INVESTIGATION AND EVALUATION OF FIREWOOD CONSUMPTION IN TRADITIONAL HOUSES IN NEPAL

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ABSTRACT
Firewood consumption and air temperature were investigated in winter and summer in traditional houses in the Banke, Bhaktapur, Dhading, Kaski and Solukhumbu districts of Nepal. The firewood consumption rate was 235-1130kg/capita/year. The results showed that the temperate climate used less firewood than the sub-tropical climate. The indoor and outdoor temperature difference (7.8^{o}C), the vertical temperature difference (7.1^{o}C) and maximum indoor air temperature (42^{o}C) were most significant in the kitchen. The results demonstrated a waste of energy in winter and an uncomfortable thermal environment in summer. If thermal storage on the wall were introduced as well as airtight openings and improvements in fireplaces, we could reduce the usage of firewood, and the thermal and air environment would be improved.

INDEX TERMS
Firewood, Energy, Thermal environment, Regional difference, Nepal

INTRODUCTION
In rural areas of Nepal firewood is a main source of energy for cooking, heating and lighting. In the past, firewood was abundant and it could be easily collected in the vicinity of the villages. However, collecting firewood is becoming more difficult due to overuse and the shrinking of forest areas. Therefore, a reduction of firewood consumption is presently one of the most important issues in Nepal. Another important issue is the improvement of the thermal environment and of air quality. In Nepal, firewood is burned in an open fireplace, is very energy inefficient and creates high indoor air temperatures and low indoor air quality. In Nepal, there have been a few studies conducted on firewood consumption and indoor air quality (Fox, 1984, Davidson *et al.,* 1986, Pandey *et al.,* 1990), but, no such research has been found on the thermal environment in relation to firewood consumption. In this research we focus on energy consumption and the thermal environment in terms of firewood usage. We try to quantify these elements by considering the regional and seasonal differences of Nepal. In the future, we also plan to measure the indoor air quality.

In order to evaluate and improve the energy consumption and thermal environment in the traditional houses of the 5 districts of Nepal, the firewood consumption rates and air temperatures were measured and investigated in winter and summer. The objectives of this research are: 1) to estimate the energy consumption, such as firewood consumption for cooking and heating and 2) to measure the relationship between firewood consumption and the thermal environment, such as indoor and outdoor temperature differences, and the vertical temperature differences in the kitchen.

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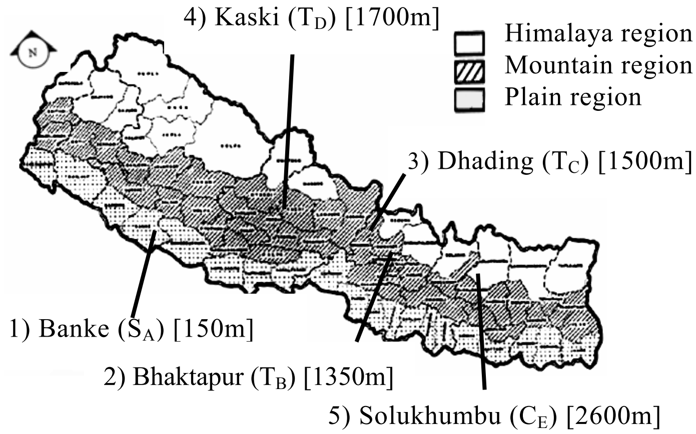

Figure 1. Location of survey districts [altitude]

Figure 2. Measurement of firewood

THE STUDY AREA

The research areas are Banke (A), Bhaktapur (B), Dhading (C), Kaski(D) and the Solukhumbu (S) districts of Nepal (Figure 1, Panday, 1995). The climatic zone of A is sub- tropical (S), B, C and D are temperate (T), and E is cool climate (C), these are abbreviated as S_A, T_B, T_C, T_D and C_E. They were chosen according to the altitude, climate, topography, ethnicity, energy and housing conditions in Nepal. Bhaktapur is an urban area and the other districts are rural. In the rural areas, agriculture and livestock are the main occupations and firewood is used for cooking and heating. In the Bhaktapur, straw, twigs and rice husks are also used for cooking. Firewood was burned in an open-hearth stove and the semi-open stove. In Banke, people also burned the firewood in living rooms and semi-public spaces for heating. The kitchen room was used for dining and living. In Dhading and Kaski, the kitchen was also used for sleeping. In Solukhumbu, because of the cold climate, people spent most of their time in the kitchen.

