Rural Household Energy Use and Thermal Environment in Three Climatic Regions of Nepal

IOP Conf. Series: Earth and Environmental Science **294** (2019) 012093 doi:10.1088/1755-1315/294/1/012093

Rural Household Energy Use and Thermal Environment in Three Climatic Regions of Nepal

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Abstract. Nepal is a mountainous country with low energy use so far and its climatic patterns remarkably differ from one place to another due to its geographical variation. In the north summer is cool and winter severe, while in the south summer is tropical and winter is mild. Indoor thermal environment and household energy use of residential buildings are in general very much associated so that there have been guide a lot of research; however, there has not been sufficient number of such studies focusing on Nepal. In this study, we aim to analyze the current situation of household energy use and indoor thermal environment of residential buildings in three different ecological regions of Nepal. This study was carried out in mountain, hill and terai regions representing cold, temperate and sub-tropical climate in Nepal from 21st December, 2017 to 20th January, 2018. Indoor and outdoor air temperature and humidity were measured by electronic sensors with the help of data logger for every 10-minute interval from 5 households from each region. The mass of firewood used was also measured at those houses. Household energy-use data of 516 houses were collected by the method of questionnaire survey. We found that mean indoor temperature was 3.6℃, 9.4℃ and 19.0℃ in cold, temperate and sub-tropical regions respectively. Based on this field study, we concluded that firewood is the primary source of household energy for cooking. The present finding suggests that an intensive and extensive improvements of the indoor thermal environment together with rationalization of energy use must be important especially for winter seasons.

1. Introduction

Nepal is one of the countries with low energy use and its energy sector is dominated by the traditional energy sources such as fuel woods, crop residues and animal dung. Domestic purpose alone occupies about 80% of the total energy use in Nepal. Based on topography and distinct climatic features, Nepal is broadly classified into three ecological regions; the Mountain, Hill and Terai regions, all of which extend from east to west with some irregular widths from north to south [1]. Different climatic regions can be seen within short distance due to geographical location and altitudes. In the north, summer is cool and winter is severe, while in the south, summer is tropical and winter is mild. Adjustment of indoor thermal environment suitable for comfortable living is directly related to the patterns of energy use and the availability of commercial fuels. In Nepal, due to relatively high cost and limited supply of commercial fuels, 80% of rural people still rely on traditional fuels like firewood, agricultural residue and animal dungs for cooking and space heating [3], [4]. They usually maintain their indoor thermal environment by applying different passive measures without mechanical devices for heating and cooling

that require the input of commercial fuels. The harsh thermal environment without proper heating and cooling systems creates various problems, not just mere discomfort but serious illness and death [8]. In the developed countries, the use of heating and cooling devices play major role for thermal environment adjustment; however, in developing countries, rural areas in particular, the mechanical heating and cooling systems have not yet been widely used and most of the people living with passive means of heating and cooling such as clothing adjustment, window opening/closing, and taking hot or cold drinks depending on the occupants' surrounding conditions [2]. Suitable design of houses under local climate and the use of locally available suitable materials for the construction of houses in different regions play an important role for the thermal environment improvement; Nepal is no exception.

Various studies [1, 2] illustrated that the energy access situations and energy use in Nepal are far below the level of basic human needs, and firewood must be expected to remain the dominant fuel source for cooking and heating. Recently, researches have been done with respect to energy use and its socio-economic and environmental effect. However, there have been very limited researches focusing both on thermal environment and on the energy use in Nepal. It is therefore necessary to conduct research aiming at a better quantitative knowledge on the current energy situation in relation to the indoor thermal environment under the effect of different outdoor environment; and hopefully leading to the identification of the solution for creating better living conditions in Nepalese houses. This paper describes the current situation of the household energy use and indoor thermal environment of different climatic regions based on the field study. The purpose of this paper is to provide basic information of energy use and thermal environment of studied regions.

2. Methodology

2.1. Study area

The three research area are Solukhumbu district from mountain region having cold climate, Panchthar district from hill region representing temperate climate, and Jhapa district from terai region having sub-tropical climate. The altitude of the mountain region is over 2000m, while the Hills are between 300m to 2000m and terai area is up to 300m from the sea level.

