from the dispensary in Kiwengwa. Below is a monthly summary of the number of reported cases:

Kiwengwa Dispensary Records		
Month	ARI	Eye Diseases
Jan	151	15
Feb	99	9
Mar	47	3
April	78	3
May	80	2
June	74	7
July	89	11
Aug	71	5
Sep	69	13
Oct	43	8
Nov	63	9
Dec	74	6
2006 total	938	91

Statistical Analysis

To determine the significance of the relationships our study data to the stated mean incidence of ARI/person/year a combination of parametric statistical test were used. These include two-sample T tests, multivariate regression analysis, and ANOVA. For each test a listing of pertinent variables and hypotheses are included as well as statistical output produced in the computational software package Minitab V.15. A brief interpretation of the results accompanies each of the included Minitab output sections.

Stove Performance Metrics

Test 1: Multivariate regression analysis for the relationship between various cook stove performance metrics mean incidence of ARI/person/year

Dependant Variable: mean incidence of ARI/person/year

Independent Variables: Hc, Rcb, SCc, SCTc, FPc (see appendix H for descriptions)

Factor Selection Method: Backward elimination (Alpha-to-Remove: 0.15)

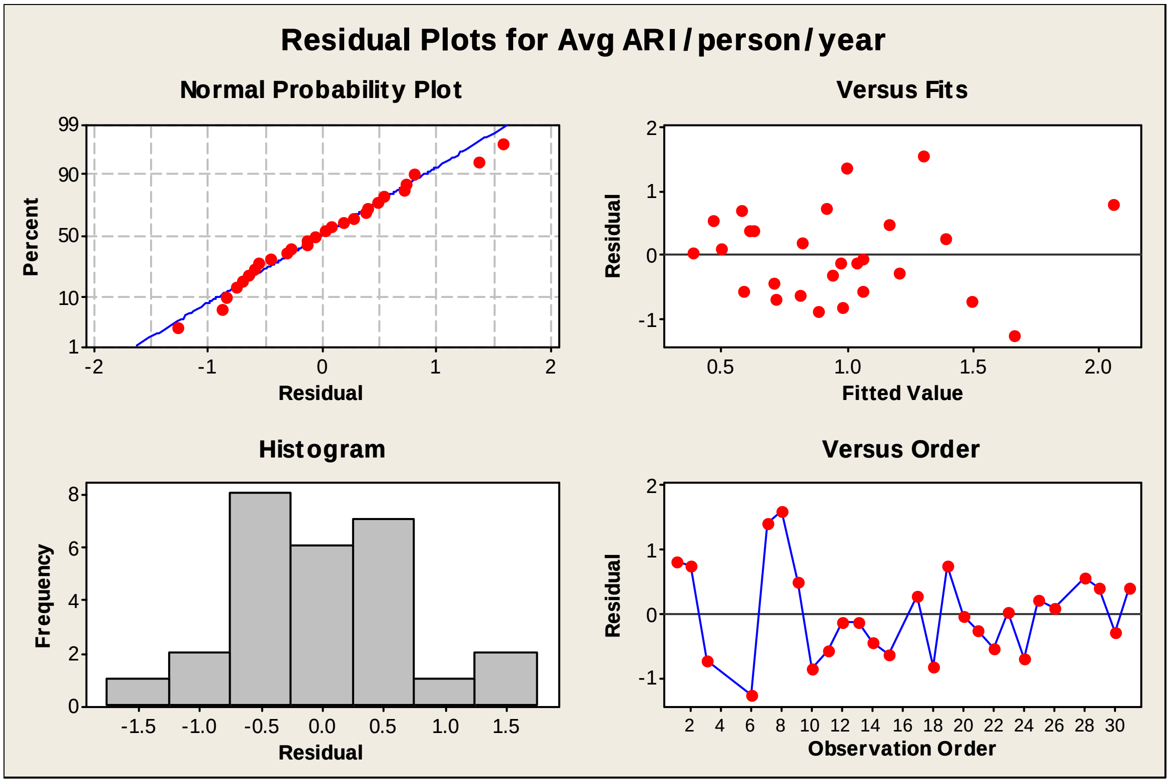
Stepwise Regression: Avg ARI/person/year versus Avg. Hc, Avg. Rcb, ...

```
Response is Avg ARI/person/year on 5 predictors, with N = 27
N(cases with missing observations) = 4 N(all cases) = 31

Step                1         2          3
Constant     -1.40545  0.04033  -0.03510

Avg. Hc           3.5
T-Value          0.70
P-Value         0.492

Avg. Rcb        -0.18    -0.15      -0.22
T-Value         -1.23    -1.09      -1.74
P-Value         0.232    0.286      0.095

Avg. SCc       0.1121   0.1291     0.0084
T-Value          0.97     1.16       1.95
P-Value         0.341    0.258      0.063

Avg. SCTc       -0.10    -0.12
T-Value         -0.84    -1.09
P-Value         0.409    0.289

Avg. FPc      0.00061  0.00051    0.00072
T-Value          1.27     1.12       1.74
P-Value         0.220    0.274      0.095

S               0.748    0.739      0.742
R-Sq            29.27    27.63      23.74
R-Sq(adj)       12.43    14.47      13.79
Mallows Cp        6.0      4.5        3.6
```

Based upon this factor selection method it was determined that the only factors with a statistically significant relationship (at the 90% confidence level) to the dependant variable were Rcb, SCc, and FPc. Consequently, a regression analysis was performed investigating the relationship between these factors and the dependant variable.

Regression Analysis: Avg ARI/pers versus Avg. Rcb, Avg. SCc, Avg. FPc

```
The regression equation is
Avg ARI/person/year = - 0.035 - 0.222 Avg. Rcb + 0.00837 Avg. SCc
                      + 0.000719 Avg. FPc

Predictor       Coef    SE Coef      T      P
Constant     -0.0351     0.5059  -0.07  0.945
Avg. Rcb     -0.2215     0.1271  -1.74  0.095
Avg. SCc    0.008368   0.004284   1.95  0.063
Avg. FPc   0.0007186  0.0004131   1.74  0.095

S = 0.742250   R-Sq = 23.7%   R-Sq(adj) = 13.8%

Analysis of Variance

Source          DF       SS      MS     F      P
Regression       3   3.9442  1.3147  2.39  0.095
Residual Error  23  12.6715  0.5509
Total           26  16.6157

Source    DF  Seq SS
Avg. Rcb   1  0.4755
Avg. SCc   1  1.8020
Avg. FPc   1  1.6667
```



<u>Interpretation</u>: According to this regression analysis we can conclude at a 90% confidence level that the stove performance factors Rcb (p-value 0.095), SCc (p-value 0.063), and FPc (p-value 0.095) are all significant predictors of the mean incidence of ARI/person/year.

Test 2: Comparison of mean efficiencies (Hc levels) between different stove types

Null Hypothesis: The mean efficiencies are equivalent between the different stove types.

Alternative Hypothesis: The mean efficiencies are non-equivalent between the different stove types

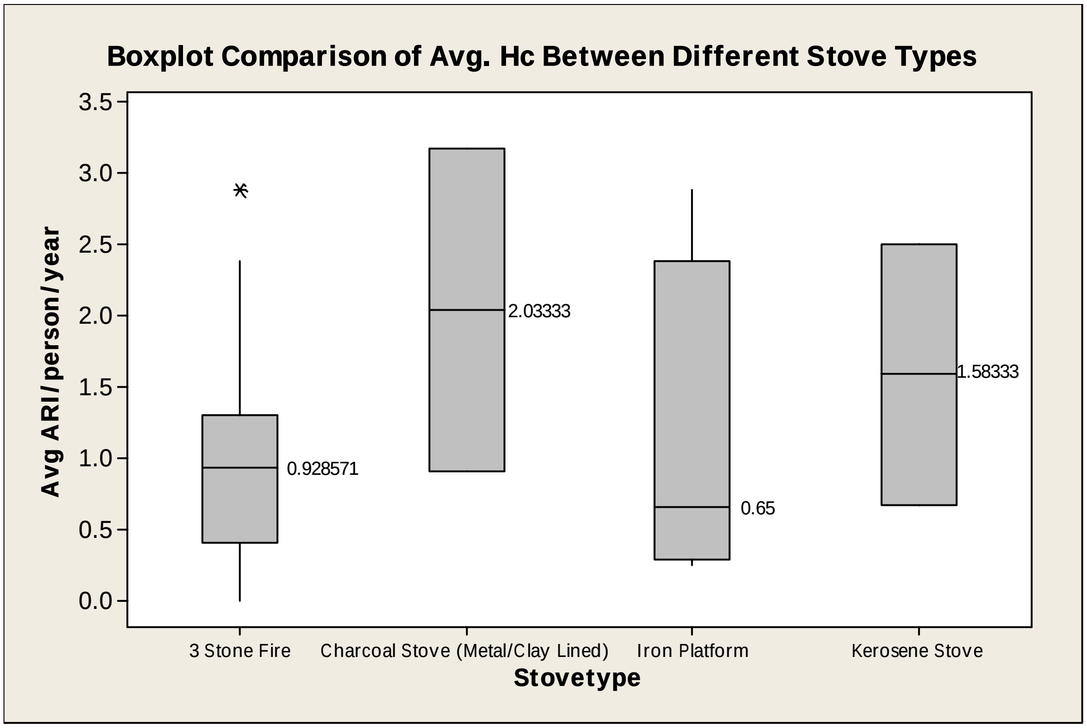
General Linear Model: Avg. Hc versus Stovetype

Factor	Type	Levels	Values
Stovetype	fixed	4	3 Stone Fire, Charcoal Stove (Metal/Clay Lined), Iron Platform, Kerosene Stove

Analysis of Variance for Avg. Hc, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Stovetype	3	0.142002	0.142002	0.047334	8.68	0.000
Error	27	0.147219	0.147219	0.005453		
Total	30	0.289221				

```
S = 0.0738414   R-Sq = 49.10%   R-Sq(adj) = 43.44%
```



<u>Interpretation:</u> According to the output for the ANOVA test above it can be concluded that the mean efficiency levels between the different stove types are statistically significant (p-value 0.000). Also, on the basis of the R-squared value (49.1%) it can be concluded that stove type alone does a reasonably good job as a predictor for the dependant variable (efficiency).