METHODS

Investigations were conducted in winter (December, 2000 to January, 2001) and summer (April to May 2000). In the 5 districts, the daily firewood consumption rate was measured in 133 households for 32 days (in Dhading 3 households for 486 days from August 18, 1999 to November 27, 2000) (Figure 2). The short period measurement was 3-7 days, and the long period measurement was 468 days. The amount of firewood consumed in a day was determined by first allocating each family a specific amount of firewood each day, which was weighed using a scale. In the morning of the next day, the amount of firewood leftover was weighed and recorded and the families were then given more firewood. This process was repeated for 468 consecutive days. Family size was divided into 3 types, a) large (more than 9 persons), b) medium (5-8 persons) and c) small (1-4 persons). The number of family members and guests were recorded. Children below 5 years of age were counted as 0.5 person, because of their lower amount of food consumption. The weight of firewood included: twigs, crop residues, bamboo, straw and rice husks. Only well dried firewood was measured. Outdoor (above 1.5m from ground level) and kitchen air temperatures (above 0.6m from floor level) were measured in 5-minute intervals and recorded by a data logger. Measured data were calibrated.

RESULTS

Average firewood consumption is shown in Table 1. Firewood consumption per capita per day is calculated by dividing the total firewood consumption by the total number of consumers. Firewood consumption is classified as cooking and heating. Firewood for cooking per year was estimated by taking the firewood consumption per capita per day in the summer and multiplied by 365(days). For heating, the amount was determined by subtracting the amount of firewood used per capita per day in the winter from the amount of firewood per capita per day in the summer and multiplied by 90(heating days). In Dhading, summer and winter firewood consumption was 1.4kg/capita/day, therefore we could not estimate the firewood for heating. Total firewood consumption is the sum of cooking and heating firewood.

1. The regional and seasonal difference of firewood consumption

Figures 3 and 5 show the daily firewood consumption in short and long period measurements. The average firewood consumption rates were 0.6(T_B) -4.6(C_E) and 0.8(T_D) -2.6(C_E) kg/capita/day in winter and summer (Table 1). Firewood consumption was higher in winter because people use extra firewood for heating. In winter, firewood consumption was highly correlated to the outdoor air temperature during the cooking and heating period (r=0.91, Figure 7). Because the cool climate (C_E) had the lowest outdoor air temperature, the rate of firewood consumption in that area was the highest in both winter and summer. In winter, the outdoor air temperatures are similar in the sub-tropical (S_A) and temperate climates (T_C, T_D), however the firewood consumption rate was 1.5kg/capita/day higher in the sub-tropical climate. The reason for this is that people burn the firewood not only in the kitchen, but also in the living room and the front yard for heating. While in summer, firewood consumption of the sub-tropical climate was 0.4kg less than that of the temperate climate (T_C). This is because, the maximum outdoor air temperature in sub-tropical climate reaches 42^{o}C in the summer, therefore people put out their fires soon after cooking. The climates, topographies, ethnic groups of T_C and T_D are similar, therefore the firewood consumption in these areas was 1.4 kg/capita/day in winter. But, in summer firewood consumption of T_D was 0.6kg/capita/day lower than T_C. This could be due to the fact that T_D has insufficient firewood compared to T_C and its people might have used their firewood more sparingly. The firewood consumption of T_B was lowest because people often used other forms of fuel for cooking only, including straw, rice husks, twigs, electric heaters and kerosene stoves. 2.1, 5.2 and 5.2 times more firewood was used for cooking than for heating in the S_A, T_D and C_E areas. Total firewood consumption rates was 235(T_B)-1130(C_E) kg/capita/year. In Dhading, the difference between measured and estimated firewood consumption was 50kg/capita/year. It can be said that measured and estimated data are well matched.