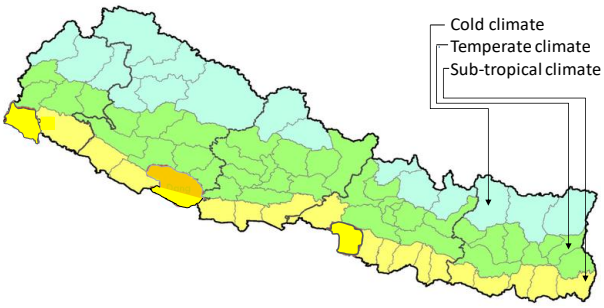


Fig. 1. Map of Nepal showing the study areas in different climatic regions.

2.2. Data source

From each region, five houses were selected randomly for thermal environment measurements and daily firewood use measurements for five days. The survey period was from 21st December 2017 to 20th January 2018. Measurement of indoor air temperature, outdoor air temperature and relative humidity were performed at 10-minute intervals by the use of TR-74Ui data logger with the sensor (measurement accuracy of temperature ±0.5℃, relative humidity ±5%). Measurement devices were placed 1m above the floor surface. Daily firewood use was measured by weight survey method [6, 11]. For this purpose, we first measured the weight of dried firewood ready for use by the help of spring balance and left in kitchen of each households with instruction to burn firewood only from the weighted bundles. On the next day remaining wood was weighted to calculate the amount of firewood used in the previous day. Household electricity expenses was obtained from previous months' electricity bill provided by

electricity supplier. In addition, the residents in 78 houses from mountain region, in 260 houses from hill region and in 168 houses from terai region were interviewed for knowing the household energy use pattern. The interviews were made based on the list of questions on family size, occupation, amount and types of energy used, source of firewood, distance of firewood source, time required for cooking activities, participation in cooking activities.

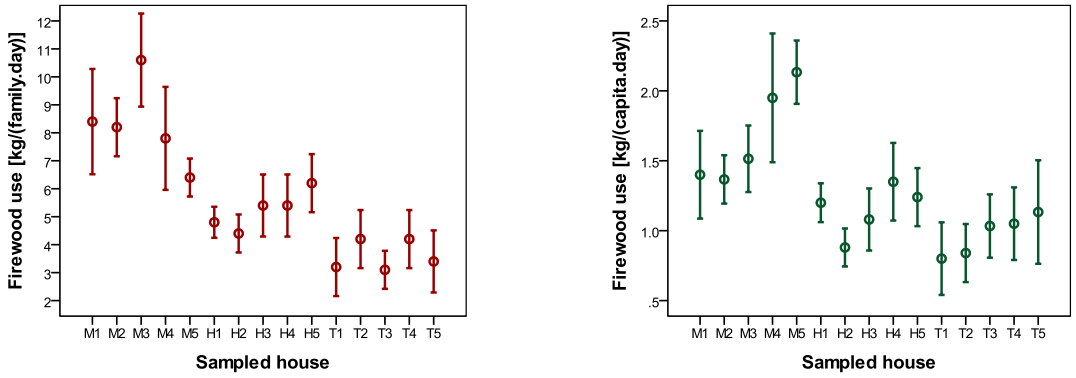
a) Firewood room heater **b) Improved cook stove**

Figure 2. Room heater and improves cook stoves used in Solukhumbu district

3. Results and discussion

3.1. Household energy use

All of the studied houses in terai region and 40% of houses of hill region were connected with rural electrification networks of national electricity grid, no houses of mountain regions were connected with rural electrification networks during our survey; however, many of them were using the electricity locally generated by small scaled hydro-power plants. In this study we found firewood, electricity and liquefied petroleum gas (LPG) as the main source of household energy for cooking, heating and lighting purpose. Firewood is used for cooking and heating purpose in all regions. After cooking meal, firewood was used for boiling water and improving the thermal environment of the houses. Fig. 3 shows the household and per-capita firewood uses of three ecological regions of Nepal obtained from the firewood use measurements of five households from each region for five days.