Observation of Physical Cooking Environment: Statistical Analysis

Test 3: Multivariate regression analysis for the relationship between physical cooking environment metrics and the mean incidence of ARI/person/year

<u>Dependant Variable</u>: Mean incidence of ARI/person/year

<u>Independent Variables</u>: Percent of total kitchen structure surface area open to ventilation, interior volume, and total surface area of kitchen structure

Regression Analysis: Avg ARI/pers versus Percent of T, Interior Vol, ...

```
The regression equation is
Avg ARI/person/year = 1.26 + 0.0158 Percent of Total Surface Area a
                      + 0.113 Interior Volume (m^3) - 0.0716 SA Total (m^2)
```

Predictor	Coef	SE Coef	T	P
Constant	1.262	1.246	1.01	0.320
Percent of Total Surface Area a	0.01583	0.02115	0.75	0.461
Interior Volume (m^3)	0.1126	0.1225	0.92	0.366
SA Total (m^2)	-0.07157	0.09815	-0.73	0.472

S = 0.906031   R-Sq = 6.0%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	1.4246	0.4749	0.58	0.634
Residual Error	27	22.1641	0.8209		
Total	30	23.5887			

Source	DF	Seq SS
Percent of Total Surface Area a	1	0.2499
Interior Volume (m^3)	1	0.7382
SA Total (m^2)	1	0.4365

Interpretation: According to the output from this regression analysis it must be concluded that the three physical cooking environment metrics are non-significant as predictors of the incidence of ARI/person/year. Their respective p-values were all far above the threshold of 0.10 for a positive conclusion at a 90% confidence level.

Cooking Behaviors

Test 4: A multivariate regression analysis was performed to asses the significance of the relationship between suspected risk increasing behaviors and stated incidence of ARI.

Dependant Variable: Average stated incidence of ARI/person/year

Independent Variables: Suspected risk increasing behaviors 1a-4c (See Appendix D for individual descriptions)

Factor Selection Method: Backward elimination (alpha-to-remove: 0.1)

Stepwise Regression: ARI in last year versus % 1a, %1b, ...

Response is ARI in last year on 8 predictors, with N = 167

Step	1	2	3	4	5	6
Constant	0.9180	0.9179	0.9158	0.9160	0.9188	0.9150
% 1a	-0.21	-0.22	-0.26			
T-Value	-0.64	-0.66	-0.84			
P-Value	0.525	0.510	0.403			
%1b	0.15	0.15	0.14	0.13		
T-Value	1.05	1.05	0.99	0.97		
P-Value	0.297	0.298	0.325	0.332		

% 2a	-0.022	-0.026				
T-Value	-0.34	-0.45				
P-Value	0.735	0.655				
%2b	-0.043	-0.042	-0.052	-0.058	-0.046	-0.050
T-Value	-0.86	-0.87	-1.24	-1.39	-1.16	-1.27
P-Value	0.389	0.386	0.218	0.166	0.247	0.208
% 3a	-0.01					
T-Value	-0.10					
P-Value	0.922					
% 4a	0.0148	0.0147	0.0141	0.0132	0.0136	0.0121
T-Value	1.81	1.84	1.79	1.70	1.75	1.60
P-Value	0.072	0.068	0.075	0.091	0.081	0.112
% 4b	0.061	0.060	0.062	0.061	0.057	0.058
T-Value	2.12	2.17	2.28	2.23	2.11	2.16
P-Value	0.035	0.032	0.024	0.027	0.036	0.032
% 4c	-0.049	-0.048	-0.055	-0.055	-0.048	
T-Value	-0.84	-0.84	-1.00	-1.00	-0.88	
P-Value	0.402	0.404	0.318	0.321	0.380	
S	1.40	1.40	1.39	1.39	1.39	1.39
R-Sq	5.35	5.35	5.23	4.81	4.25	3.79
R-Sq(adj)	0.56	1.18	1.67	1.85	1.89	2.02
Mallows Cp	9.0	7.0	5.2	3.9	2.8	1.6

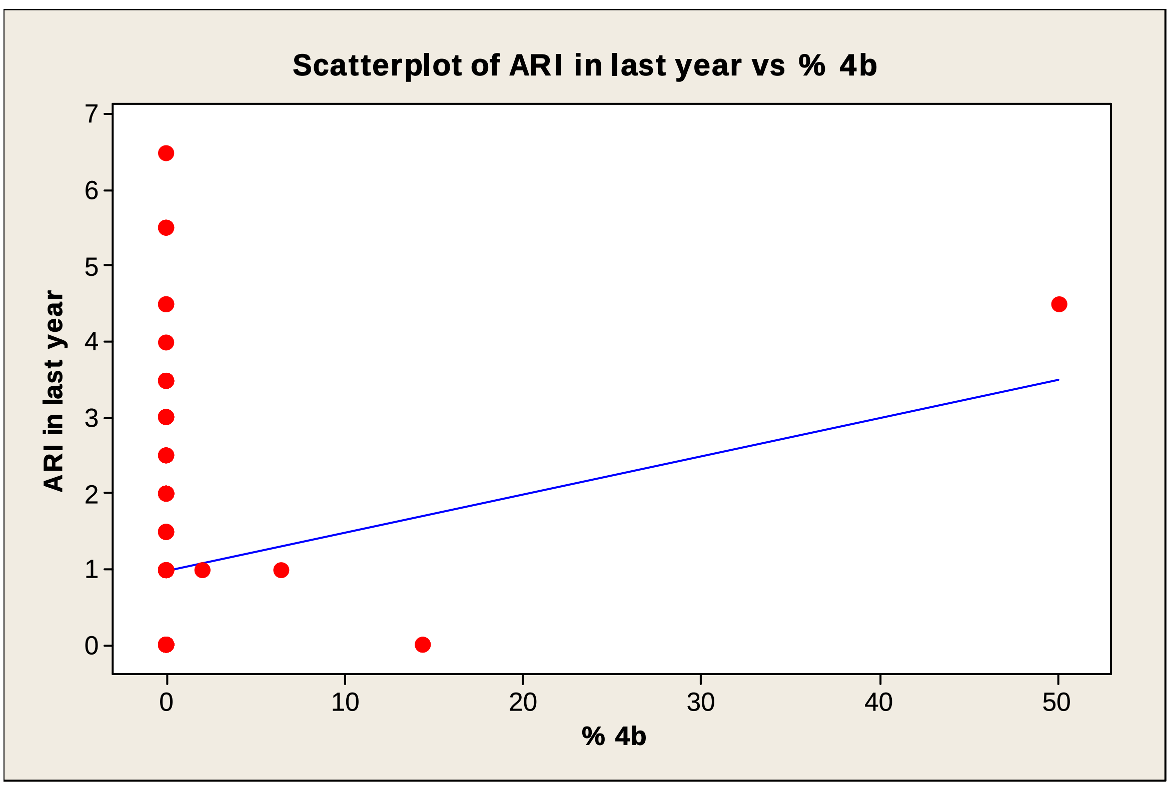
Step	7	8
Constant	0.9054	0.9616
% 1a		
T-Value		
P-Value		
%1b		
T-Value		
P-Value		
% 2a		
T-Value		
P-Value		
%2b		
T-Value		
P-Value		
% 3a		
T-Value		
P-Value		
% 4a	0.0047	
T-Value	0.98	
P-Value	0.330	
% 4b	0.049	0.051
T-Value	1.89	1.96
P-Value	0.060	0.051
% 4c		
T-Value		