Table 1. Average firewood consumption in each district (winter / summer)

Items (winter/summer)	S_A	T_B++	T_C	T_C*	T_D	C_E
No. of household in survey	41/2	4	39/3	3	28/2	21/1
No. of measurement days	7/4	5	7/4	468	7/4	6/3
Total no. of consumer	1,890/100	143	1521/93	9,240	1228/67	636/32
Family size	6.6/12.5	8.4	5.7/7.8	6.6	6.4/8.4	5.0/10.5
Total firewood consumption [kg]	5,464/100	92	2139/132	13,482	1,744/51	2,933/83
Firewood consumption [kg/household/day]	19.2/12.3	5.4	8.0/11.0	9.6	9.1/6.4	23.3/27.7
Firewood consumption [kg/capita/day]	2.9/1.0	0.6	1.4/1.4	1.5	1.4/0.8	4.6/2.6
Firewood for cooking+ [kg/capita/year]	365	235	511	-	292	949
Firewood for heating+ [kg/capita/year]	170	-	-	-	56	181
Total firewood consumption+ [kg/capita/year]	535	235	511	561**	348	1,130

S_A: Banke, T_B: Bhaktapur, T_C: Dhading, T_D: Kaski, C_E: Solukhumbu, +: estimated value, ++: winter data only, mainly straw burn, *: long period measurement, **: accumulated value in a year

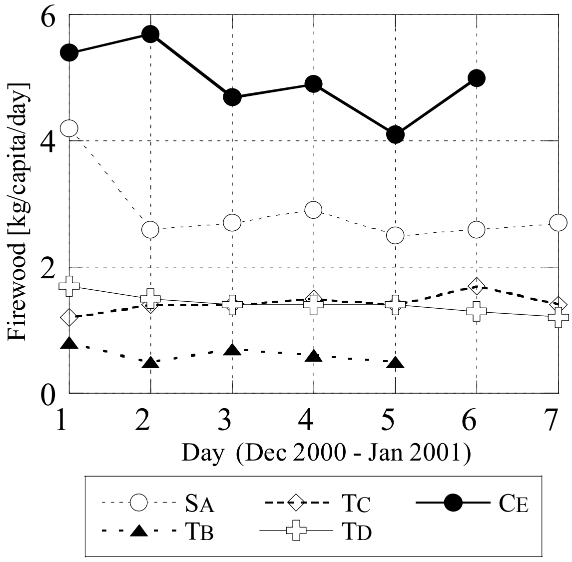

Figure 3. Daily firewood consumption per capita per day in winter

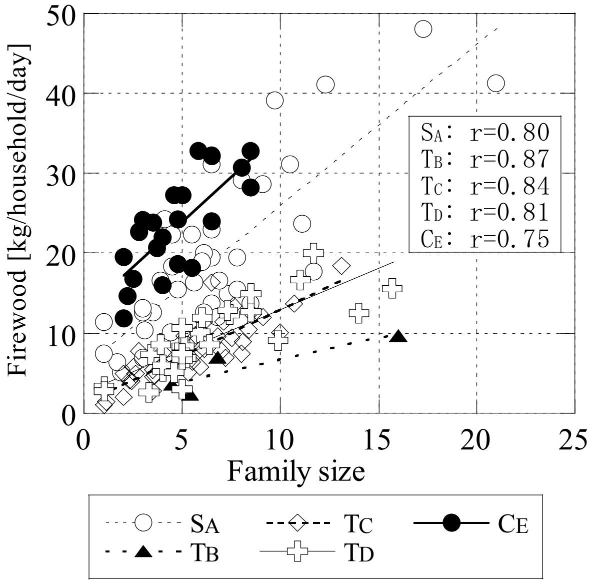

Figure 4. Relation beween family size and firewood consmption in winter

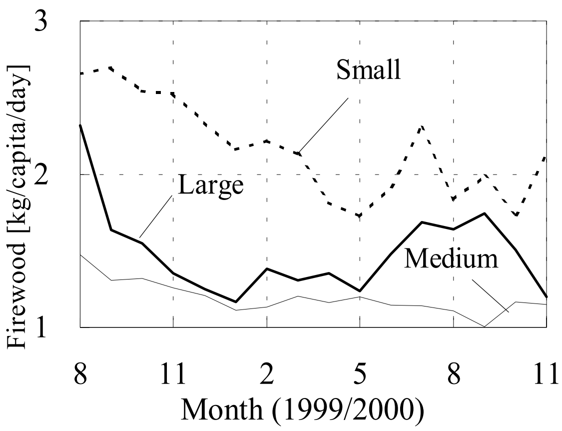

Figure 5. Daily firewood consumption per capita per day (Dhading)