a) Household firewood use **b) Per-capita firewood use**

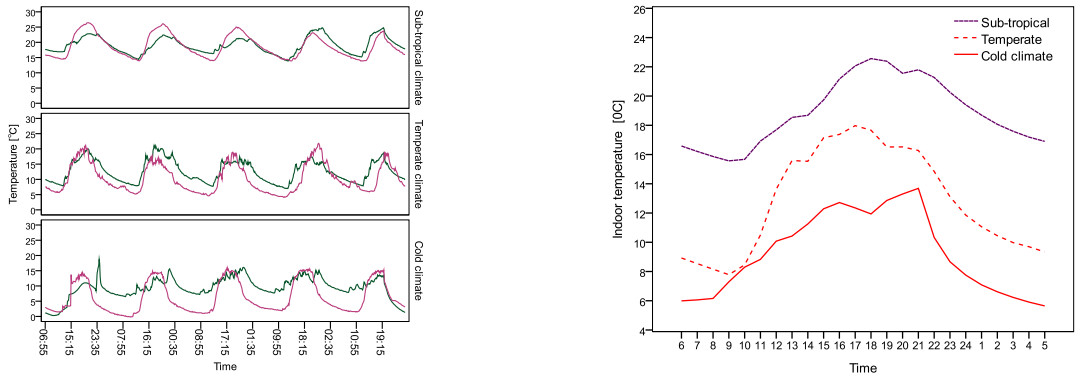
Fig. 3 Firewood use in investigated households in different regions

Fig. 3a and 3b shows that the largest amounts of daily firewood required in all houses in cold regions (M1-M2…) while lowest amount of daily firewood is required in sub-tropical regions (T1, T2...). We calculated average per-capita firewood use as 1.7, 1.2 and 1kg/(capita·day) and household firewood use as 8, 5 and 3.5 kg/(family·day) for cold, temperate and sub-tropical regions respectively. The low firewood use in the sub-tropical region probably due to the availability of commercial fuel and the lack of firewood sources in that region. High firewood use in cold and temperate regions may be due to the lack of access to the commercial fuels and the more firewood requirement for space heating than other regions. Bhatta and Sachan [11] reported that the firewood use was 2.6 times larger at high altitude (above 2000m) than at low (up to 500m) altitude. This study also shows the larger use of firewood at high altitude (mountain region).

3.2. Thermal environments

3.2.1 Indoor and outdoor air temperature variation

Fig. 4a illustrates the indoor and outdoor air temperature variation among three regions during the whole of study period. Figure 4 b presents the average indoor air temperature variations. As indicated in Figure 3a, outdoor air temperature ranges from 13.9℃ to 26.4℃ with an average of 19.0℃ in sub-tropical region, while those of cold and warm-temperate region ranges from -0.2℃to 16℃ and 4.1℃ to 21.8℃ with an average of 6.2℃ and 10.3℃ respectively. The corresponding indoor air temperature ranged from 3.3℃ to 29℃ in sub-tropical region, 7℃ to 21.1℃ in temperate region, and 0.3 to 20.8 in cold region with the average of 19.0℃, 9.4℃ and 3.6℃ in sub-tropical, temperate and cold climatic regions respectively.



a) **Indoor and outdoor air temperature variation** b) **Indoor air temperature variations**

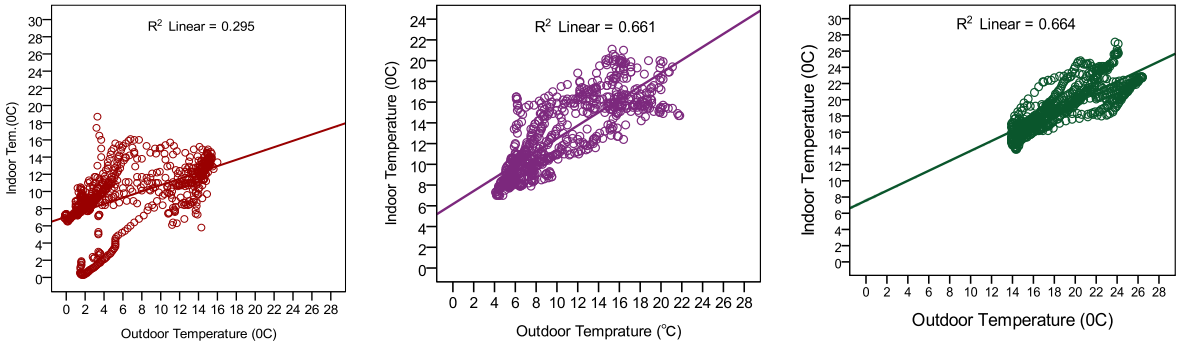
Fig. 4 Temperature variation in three climatic regions in January 2018

The peak value of outdoor air temperature appears higher than indoor air temperature in sub-tropical region while it is lower than indoor air temperature in other regions. Availability of solar radiation, thermal mass of building materials, energy use behaviour and window opening/closing behaviour could affect the indoor air temperature variation among all regions. High minimum indoor temperature in warm-temperate region is due to the climatic characteristics of this region. Susan et al. [9] mentioned that temperature in warm temperate region of Nepal does not drop down drastically in winter. Mean indoor air temperature of all region was found higher than mean outdoor air temperature. That may be due to the thermal mass of buildings and the thermal energy generation inside the houses due to heating and cooking activities and the large difference between mean indoor and outdoor air temperature in cold climatic region indicates that the buildings constructed in the cold region are best suited for low heat energy transfer by using appropriate design and materials. Window size and opening behaviour of different regions also affect indoor air temperature variations.