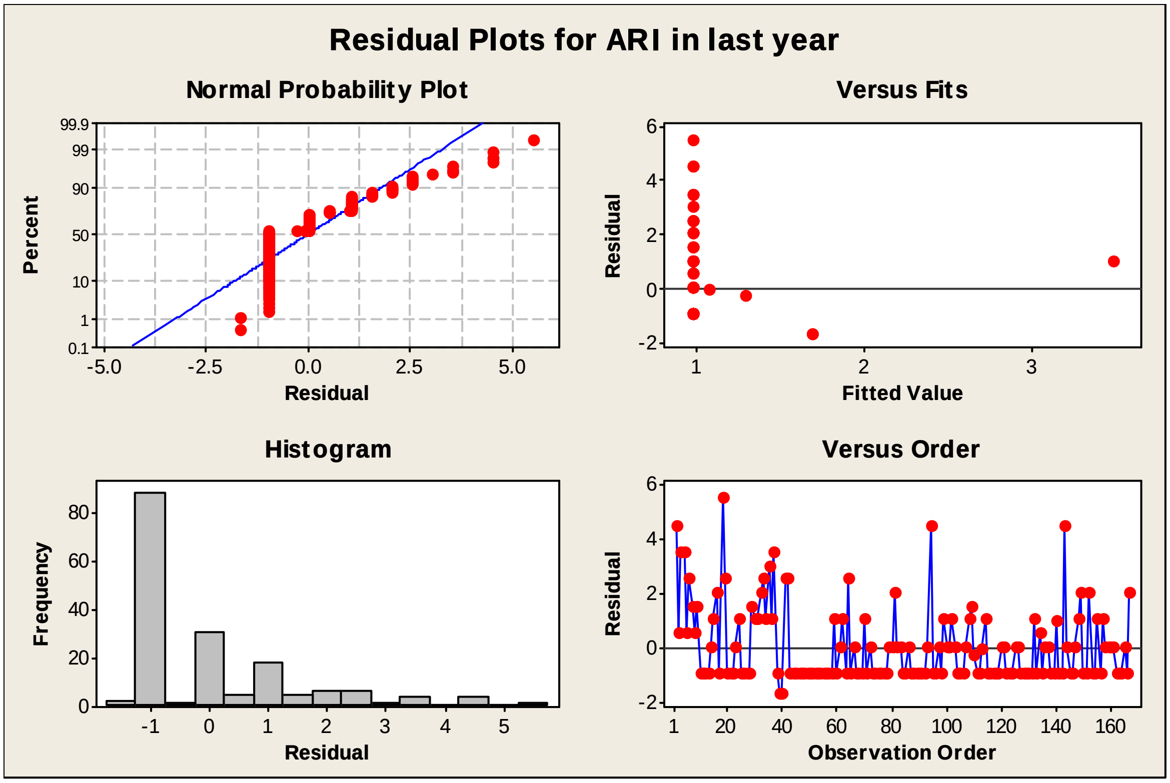
```
P-Value

S               1.39    1.39
R-Sq            2.85    2.28
R-Sq(adj)       1.66    1.69
Mallows Cp       1.2     0.1
```

The backwards selection method determined the behavior 4B to be the only factor to have a statistically significant relationship to the stated mean incidence of ARI/person/year. On the basis of this test the following regression analysis was performed.

Regression Analysis: ARI in last year versus % 4b

```
The regression equation is
ARI in last year = 0.962 + 0.0507 % 4b

Predictor      Coef  SE Coef     T      P
Constant     0.9616   0.1086  8.85  0.000
% 4b        0.05070  0.02582  1.96  0.051
S = 1.39262   R-Sq = 2.3%   R-Sq(adj) = 1.7%
Analysis of Variance

Source           DF       SS     MS     F      P
Regression        1    7.476  7.476  3.86  0.051
Residual Error  165  320.000  1.939
Total           166  327.476
```





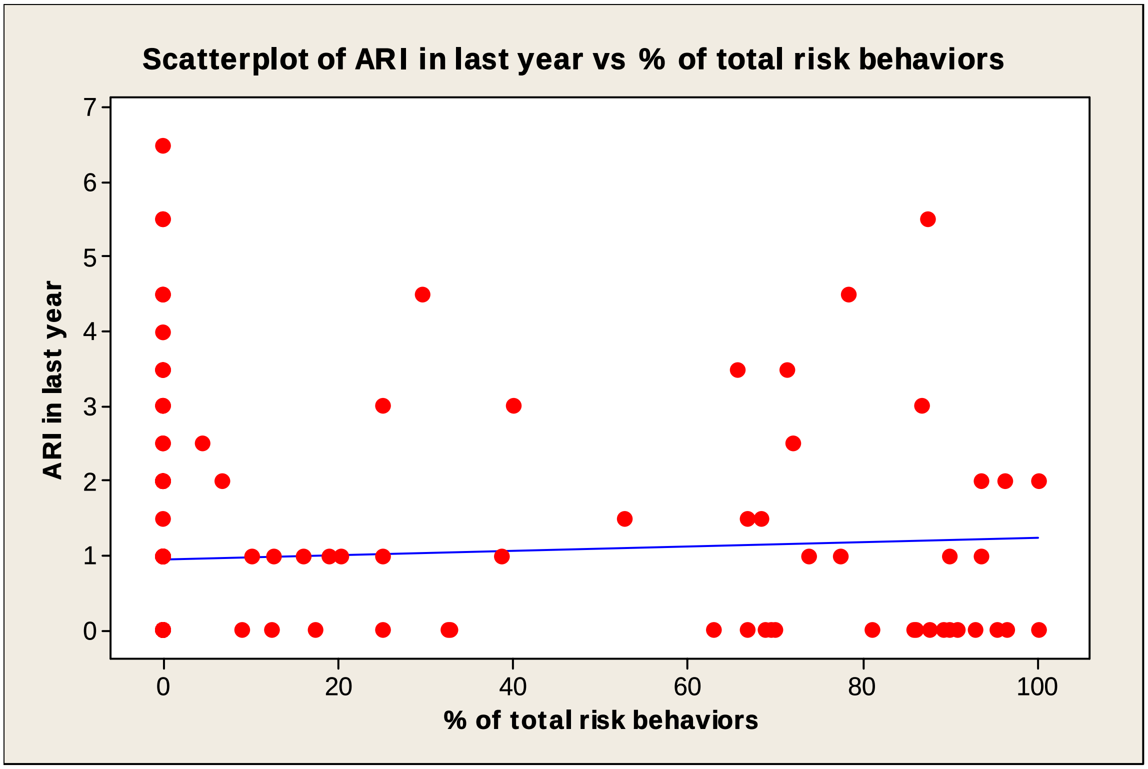
<u>Interpretation:</u> The regression analysis indicated that at a 90% confidence level, the specific cooking behavior #4b was found to be a statistically significant predictor (p-value 0.051) of the mean incidence of ARI/person/year in our sample group. However, the low r-squared value (2.3%) for this model and the presence of non-normally distributed residuals suggests that the lone factor, behavior #4b, does not adequately predict the incidence of ARI/person/year in the sample population. Instead it is suspected that there are one or many other lurking variables, outside the scope of the data set, which are significantly related to the incidence of ARI/person/year.

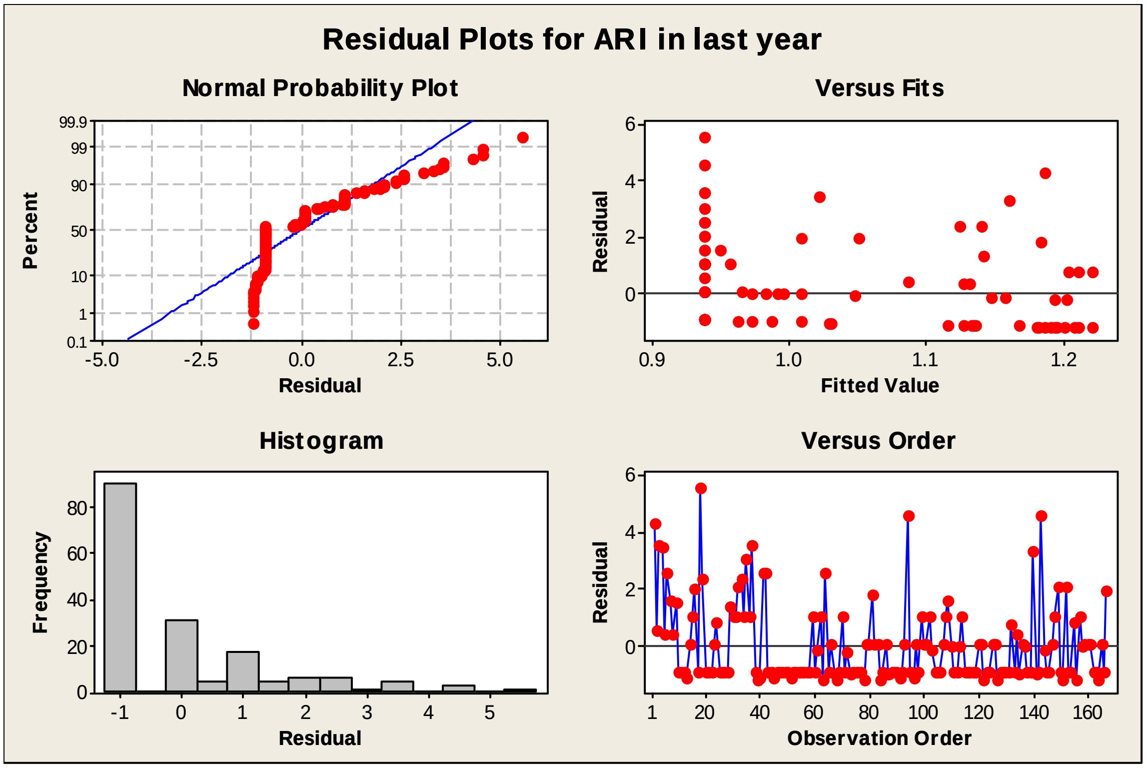
Test 5: Regression analysis for the relationship between the % of total cooking time engaged in suspected risk increasing behaviors to the incidence of ARI/person/year.