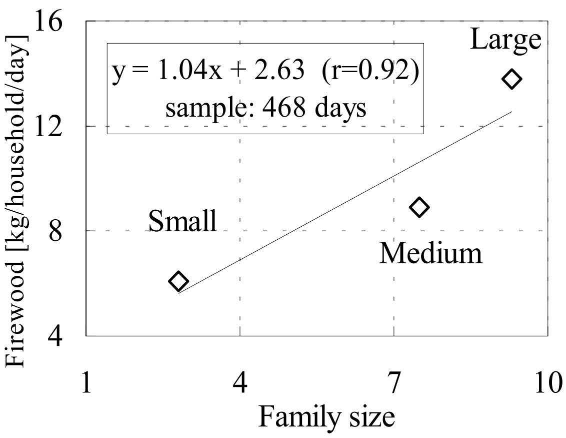

Figure 6. Relation between family size and firewood consmption (Dhading)

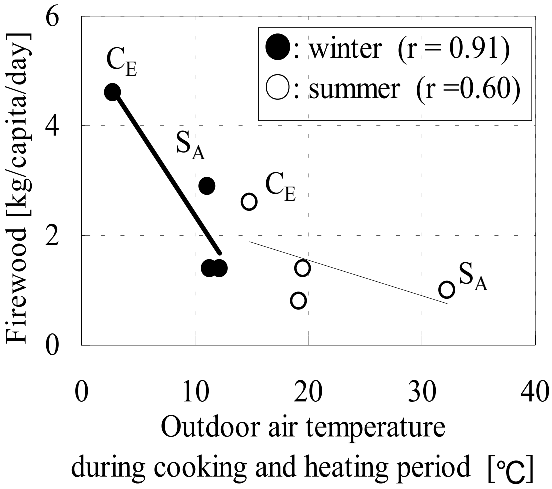

Figure 7. Relation between firewood consumption and outdoor air temp.

Table 2. Thermal environment in the kitchen during cooking and heating

Items	Season	S_A	T_B	T_C	T_D	C_E
T_{out}	winter	11.1	9.2	11.3	12.2	2.8
[°C]	summer	32.2	21.0	19.5	19.2	14.8
	sample*	8/6	5/5	6/4	7/7	5/5
T_{in}	winter	14.9	11.1	19.1	16.3	6.7
[°C]	summer	32.2	23.6	25.6	22.2	17.8
T_{in}-T_{out}	winter	3.8	1.9	7.8	4.2	4.0
[°C]	summer	0.0	2.6	6.0	3.0	3.0
T_c-T_f	sample	5	2	3	4	2
[°C]	winter	4.3	2.9	7.1	5.8	5.0

T_{out} & T_{in}: outdoor & indoor air temp.
T_c & T_f: air temp. around ceiling & floor level
*: winter/summer, winter:7-10 am & 5-8 pm
summer: 6-9 am & 6-9 pm

The results showed that firewood consumption has regional and seasonal differences. The regional difference was 4.0kg/capita/day in winter and 1.8kg/capita/day in summer. The maximum seasonal difference was 2.0kg in the cool climate (C_E). The temperate climate used the least amount of firewood followed by the sub-tropical climate using more and the cold climate using the most. It was unexpected to find that the temperate climate used less firewood than the sub-tropical climate. This could be due to the fact the sub-tropical climate has a greater annual temperature range. Over the winter, the people in the sub-tropical climate, who are less resilient to cooler temperature, unnecessarily use more firewood than the people in the temperate climate. Ironically, they also use more firewood in the summer in order to more quickly built fires for cooking. After they have quickly cooked their food, they extinguish the fires wasting some of the firewood.

2. Relation between firewood combustion and thermal environment

Figures 4 and 6 show the relation between family size and firewood consumption in the short and long measurement period. Firewood consumption was highly correlated to the family size (r=0.75(C_E) to 0.92(T_C)). Because of the great amount of food cooked in large families, firewood consumption per day was higher than that of small or medium sized families. However, the volume and openings of the kitchens in each climatic zone were similar, irrespective of family size. This meant that the large family kitchen created higher indoor air temperatures than did small or medium sized family kitchens and caused greater discomfort.