As seen in fig. 3b, the indoor air temperature in the cold region started to ascend at 5:00 while it is 9:00 in the temperate region and 10:00 in the sub-tropical region. In cold area of Nepal, particularly in winter season low indoor air temperature creates uncomfortable for living therefore one household member wake up first and burn firewood which helps to increase indoor air temperature. While in other two regions, there was quite suitable thermal environment and no need to burn excess firewood to maintain thermal environment therefore indoor air temperature incensement starts only after getting solar heat energy through outdoor air temperature.

3.2.2 Relationship between indoor and outdoor air temperature

Based on the 5-day measured indoor and outdoor temperature of three regions, we conducted regression analysis between indoor and outdoor air temperature. The coefficient of determination was 0.30 in cold and 0.66 in temperate and sub-tropical regions. It indicates that the influence of outdoor air temperature to the indoor air temperature is low in mountain region than other two regions. It is due to the thermal control behaviours like opening of windows only for a short duration of time, and being closed the door and windows to prevent the entrance of cold air inside the rooms, and burning of firewood inside the house. In temperate and sub-tropical regions, on the other hand, people often open the doors and windows during the day time so that the indoor air is reheated by outdoor air and the influence of outdoor air temperature is much more in temperate and sub-tropical regions than in cold region.



a) Cold climate **b) Warm-temperate** **c) Sub-tropical**

Fig. 5 Relationship between outdoor and indoor air temperature in different clinatic area if Nepal

3.3. Relationship between energy use and thermal environments

To evaluate the relationship between thermal environment and energy use in different regions, regression analysis between household firewood use and indoor temperature was carried out.

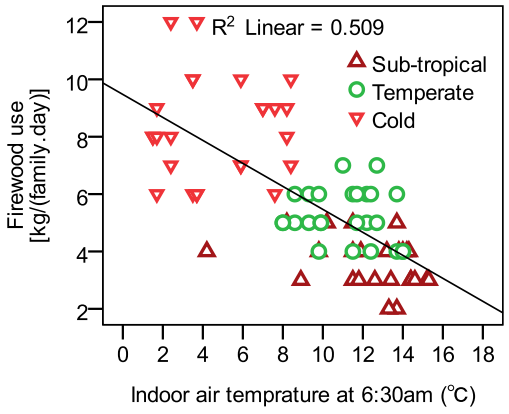


Fig. 6 Relationship between indoor and outdoor air temperature

Fig. 6 demonstrate the relationship between the household firewood use and indoor temperature (at 6:30) of five studied households for five days from each region (n=75). In this Figure different marker represent the different regions as indicated in the right side of the Figure. The correlation coefficient (r^2= -0.72) shows the negative linear relationship between household firewood use and indoor air temperature. As seen in Fig. 6, household firewood use decreases with increase in the indoor air temperature. It indicates that low household firewood have been using in terai area and high household firewood have been using in cold region. This difference in household firewood use may be due to the variation of the thermal environments in different regions.

4. Conclusions

Household energy use and thermal environment of residential buildings are very important data required for a basic understanding and to draw the future consideration about energy saving policy in developing country like Nepal. This study suggests that an intensive and extensive improvements of the indoor thermal environment together with rationalization of energy use must be important especially for the winter thermal improvements in cold climatic regions. The conclusions of household energy use and thermal environment of different regions can be made as follows:

1. Firewood and electricity are the main sources of household energy in all climatic regions of Nepal for cooking, heating and lightening purpose.
2. Average daily per-capita firewood use was found 1.7 kg, 1.2 kg and 1kg for cold region, temperate and sub-tropical regions of Nepal.
3. Thermal environment and firewood use is significantly correlated with each other (r^2= -0.72)
4. The main reason behind high firewood use in the mountain region is the low indoor air temperature.
5. Mean temperature was found 3.6℃, 9.4℃ and 19.0℃ for cold, Temperate and sub-tropical regions respectively.

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