Regression Analysis: ARI in last year versus % of total risk behaviors

```
The regression equation is
ARI in last year = 0.937 + 0.00285 % of total risk behaviors

Predictor                     Coef   SE Coef     T      P
Constant                    0.9372    0.1243  7.54  0.000
```

```
% of total risk behaviors  0.002847  0.003371  0.84  0.399

S = 1.40576   R-Sq = 0.4%   R-Sq(adj) = 0.0%

Analysis of Variance

Source           DF       SS     MS     F      P
Regression        1    1.410  1.410  0.71  0.399
Residual Error  165  326.066  1.976
Total           166  327.476
```





Interpretation: The data output given above shows that the p-value for this regression analysis was 0.399 thus supporting the conclusion that % of cooking time spent engaging in suspected risk increasing behaviors is a non-significant predictor of the incidence of ARI/person/year at the 90% confidence level.

Test 6: Comparison of % of cooking time spent engaging in suspected risk increasing behaviors between three target demographic groups

Null Hypothesis: The % of cooking time spent engaging in suspected risk increasing behaviors is equivalent across the three demographic groups.

Alternative Hypothesis: The % of cooking time spent engaging in suspected risk increasing behaviors in non equivalent between the demographic groups.

General Linear Model: % of total risk behaviors versus Demographic

```
Factor        Type   Levels  Values
Demographic   fixed       3  Children Under Ten, Female Above Forty, Female
                             Between Eighteen and Forty

Analysis of Variance for % of total risk behaviors, using Adjusted SS for Tests
```

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Demographic	2	37032	37032	18516	17.48	0.000
Error	81	85782	85782	1059		
Total	83	122814				

S = 32.5429   R-Sq = 30.15%   R-Sq(adj) = 28.43%

Interpretation: The p-value for this ANOVA analysis (0.000) indicates that % of time cooking spent engaging in suspected risk increasing behaviors was significantly different for each of the 3 target demographic groups. Thus at a 95% confidence level it can be concluded in favor of the alternative hypothesis that that the % of time cooking spent engaging in suspected risk increasing behaviors is significantly different between the demographic groups.

Test 7: Comparison of mean incidence of ARI/person/year between three target demographic groups

Null Hypothesis: The mean incidence of ARI/person/year is equivalent between all of the demographic groups.

Alternative Hypothesis: The mean incidences of ARI/person/year for the three demographic groups are not equivalent to one another.

General Linear Model: ARI Incidence versus Demographic

Factor	Type	Levels	Values
Demographic	fixed	3	Children Under Ten, Female Above Forty, Female Between Eighteen and Forty

Analysis of Variance for ARI Incidence, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Demographic	2	8.113	8.113	4.056	1.80	0.172
Error	81	182.697	182.697	2.256		
Total	83	190.810				

S = 1.50184   R-Sq = 4.25%   R-Sq(adj) = 1.89%

Interpretation: The p-value in this ANOVA analysis (0.172) indicates that there is not sufficient evidence to reject the null hypothesis. Thus it must be concluded at the 90% confidence level that the different demographic groups share equivalent mean levels of incidence of ARI/person/year.

Interviews

Test 8: Analysis of relationship between total time spent in cooking environment and mean incidence of ARI/person/year

Independent Variable: Total time spent in cooking environment

Dependant Variable: Mean incidence of ARI/person/year

Regression Analysis: ARI in last year versus average time in

The regression equation is
ARI in last year = 0.887 + 0.00154 average time in cooking environ

Predictor	Coef	SE Coef	T	P
Constant	0.8872	0.1407	6.31	0.000
average time in cooking environ	0.001544	0.001369	1.13	0.261

S = 1.40340   R-Sq = 0.8%   R-Sq(adj) = 0.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2.504	2.504	1.27	0.261
Residual Error	165	324.972	1.970		
Total	166	327.476			

Interpretation: The p-value for this linear regression analysis was found to be 0.261 for the independent variable. Thus, at a 90% confidence level it must be concluded that it is a non-significant predictor of the mean incidence of ARI/person/year in the sample population.

Test 9: Regression analysis of the relationship between age and the incidence of ARI/person/year

Regression Analysis: ARI in last year versus age

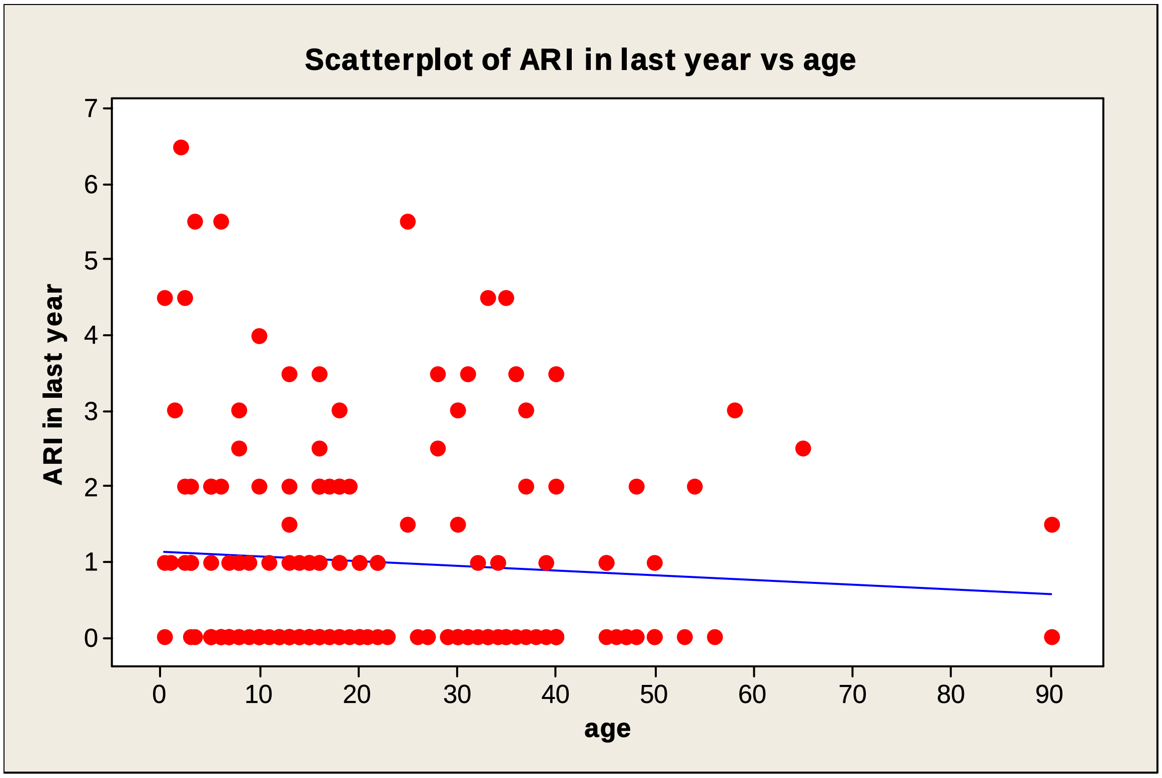
The regression equation is
ARI in last year = 1.12 - 0.00599 age