Table 2 shows the outdoor and indoor air temperatures, the indoor and outdoor temperature differences and the vertical temperature differences. The daily mean indoor and outdoor temperature difference (T_{in}-T_{out}) was 1.9(T_B) to 7.8^{o}C (T_C) in winter and 0.0(S_A) to 6.0^{o}C (T_C) in summer. Because of lesser firewood consumption, the T_{in}-T_{out} was smaller in summer than in winter. The maximum air temperature was 37^{o}C in winter and 42^{o}C in summer. The vertical temperature difference (T_c-T_f) was 2.9(T_B) to 7.1^oC (T_C) in winter. In winter, because of lower firewood consumption, the T_{in}-T_{out} and the T_c-T_f of T_B was the smallest. However, T_C consumed less firewood than S_A and C_E, the T_{in}-T_{out} and the T_c-T_f was highest in winter and summer. This was due to the volume of the kitchen. The T_C was lesser in volume compared to S_A and C_E. In Dhading, the vertical temperature difference was 6.5^oC in winter (Rijal *et al.,* 2001), which is similar to present research. The vertical temperature difference was greater than the ASHRAE ST-55 thermal comfort standard (3^oC).

DISCUSSION

In the present research, the firewood consumption rates were 0.6-4.6kg/capita/day. In Bhogteni, the firewood consumption rate was 0.96-1.75kg/capita/day (Fox, 1984). Bhogteni is similar to T_C, T_D in climate, topography, and ethnic group, and as a result it is close to 1.4kg/capita/day. In Bhogteni the firewood consumption was 0.95m^3/capita /year (570kg), which is similar to T_C (561kg). In high elevations (2700-3900m) and low elevations (1300m), firewood consumption was 8.2 and 2.8kg/capita/day (Davidson *et al.,* 1986). Compared to high elevations, C_E had 3.6kg/capita/day lower firewood consumption. The reason for this could be that C_E is located at 100-1300m lower than the areas of high elevation studied by Davidson *et al.* Therefore, outdoor air temperature is 10^oC higher. As a results C_E needed less firewood than high elevations. Furthermore, compared to low elevations, T_C, T_D had a 1.4kg lower firewood consumption. Compared with existing research, the firewood consumption rate was found to be similar in areas with similar climates. It can be assumed that the condition of the indoor thermal environment in Bhogtani and lower elevations would be similar to T_C and T_D, while the temperature distribution in higher elevations would be higher than C_E.

Firewood was burned in open fireplaces in excessively ventilated rooms, which accelerated the firewood combustion speed. As a result, more firewood for cooking and heating was required. Because of inadequate firewood usage, low thermal efficiency and high temperature distribution was observed. In winter, the heat loss was greater because cold air entered inside and hot air went outside from the opening of the kitchen. In summer, there was no system for expelling the hot indoor air, and as a result, the temperature rose substantially, which created an uncomfortable indoor environment. Therefore, a waste of energy in winter and an uncomfortable thermal environment in summer was observed. If thermal storage on the wall were introduced as well as airtight openings and improvements in fireplaces, we could reduce the usage of firewood, and the thermal and air environment would be improved.

CONCLUSION

In the present research we investigated firewood consumption and air temperature in winter and summer of the traditional houses in the Banke, Bhaktapur, Dhading, Kaski and Solukhumbu districts of Nepal. The results are as follows:

1) The firewood consumption rates were 0.6-4.6 and 0.8-2.6kg/capita/day in winter and summer. The firewood required for cooking was 2.1-5.2 times more than for heating. Total firewood consumption rates were 235-1130kg/capita/year. The results showed that the temperate climate used less firewood than the sub-tropical climate. Regional differences depended on the method of firewood usage. If proper firewood usage methods were introduced, we could minimize the regional differences of firewood consumption.
2) The indoor and outdoor air temperature differences were 1.9-7.8^{o}C in winter and 0.0-6.0^{o}C in summer. The vertical air temperature difference was 7.1^{o}C in winter. The maximum air temperature was 37^{o}C in winter and 42^{o}C in summer. This demonstrated a waste of energy in winter and an uncomfortable thermal environment in summer.

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