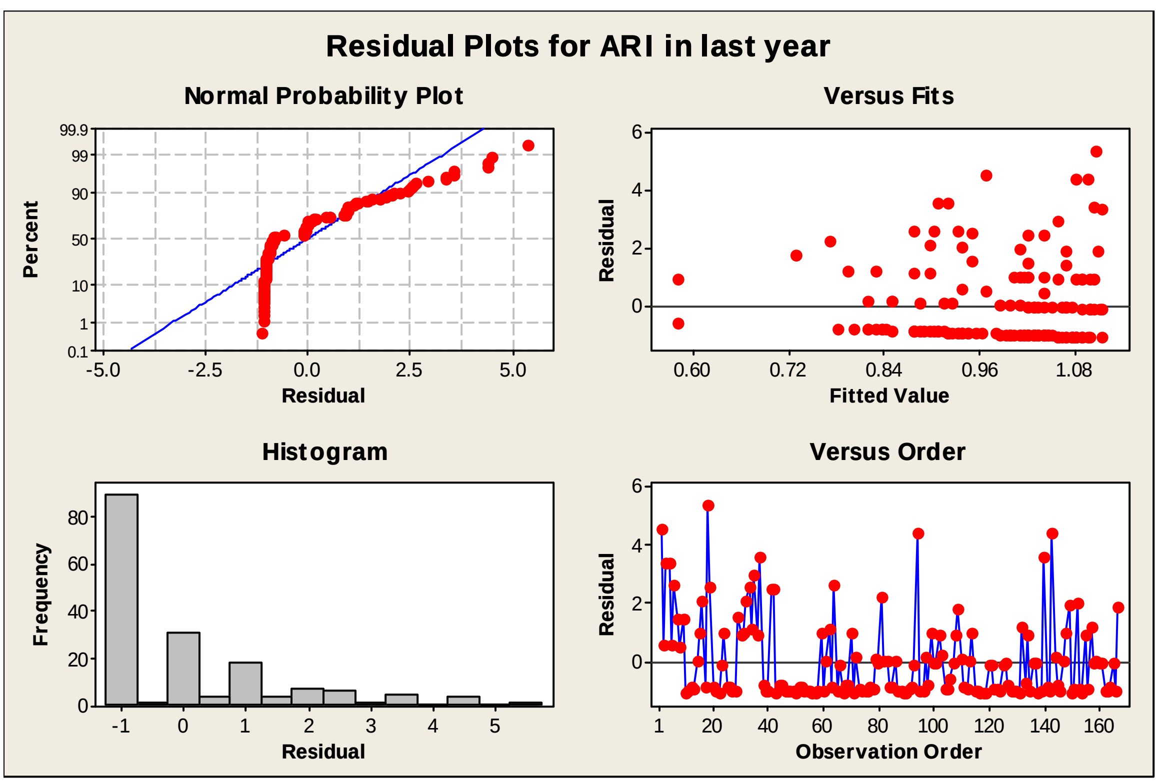
Predictor	Coef	SE Coef	T	P
Constant	1.1176	0.1800	6.21	0.000
age	-0.005988	0.006631	-0.90	0.368

S = 1.40533   R-Sq = 0.5%   R-Sq(adj) = 0.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.611	1.611	0.82	0.368
Residual Error	165	325.865	1.975		
Total	166	327.476			


Scatterplot of ARI in last year vs age
ARI in last year
age
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90


Residual Plots for ARI in last year
Normal Probability Plot
Percent
Residual
99.9
99
90
50
10
1
0.1
-5.0
-2.5
0.0
2.5
5.0
Versus Fits
Residual
Fitted Value
6
4
2
0
0.60
0.72
0.84
0.96
1.08
Histogram
Frequency
Residual
80
60
40
20
0
-1
0
1
2
3
4
5
Versus Order
Residual
Observation Order
6
4
2
0
1
20
40
60
80
100
120
140
160

Interpretation: The data output given above reveals that the p-value from the regression analysis was 0.368. Also, the r-squared value, an indicator for the competency of the model in explaining the observed variation in the data was woefully low (0.5%). And finally, a histogram of the residuals from the regression fit was non-normally distributed. From all of this evidence it can be concluded at the 95% confidence level that the variable ‘age’ is a non-significant predictor of the incidence of ARI/person/year.

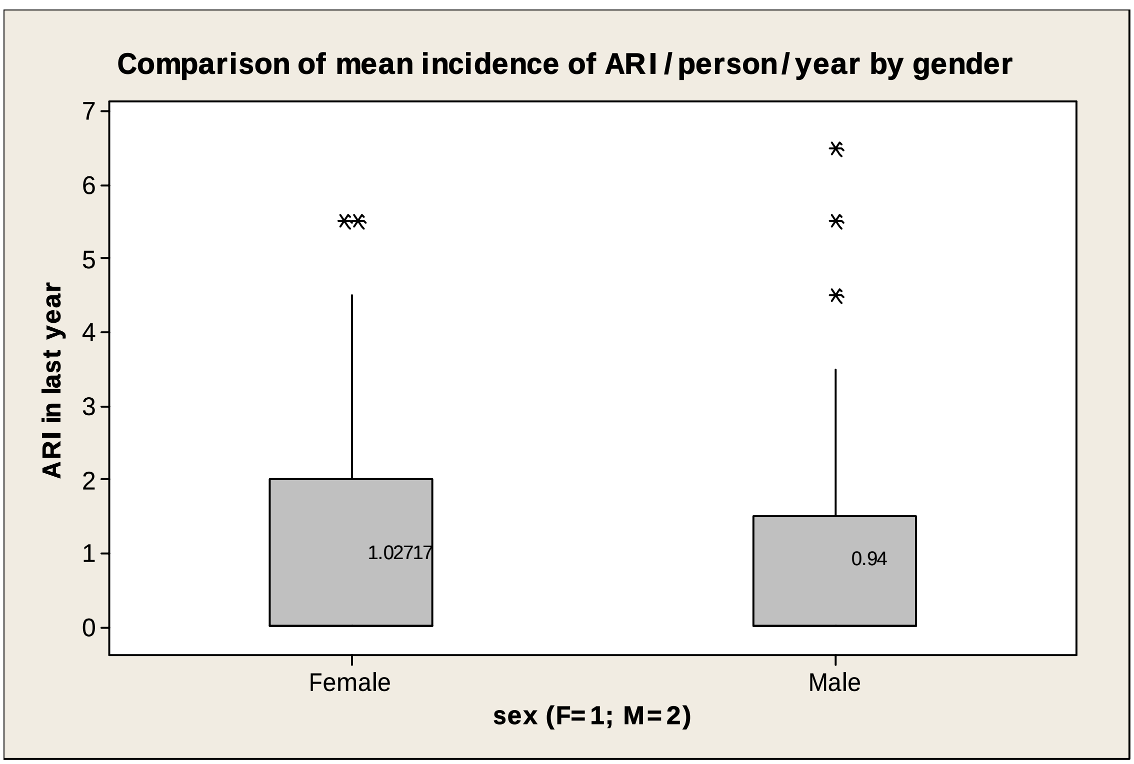
Test 10: Analysis of mean incidence of ARI/person/year by gender

Null Hypothesis: The mean incidence of ARI/person/year is equivalent between genders

Alternative Hypothesis: The mean incidence of ARI/person/year is not equivalent between genders

Two-Sample T-Test and CI

```
Sample   N  Mean  StDev  SE Mean
1       92  1.03   1.41     0.15
2       75  0.94   1.41     0.16

Difference = mu (1) - mu (2)
Estimate for difference:  0.087
95% CI for difference:  (-0.346, 0.520)
T-Test of difference = 0 (vs not =): T-Value = 0.40  P-Value = 0.692  DF = 158
```



Interpretation: The results of the two-sample T-test prevent us from rejecting the null hypothesis. With a p-value of 0.692 it must be concluded at a 90% confidence level that the mean incidences of ARI/person/year are equivalent between the two genders.

Dispensary Records

Test 11: Comparison of recorded incidence of ARI/person/year at the Kiwengwa Dispensary to the stated incidence of ARI/person/year by interview subjects from the Kumbaurembo study.

Null Hypothesis: The mean incidence of ARI/person/year as stated by the Kumbaurembo interview subjects is the same as the mean incidence of ARI/person/year from the Kiwengwa Dispensary records.

Alternative Hypothesis: The mean incidence of ARI/person/year as stated by the Kumbaurembo interview subjects is different from the mean incidence of ARI/person/year from the Kiwengwa Dispensary records.

Two-Sample T-Test and CI

```
Sample                          N    Mean  StDev    SE Mean
Kumbaurembo Study Data        168    0.99   1.41      0.11
Kiwengwa Dispensary Records   1179   0.80   1.41**    0.041
Difference = mu (1) - mu (2)
Estimate for difference:  0.193
95% CI for difference:  (-0.035, 0.421)
T-Test of difference = 0 (vs not =): T-Value = 1.67  P-Value = 0.097  DF = 217
```

**Because of the format in which the data from the Kiwengwa dispensary was recorded (#of cases/month) we were unable to determine the standard deviation for the population. However, for the sake of facilitating these calculations it was conservatively assumed that the standard deviation of the Kumbaurembo study data was roughly equal to the standard deviation of the larger population, represented in the Kiwengwa Dispensary records. This assumption was made on the basis of our sample size constituting a sizeable portion (15%) of the entire Kiwengwa population.

Interpretation: The p-value for this two-sample T test (0.097) is significant at the 90% confidence level. In favor of our alternative hypothesis it can be concluded that the mean incidence level of ARI/person/year on record at the Kiwengwa dispensary is different from the mean level of ARI/person/year as stated by the interview subjects in this study. The data output above shows that the mean incidence of ARI/person, as stated by the interview subjects, is predicted to be 0.193 higher than the incidence levels on record at the dispensary. This indicates that there is statistically significant under-reporting of ARI (at the 90% confidence level) in the village of Kiwengwa.

Conclusions

The goal of this project was to determine whether or not variables relating to cooking behavior, cook stove performance, or the physical cooking environment were positively related to the incidence of ARI/person/year in the village of Kiwengwa. Accordingly, statistical analyses were performed looking at the relationship of a number of different variables within each of these three categories to the stated incidence of ARI/person/year in the sample group.

Cook Stove Performance

- The analysis of the relationship between stove performance metrics and the incidence of ARI/person/year found the only significant predictors to be Rcb- burning rate, SCc- specific fuel consumption, and FPc- firepower. Contrary to our expectations Hc- thermal efficiency was found to be a non significant predictor. Interestingly, the three significant factors described above all involve the rate of fuel consumption and the power output of the fire (which is associated with cooking time).
- The analysis revealed that the mean efficiencies of the different stove types were indeed significantly different. The charcoal cook stoves were found to have higher observed mean efficiency levels than all three of the other stove models.

Observation of Physical Cooking Environment

- The comparison of incidence of ARI/person/year across the different measures of the physical cooking environment found the means to be statistically equivalent. It appears that either the level of air exchange present in the cooking environment is not related to the incidence of ARI or the method used for the estimation of the metric was somehow deficient.
- The relationship between the total percentages of cooking time spent engaging in suspected risk increasing behaviors to the mean incidence of ARI/person/year was found to be statistically insignificant. This may be an

indication of one of two things. The first is that cooking behaviors do not increase the potential risk for developing ARI. The second is that certain cooking behaviors may indeed be positively related to the incidence of ARI, however these behaviors were either overlooked in the study or somehow improperly categorized/quantified.

Cooking Observations

- Of all the suspected risk behaviors present on the observation checklist the only one which was found to have a statistically significant relationship to the mean incidence of ARI/person/year was behavior # 4b. This refers to the simultaneous use of two stoves during the cooking period. The relationship was found to be a positive one, meaning the more time spent in the use of two stoves while cooking the higher the incidence of ARI/person/year. However, the extremely low r-squared value calls into question the validity of these results.
- The comparison of time spent engaging in suspected risk increasing behaviors while cooking across three target demographic groups found that there was indeed a significant difference in the mean values. Women 18-40 were found to spend significantly more time engaged in suspected risk increasing behaviors than women aged 40+ and children aged 10 and under.

  In contrast to these findings, a comparison of the incidence of ARI/person/year across the same demographic groups found the means to be statistically equivalent. The data therefore suggests that the incidence of ARI between these different demographics is the same regardless of the fact that they were found to spend significantly different amounts of time engaged in suspected risk increasing behaviors.

Interviews

- A statistical investigation into the significance of the relationship between total amount of time spent in the cooking environment per day and the mean incidence of ARI/person/year was carried out. Total cooking time/day was found to be insignificant as a predictor of the mean incidence of ARI/person/year. This finding was contrary to our initial expectations. We believe that the interview respondents were unable to respond accurately to our questions on this topic because they all expressed that they rarely, if ever, quantify the amount of time spent cooking throughout the day. Also, it was often the case that individuals who were said by the interview respondent to not spend time in the cooking environment were indeed observed there for significant periods of time during the observation session.

- The analysis which looked at age as a potential predictor for the mean incidence of ARI/person/year found that there was a non-statistically significant relationship. The incidence of ARI was highly variable across all ages.
- The comparison of the incidence of ARI/person/year between the different genders revealed that there was no significant difference in the means. From this analysis it appears that men and women experience equivalent levels of ARI/person/year. However, many women indicated having no knowledge of their husbands smoking habits. This presents a problem of interpretation as the male ARI incidence levels may be higher as a result of this possibly unaccounted for behavior.

Dispensary Records

- The comparison of the Kiwengwa dispensary records for ARI/person/year to the stated incidence of ARI/person/year determined in our study found that there was statistically significant difference in the means. An estimate of the difference in means revealed that there is significant problem of under reporting ARIs to the Kiwengwa Dispensary. Many interview respondents attributed this to a combination of the high cost of modern ARI treatments as well as the widespread reliance on traditional medicinal remedies.

Conclusions Summary

It was observed that the only significant factors positively related to the incidence of ARI/person/year in the sample group were the percentage of cooking time spent in the simultaneous use of multiple stoves and the cook stove performance metrics: burning rate, specific fuel consumption, and firepower. When comparing the data from the Kiwengwa village dispensary regarding the incidence of ARI to the stated incidence recorded in the interviews it was found that there was significant under reporting of ARIs in the region. Further research is necessary to confirm the relationships between cook stove usage, indoor air pollution, and the incidence of ARI found in this study.

Recommendations:

Further Studies

Although many of our conclusions contradicted our initial hypotheses, based upon our experiences during the data collection period, we feel that the potential to observe strong positive correlations between ARI and variables associated with cooking environment and behaviors still exists. However, for this to be possible a potential follow up study would require: sophisticated instrumentation for quantifying levels of indoor air pollution, a larger sample size, and more time to observe each individual household.

Sources of Error

In the progression of our study some potential sources of error became apparent. These include:

- Difficulty in precisely observing the times engaged in potential risk behaviors in situations with multiple individuals present in the cooking environment
- Respondents lack of ability to accurately estimate the time young children spent in cooking environment
- Elderly respondents inability to recall ARI data
- Difficulty in defining the area which encompasses the cooking environment.
- Many people underestimated the time they spent in the kitchen, and some respondents who supposedly spent no time in the cooking environment were observed in the cooking environment engaging in potential risk behaviors.
- Variability in the salinity (and thus the boiling point) of well water used for the water boiling tests.
- Different cooking environments were constructed with widely different building materials, all of which have different levels of permeability. This may have an impact on the level of air exchange.
- The use of a wide variety of different and tree species for firewood whose specific caloric energy densities have not been determined.

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Acute Respiratory Infections: Clinical Syndromes (appendix A)- Ezzati et al, 2001

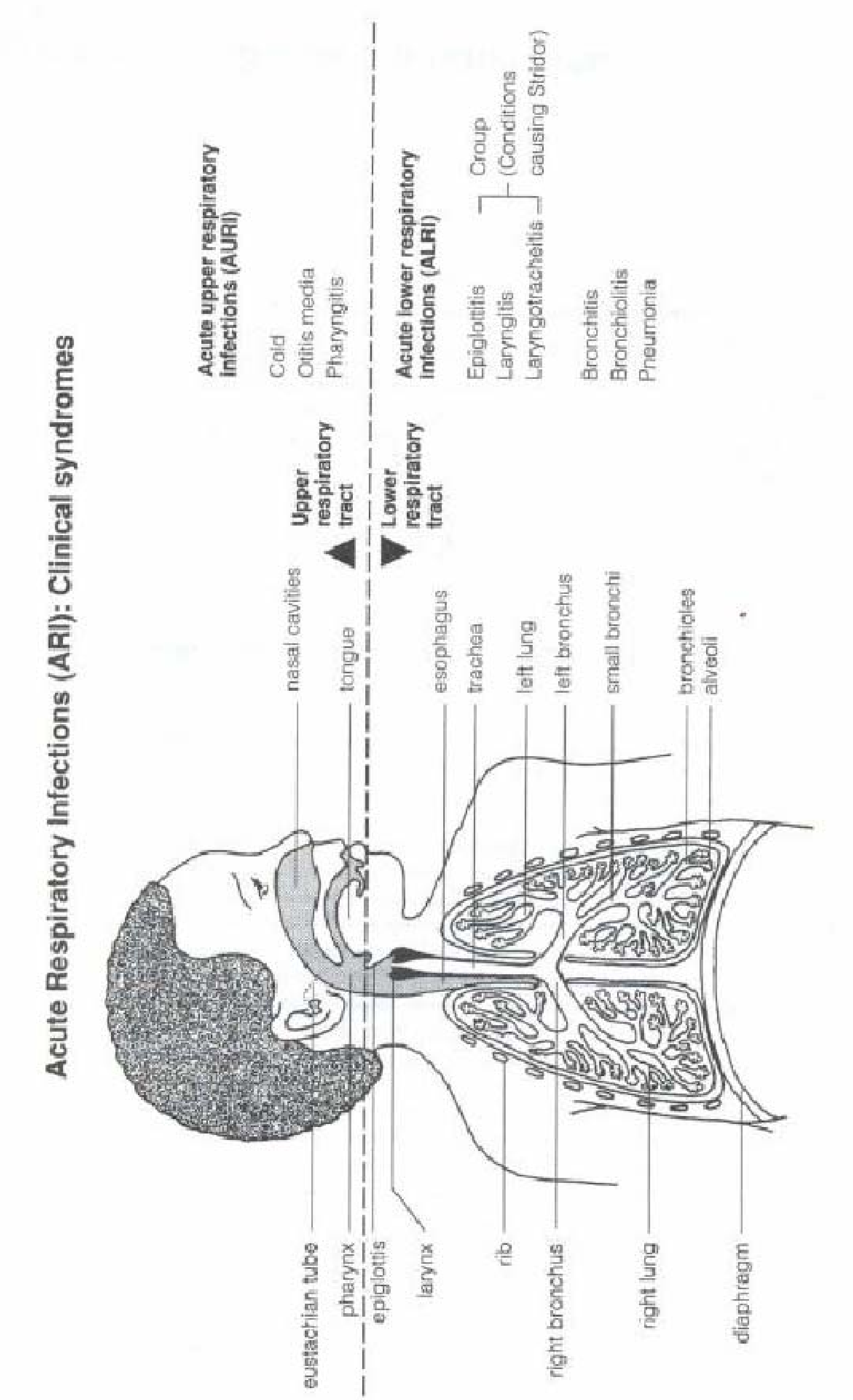

Figure 2.3: The respiratory tract. In ARI classification the infections of middle section of the respiratory tract are grouped together with the acute upper respiratory infections (AURI). ALRI refers to the infections of the bronchi and lungs (source: 54).

The Water Boiling Test Procedure (appendix B)

The Water Boiling Test, Version 1.5 August 20, 2004 ***The Water Boiling Test (WBT)***
Prepared by Rob Bailis, Damon Ogle and Dean Still with input from Kirk R. Smith and Rufus Edwards
Household Energy and Health Programme, Shell Foundation

Excerpt:

Phase 1: High Power (Cold Start)

Data recorded in the remaining phases of the test should be recorded on page two of the Data and Calculation form.

1. Prepare the timer, but do not start it until fire has started.

2. Fill each pot with 5 kg (5 liters) of cold clean water. This amount of water should be determined by placing the pot on the scale and adding water until the total weight of pot and water together is 5 kg more than the weight of the pot alone. Record the weight of pot and water on the Data and Calculations Sheet.

(If the stove can not accommodate the standard pot and the pot that is used can not accommodate 5 kg of water, OR if a multi-pot stove is used with non-standard pots that can not accommodate 5 kg of water, fill each pot ~2/3 full and record the change in procedure in the comment space. Record the weight of the pot(s) with the water on the Data and Calculation Form.)

3. Using the wooden fixtures, place a thermometer in each pot so that water temperature may be measured in the center, 5 cm from the bottom. Make sure the digital thermometer is used in the primary pot. (If there are additional pots, use the extra thermometers provided in the testing kit. Record the initial water temperature in each pot and confirm that it does not vary substantially from the ambient temperature.)

4. The stove should be at room temperature. Start the fire in a reproducible manner according to local practices. Record any starting materials that are used other than the wood from the first bundle of pre-measured wood (e.g. paper or kerosene).

5. Once the fire has caught, record the starting time. Throughout the following “high power” phase of the test, control the fire with the means commonly used locally to bring the first pot rapidly to a boil without being excessively wasteful of fuel.

6. When the water in the first pot reaches the pre-determined local boiling temperature as shown by the digital thermometer, rapidly do the following:

   a. **Record** the time at which the water in the primary pot (Pot # 1) first reaches the local boiling point of water. Record this temperature for primary pot as well.

b. Remove all wood from the stove and extinguish the flames (flames can be extinguished by blowing on the ends of the sticks or placing them in a bucket of ash or sand; do not use water – it will affect the weight of the wood). Knock all loose charcoal from the ends of the wood into the container for weighing charcoal.

c. Weigh the unburned wood removed from the stove together with the remaining wood from the pre-weighed bundle. **Record** result on the Data and Calculation form.

d. For multi-pot stoves, measure the water temperature from each pot (the primary pot should be at the boiling point). **Record** the temperatures on the Data and Calculation Form.

e. Weigh each pot, with its water. **Record** weight on Data and Calculation form

f. Extract all remaining charcoal from the stove, place it with the charcoal that was knocked off the sticks and weigh it all. **Record** the weight of the charcoal + container on the Data and Calculation Form.

Summary

Make sure that you have recorded time and temperature of the boiling water in the first pot, the amount of wood remaining, the weight of Pot # 1 with the remaining water, and amount of charcoal remaining on the Data and Calculation Form. For multi-pot stoves, be sure that you have recorded the temperature that each additional pot reached **when Pot # 1 first came to its full boiling temperature**.

This completes the high power (cold start) phase. Continue directly without pause to the high power (hot start) portion of the test. Do not allow the stove to cool.

Phase 2: High Power (Hot Start)

The stove will be hot from the first test. Be careful not to burn yourself!

1. Reset the timer, but do not start it until fire has started.

2. Refill the pot with 5 kg of fresh cold water. Weigh pot (with water) and measure the initial water temperature; **record** both measurements on the Data and Calculations sheet. For multi-pot stoves, fill the additional pots, weigh them and record their weights.

3. Rekindle the fire using kindling and wood from the second pre-weighed bundle designated for this phase of the test.

4. Record the starting time, and bring the first pot rapidly to a boil without being excessively wasteful of fuel using wood from the second pre-weighed bundle.

5. Record the time at which the first pot reaches the local boiling point as indicated on the Data and Calculation form. Record this temperature for the first pot.

6. After reaching the boiling temperature, rapidly do the following:

   a. Remove all wood from the stove and knock off any loose charcoal into the charcoal container. Weigh the wood removed from the stove, together with the unused wood from the previously weighed supply. **Record** result on Data and Calculation form.

   b. **Record** the water temperature from other pots.

   c. Weigh each pot, with it's water and **record** the weights.

7. Extract all remaining charcoal from the stove and weigh it (including charcoal which was knocked off the sticks). **Record** the weight of the charcoal plus container on the Data and Calculation form.

Biomass Combustion (appendix C)

A generalized chemical equation for the *complete combustion* of a carbon based fuel source can be written as:

$$C_XH_YO_Z + O_2 \rightarrow CO_2 + H_2O + \text{Heat Energy}$$

On the basis of this equation the precise quantity of heat produced by a biomass combustion reaction can be determined from

1.) The caloric energy density of the fuel source being used
2.) The quantity of fuel consumed in the reaction

The unique condition of *complete combustion* for which the equation above has been given does not accurately model the chemical products produced by the open air combustion of biomass fuels which occur in the natural environment. There are two main considerations:

1.) The earth's atmosphere, by volume, is composed of roughly 78% nitrogen (N_2) and 21% (O_2) with trace amounts of other gases such as argon, xenon, CO_2 ,etc. Diatomic nitrogen has an extraordinarily high heat of combustion (a chemical term used to describe the quantity of energy needed to break the chemical bonds holding together the individual atoms in a compound) and will only react in combustion systems to produce measurable chemical byproducts at temperatures above 2800 F (at a pressure of 1 atm). Since these temperatures are not achieved by the combustion of biomass in simple cook stove systems the nitrogen in the air can by and large be considered to be chemically inert. The presence of large amounts of this inert gaseous species (N_2) mixed in with the oxidizing agent (O_2) is problematic because, in the extremely rapid process of combustion, there simply is not a sufficient quantity of oxygen available to completely oxidize the fuel source. Incomplete oxidation (i.e. partial combustion) is manifest by *both* a reduced quantity of heat produced (as compared to the calorific energy density of the fuel source) *and* the production of chemical products other than CO_2 and H_2O.

2.) There can be significant variability in the chemical composition of the fuel source. For instance, the generalized chemical equation for combustible biomass material is given as $C_XH_YO_Z$; however, consideration must also be given to the potential for there to be appreciable amounts of other non combustible compounds in the fuel's chemical structure. There are several ways in which the presence of these chemicals can result in harmful consequences during a combustion reaction. For some inert species which are harmful in their present form, the combustion reaction functions to simply release them into the atmosphere where they can be absorbed by human tissue. For other more reactive species that may not necessarily be dangerous on their own, the high temperatures of combustion may be sufficient to induce a secondary reaction which can result in a noxious byproduct.

The necessary link between reduced thermal efficiency and the production/release of noxious byproducts is critical to the methodology being employed in our study. For the goals of this study, in ideal circumstances, we would directly sample the emissions of the cook stoves being used by our interview subjects using automated equipment capable of determining both the concentration and size distribution of particulate emissions. Unfortunately, our project is constrained by limitations on both the amounts of available time and funding.

Cooking Behaviors Checklist (appendix D)

Description of risk increasing behavior	Observed	Duration/ frequency of behavior	Number and identity of individuals engaging in behavior	Comments
Stage 1: Lighting of the fire				
1-A: Use of a hazardous material as ignition source for charcoals or tinder (Examples include: disposable plastic bags, plastic bottles, and other miscellaneous flammable garbage items)				
1-B: Placing one's face within 1-3 feet of the flame during ignition and using the mouth to physically stoke the ignition source via blowing				
Stage 2: General cooking period				
2-A: Placing one's face within 1-3 feet of the flame while manipulating the fuel source to increase heat output (defined as physically moving/shaking coals or fuel wood to shake off spent ashes)				
2-B: Placing one's face within 1-3 feet of the flame while stirring or simmering foodstuffs using a hand utensil				
Stage 3: Fire extinction and spent fuel disposal				
3-A: Collection and disposal of ash in an unhealthful manner (any sort of behavior causing excessive quantities of the particulate spent fuel/ash materials to become airborne)				
Other Behaviors				
4-A: Sitting within 1-3 feet of the flame (Examples include watching fire, cutting of vegetables, and other miscellaneous behaviors occurring close to the fire)				
4-B: Use of two or more stoves simultaneously				
4-C: Use of hazardous materials throughout cooking activities (Examples include: coconut husks, plastics, and other miscellaneous flammable garbage items)				

Interview Checklist (appendix E)

Name:
Time/Date:
Location:

				Time spent in cooking environment during cooking activities				
Name of household member	**Age**	**sex**	**relation**	**breakfast**	**lunch**	**dinner**	**misc.**	**total duration**

Health profile*:

Read the following symptoms of ARI to the interviewee:

-cough
-difficulty breathing
-chest indrawing
-not able to eat or drink
-unusually sleepy
-convulsion
-abnormal sound (wheeze) during respiration
-severely malnourished (pneumonia)

Symptoms go in order of ARI severity

Name	ARI?	Frequency**	Duration of ARI

Have you or members listed above visited the dispensary in the past year?
How many times?
For what ailments?

*only to be completed for those who are non-smokers and present during cooking activities as outlined in first checklist
**In the last 12 months

WHO Acute Respiratory Infection Checklist (appendix F)

ARI checklist

ARI
(Child with cough and/or difficult breathing)

Name of the child:		
Age:	Registration #	
Sign/symptoms of severe pneumonia or very severe disease		
Put • •mark if any of the sign(s)/symptom(s) of severe pneumonia or very severe disease is present	1. Chest indrawing	
	2. Not able to eat or drink	
	3. Unusually sleepy	
	4. Convulsion	
	5. Abnormal sound (wheeze) during respiration	
	6. Severely malnourished	
Respiratory rate		
Temperature		
Diagnosis (Put • •mark in the appropriate box)	Simple cough and cold (no pneumonia)	
	Pneumonia	
	Severe pneumonia or very severe disease	
Treatment/management		

Sample Data Entry Form from Shell Foundation Water Boiling Test (Appendix G)

WATER BOILING TEST - DATA SHEET

These sheets should be printed out so that data can be recorded manually during the WBT and entered into spreadsheets after tests are complete

Name(s) of Tester(s) ______________________________

Test Number	____________	Location	____________
Date	____________	Wood species	____________
Stove type/model	____________	Wind conditions	____________

Air temp	______	°C	Dry weight of Pot # 3 (grams)	______	g
Average dimensions of wood	______	cm x cm x cm	Dry weight of Pot # 4 (grams)	______	g
Dry weight of Pot # 1 (grams)	______	g	Weight of container for char (grams)	______	g
Dry weight of Pot # 2 (grams)	______	g	Local boiling point	______	°C

Wood moisture content - method used for calculation (circle one): Gravimetric, Moisture Meter, Other (describe) ______

If using gravimetric methods, record in the "Avg MC" space. If using moisture meter, use meter's averaging function and record in the "Avg MC" space. If you do not use the averaging function, record 9 measurements in the space provided to the right and calculate the average later using the data calculation spreadsheet. In any case, indicate if MC is on a wet or dry basis.

1 ______	4 ______	7 ______	
2 ______	5 ______	8 ______	Avg MC ______
3 ______	6 ______	9 ______	dry wet (circle one)

WBT TEST 1		HIGH POWER TEST (COLD START)				HIGH POWER TEST (HOT START)				SIMMER TEST			
		Start		Finish: when Pot #1 boils		Start		Finish: when Pot #1 boils		Start:when Pot #1 boils		Finish: 45 min after Pot #1 boils	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
Time	min	______	t_{ci}	______	t_{cf}	______	t_{hi}	______	t_{hf}	______	t_{si}	______	t_{sf}
Weight of wood	g	______	f_{ci}	______	f_{cf}	______	f_{hi}	______	f_{hf}	______	f_{si}	______	f_{sf}
Water temperature, Pot # 1	°C	______	$T1_{ci}$	______	$T1_{cf}$	______	$T1_{hi}$	______	$T1_{hf}$	______	$T1_{si}$	______	$T1_{sf}$
Water temperature, Pot # 2	°C	______	$T2_{ci}$	______	$T2_{cf}$	______	$T2_{hi}$	______	$T2_{hf}$				
Water temperature, Pot # 3	°C	______	$T3_{ci}$	______	$T3_{cf}$	______	$T3_{hi}$	______	$T3_{hf}$				
Water temperature, Pot # 4	°C	______	$T4_{ci}$	______	$T4_{cf}$	______	$T4_{hi}$	______	$T4_{hf}$				
Weight of Pot # 1 with water	g	______	$P1_{ci}$	______	$P1_{cf}$	______	$P1_{hi}$	______	$P1_{hf}$		$P1_{si}$	______	$P1_{sf}$
Weight of Pot # 2 with water	g	______	$P2_{ci}$	______	$P2_{cf}$	______	$P2_{hi}$	______	$P2_{hf}$				
Weight of Pot # 3 with water	g	______	$P3_{ci}$	______	$P3_{cf}$	______	$P3_{hi}$	______	$P3_{hf}$				
Weight of Pot # 4 with water	g	______	$P4_{ci}$	______	$P4_{cf}$	______	$P4_{hi}$	______	$P4_{hf}$				
Fire-starting materials (if any)	--	______											
Weight of charcoal+container	g			______	c_c			______	c_h			______	c_s

$T1_{si}$ is set equal to T_b because the test starts after the pot has boiled.

$P1_{si}$ should be the mass of water after the pot comes to boil.

Table of Local Tree Species Commonly Used as Firewood (Appendix H) –Ely et al 2000

Charawe

Botanical Name	Vernacular Name	Standing Volume (m^3)
Euclea recemosa	Msiliza	9566
Ficus spp	Mkuyu	5448
Olea woodiana	Kiraramba	5442
Albizia adantifolia	Mngoti	4674
Rhus natalensis	Mkumba	4331
unidentified	Mbambakofi	3640
Psychotria bibreactum	Mkonge	3297
unidentified	Mchopaka	2877
Mytenus mossambiensis	Mnusi	2293
Dichrostachys cineira	Mgunga	1194
Diospyros spp	Mnyovuo	1182
Eugenia spp	Mkaaga	1004
Terminalia boivini	Mkunguni	898
Dodonea viscata	Mkeneta	815
Euclea schimperi	Mdaa	668
Polysphaeria parvifolia	Mlapaa	626
Suregada zanzibarensis	Mdimu msitu	591
Sideroxylon inerme	Mkandika	561
unidentified	Mwangakwao	555
Anona senegalensis	Mtopetope	544
Rapanea melanosphores	Mkangara shamba	520
unidentified	Mnangachenge	402
unidentified	Mpesi	396
Mystroxylon aethiopicum	Kifugu	396
Ozona obovata	Mngombe	284
Macphersonia spp	Mjoma	284
unidentified	Mpepe	278
unidentified	Mlashore	177
Flueggia virosa	Mkwamba	148
unidentified	Mtumbua	77

Ukongoroni

Botanical name	Local Name	Standing Volume (m^3)
Ficus spp	Mkuyu	16874
unidentified	Mchopaka	10127
Mytenus mosambiensis	Mnusi	9964
Terminalia boivini	Mkunguni	8508
unidentified	Mbambakofi	8140

Albizia adiantifolia	Mngoti	7804
Euclea recemosa	Msiliza	7514
Psychotria bibreactum	Mkonge	7410
Ozona obovata	Mngombe	4866
Diospyros spp	Mnyovuo	4360
Olea woodiana	Kiraramba	4342
Rhus natalensis	Mkumba	4211
unidentified	Haungo'ngwa	3365
Mystroxylon aethiopicum	Kifugu	2967
Eugenia spp	Mkaaga	2630
Sideroxylon inerme	Mkandika	2113
Macphersonia spp	Mjoma	1686
unidentified	Mhonga	1183
Polysphaeria parvifolia	Mlapaa	1172
Dichrostachys cineira	Mgunga	991
Ficus sp	Mti mweupe	876
Euclea schimperi	Mdaa	872
Flueggia virosa	Mkwamba	800
unidentified	Mpesu	749
Rhus longipes	Mchengele	716
Rawsonia lucida	Mpera mwitu	666
unidentified	Mnangachenge	651
unidentified	Mkeketa	644
Sorindeia madagascarensis	Mpilipili doria	568
unidentified	Mbeto	568
unidentified	Mpepe	554
unidentified	Mlashore	517
unidentified	Mgeuka	398
Rapanea melanosphaes	Mkangarashamba	384
unidentified	Mwangakwao	362
unidentified	Mlalanguo	329
unidentified	Mtumbua	275
Bredelia micrantha	Mkarati	228
Suregada zanzibarensis	Mdimu msitu	185
Sorideia madagascarensis	Mtikiza	159
unidentified	Mpingaume	123
Anona senegalensis	Mtopetope	109
unidentified	Mgo	94
unidentified	Mwavikali	76
unidentified	Mdunguze	47
unidentified	Mkadamushamba	47
unidentified	Mlapunju	47
Polysphaeria parvifolia	Mgwidu	40
unidentified	Mkukupe	11
unidentified	Mkundekunde	7
unidentified	Mpikaduri	7
unidentified	Mtamagoa	4